NEP 2020

Position Paper for Science Education

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1. Preliminary information

1.1. Content outline

1.2. Executive Summary

The Science education position paper has considered a holistic approach on the implementation of science education as per the aspirations of NEP 2020. The initial phase of the paper considers the surveys performed involving the two important stakeholders, the teachers and the students from across the state in order to assess ground reality. The objective of the Teacher survey was to understand the concerns and problems of science teachers with respect to NEP 2020 and its implementation, in which, 1203 Science teachers participated. In the second survey, 2312 students participated. The objective of this survey was to understand as to how many students were interested in pursuing Science as a career option. The details and the analytics of the survey are presented in this document.

The Vision and historical perspective provided briefly emphasises the importance of Science education and significant chronological milestones in the creation of policies and implementation of Science education in the country. The rationale for the science education at different stages of a child's learning in the identified levels such as foundation, preparatory, mid and secondary levels is summarized. The blossoming of a child with very observant, curious and creative attributes at the Foundation level into a learner with capabilities to cognitively process information that help them with classification, decentration, seriation, conservation, reversibility of thoughts and inductive reasoning at the Preparatory level into an individual with well developed sensory perceptions able to acquire scientific method to differentiate between perception and reality through measurements at the mid-level to an independent thinking adult with hypothetico deductive reasoning abilities, forming defined concepts able to learn the principles related to the concepts from different branches of science in an integrated way, has been highlighted.

A detailed implementation plan, strategies for the effective implementation even during adverse conditions and the holistic assessment of the students have been elaborated.

In the role of stakeholders for the implementation of the NEP 2020, to be played by the individual stakeholders for making it effectively functional, has been provided as much in detail as the role of agencies in the promotion of science. It is in the requisites for the effective implementation of NEP 2020 that the team feels that the experiential learning of science is the most effective method for science learning. The team felt that the creation of a number of School Cluster Science Education Centres affiliated with the District Science Centres are to take central stage in the effective implementation. The suggestion is that school cluster science education centres should be able to cater to 10 schools in its vicinity for enabling experiential learning of science where a mentor will be able to upgrade the existing teaching community to adapt to the new pedagogy. Each school associated with the cluster centre will utilize the facilities to perform experiments on sharing the resources made available. For remote schools, even labs on wheels have been recommended and this has multiple advantages. While it will help to quickly implement the new pedagogy suggested as per NEP 2020, it will also enable a significant number of existing Science graduates take up such roles as resource persons, co-ordinators, quality management and laboratory associates to help in nation building exercise.

More importantly, suggestions on how a Teacher's efficiency could be improved by mainly considering them for academic roles rather than administrative ones have been provided. Also, it is important to ensure that the teachers have experienced similar transformations in curriculum focusing on process skill, pedagogy, assessments during their learning years.

1.3.List of members of the focus groups

- **Dr. M.R. Lakshminarayana. (Chairman)**
- **Dr. B.R. Guruprasad**
- **Sri. Guruprasad R. Athani**
- **Dr. K.S. Nagabhushana.**
- **Smt. Karuna K Simha**
- **Dr. Pankaj Jain**
- **Smt. Jayalakshmi.C.D (KTBS, Co-ordinator)**
- **Smt. Prema. B.R. (KTBS, Technical Assistant)**

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We owe the current form of the position paper to the DIETs, teachers of Science and students of Secondary School of the Karnataka state, for their significant contributions as stakeholders, in helping us understand the difficulties and challenges in the process of implementation of NEP 2020. Our sincere thanks to all the individuals who have been a part of this journey.

2. Introduction

2.1. Introduction to Science Education

Method of science is very close to the natural way in which a child learns. It involves exploration and discovery of its surroundings. The method of science is derived keeping the basic human nature of understanding the world in view. The process of understanding nature can be called science education. Science cannot be taught as a discipline but can only be experienced.
A child learns science as a part of its development irrespective of the formal science education. Therefore it becomes essential that science education is introduced to the child as a part of formal education right from the formative years. Human nature considers understanding every phenomenon of nature as a part of its existence. Therefore, integration of science in formal education to enable the development of human nature becomes a necessity. Moreover, a joyful science education (both curriculum and pedagogy) has a huge potential to create an overall enriched learning environment that a child looks forward to being in school. This not only incentivises science learning, but school education as a whole.

Science is an integral part of our society and the study of science is for the better adaptation of oneself to the social changes. The changes brought about by the advent of technology and science should be appropriately reflected in science education keeping the demands of the society in mind. The spirit of science for societal welfare should be made visible and felt. It should be recognised and appreciated.

There are specific abilities, attitudes and competencies that are developed through science. These abilities like observation skills, classification, drawing inference, skills of inquiry, problem solving, creative and critical thinking are essential for cognitive development. The attitudes of science like appreciating rational thinking, scientific temper, appreciation of nature, acceptance to new ideas etc. help us in progressing towards enhancing human existence in harmony with nature. Hence science education contributes greatly to the holistic development of personality.

Analysing the very nature of child development, the changing needs of the society and the perspective of holistic development as recommended by NEP 2020, science education becomes a focal point in the school education system.

2.2. A brief of mobile based survey and its implications.

Survey of Science Teachers

A brief mobile based survey was conducted by sending out the questions to the science teachers through Google Forms. The objective of the survey was to understand the concerns and problems of science teachers with respect to NEP 2020 and its implementation. The number of respondents were 1203 science teachers from different districts of Karnataka State. 58% of the teachers were from urban areas and 38% were from the rural areas of Karnataka. About 74% of the respondents were secondary school teachers, 32% middle school teachers, 11% senior secondary or PUC teachers, 6% Preparatory teachers and 4% Foundational teachers.

The survey revealed that 81.6% of teachers admitted that they needed training in the implementation of NEP 2020 recommendations but they were aware of the requirements of NEP. As many as 333 teachers expressed that they find constructive approaches and inquiry based learning difficult to practice in classrooms. 37% of the science teachers said they needed to understand new methodologies available for experiential learning. 399 teachers expressed difficulty in assessment of higher order skills. These numbers show that teachers have to be oriented, upgraded and supported in using constructivist approaches, inquiry based learning which are few of the pedagogical approaches to help experiential learning. They also need to be oriented with the new method of assessments required as per the objectives of Science.

The results of the survey imply that, first and foremost the teachers of most of the districts need to be oriented with the NEP 2020 recommendations as 33% of the science teachers found implementation of NEP 2020 a challenge as they did not know about NEP 2020 adequately. A good 57% of science teachers have accepted that they need a professional orientation to understand the NEP 2020 policy, following which they will be ready for learning other aspects of teaching and learning correspondingly. Some of the teachers have expressed concerns personally that at school level not even a single program has been organised to create awareness about NEP 2020, and have requested the same.

Career Choice Survey for Students

A mobile based survey was conducted for students studying in secondary schools of Karnataka state. The survey consisted of 2312 respondents. The objective of the survey was to understand how many students were interested in pursuing Science as a career option. The survey revealed that 46.2% of the students of secondary schools were interested in pursuing Science as a discipline in higher education. 46% of the students said they would pursue science as a discipline at higher education if they were given incentives, scholarships and financial aid.

Most of the students were keen on opting for Engineering (30.4%) medical science (27.2%), Pure science (26%) as a career option.

10% of the respondents admitted that they have not conducted any experiments in schools and hence they do not understand science.

Among the students who wanted to opt for science at higher education, about 70% of them were interested in medical, engineering and applied science. 20% of the students expressed that they do not like pure or natural sciences.

Among students who wanted to opt for science as a discipline at higher education, 35.8% agreed that they would pursue pure/natural sciences if they are provided incentives, scholarships and financial aid.

By analysing the responses of the students it can be deduced that students have to be encouraged at the school to develop an inclination to pursue science in higher education. Students with high science aptitude have to be encouraged and promoted by providing incentives for their innovation, through scholarships and financial assistance. New innovations have to be provided publicity in order to motivate such gifted students. Science enthusiasts must be provided scholarships and opportunities to follow their dream and become valuable resources for our nation. All fields of Science should be given equal importance and encouraged as per the interest of the child.

National and state level agencies can conduct aptitude exams to identify scientifically inclined and brilliant students and provide scholarships and enrol such students into esteemed institutions to pursue a career in science.

3. The vision, Perspectives and Implementation

While delivering a talk to science educators, Richard Feynman, had once very nicely summarised it-

"Each generation that discovers something from its experience must pass that on, but it must pass that on with a delicate balance of respect and disrespect, so that the [human] race–now that it is aware of the disease to which it is liable–does not inflict its errors too rigidly on its youth, but it does pass on the accumulated wisdom, plus the wisdom that it may not be wisdom.

It is necessary to teach both to accept and to reject the past with a kind of balance that takes considerable skill. "

3.1 Vision and Perspectives of Science Education

Keeping the above statement in mind, the broad vision for science education can be derived. The following statements envision the aims of science education:

- Change of outlook resulting in seeing the interconnectedness of things in nature
- Appreciation for every component in nature
- Seeing natural phenomena as a source to get inspired with a feeling of oneness and equality
- A rational outlook in seeing things
- Independence in thinking and freedom of expression
- Inculcating scientific temperament in the way of living
- Nurturing learner to be a wise and responsible citizen, while at the same time skilled enough to make better judgements for self and society

3.2 Historical perspectives in Science Education

Science is about human minds' curiosity to explore natural phenomena and understand them. Science has been a part of human civilization and humans have evolved by understanding natural phenomena around them, both informally and formally.

Formal science education has been given importance in every civilized society to help human's progress and satiate inquisitiveness. Formal science education in ancient India can be witnessed in the *Guru-Shishya Parampara* where science education was highly individualistic and based on the interest of the learner. Science education was primarily based on vocational interest and lead to the advanced developments of fields like human physiology and medicine, metallurgy, astronomy, agriculture and animal husbandry, phonics, etc.

In the modern context, science education was of least importance in the Pre-independence era as education was for only improving literacy. Post-independence period witnessed the incorporation of science as a discipline at the secondary level of schooling with the recommendations of Secondary Education Commission (1953).

The Kothari commission (1964-66), introduced science to primary level as environmental science (EVS). The NCF 2005 envisioned the need for the science education and made recommendations to provide quality science education all throughout the schooling. Here the curriculum framework stressed on the design of experiences in accordance with the developmental stages of the child. The NCF 2005 stressed that not all children become scientists but should at least be scientifically literate.

Keeping the historical perspectives in view, the NEP 2020 has made recommendations to introduce technology and advanced science into secondary level. The recommendations for experiential learning to be incorporated throughout school education is stressed to accelerate cognitive and skill development.

3.3.Rationale of science education at different stages

It is important to delve into the question of what is the need to teach science or why teach it. It is certainly important to share the vast understanding of nature that humankind has gained over a long period of time. While that is done, it is also important to take learners on a journey through the process of understanding nature.

The rationale behind science education is to help the child understand its surroundings in a formal setting, facilitated by a teacher. The process of science education should be in lieu with the development of the child. It should run parallel to the cognitive, physical and social abilities of the child at various stages. Considering the developmental tasks at various ages, the following rationales have been derived-

3.3.1.Foundational stage

- Children by nature are very observant, curious and creative. They continuously learn about the world around them by carefully observing, asking questions, and trying to make sense of what they experience in their own limited way.
- Students at this stage are also taking their first steps in literacy and numeracy. Science, as an integrated subject, provides a rich context to develop and support skills of reading, writing, counting and geometry. Therefore, science is introduced as a process of exploring a child's environment.
- Moreover, tapping on the innate curiosity and creativity forms the basis of scientific process. These skills of observation, questioning, etc. if honed well and encouraged will go a long way by setting a strong foundation for the child to build upon, later in life.

3.3.2.Preparatory stage

- There are infinite scientific concepts and phenomena surrounding us. The complex nature of the world we live in makes it inevitable for a child to understand them and coexist with it.
- Science of everyday life helps the child to satisfy its curiosity and make better use of its surroundings.
- At the preparatory level, there is an onset of concept formation in children. The child starts forming concrete concepts through its exploration. Science being the subject wherein there are innumerable concepts, learning of science aligns itself well with the conceptual development of children at the preparatory level.
- There is development of cognitive processes like classification, decentration, seriation, conservation, reversibility of thoughts and inductive reasoning between the ages 8 to 11 years. These cognitive processes can be optimally developed through the learning of science.
- The attitudes of science like curiosity, openness to new ideas, independence in thinking, satisfaction of learning can be achieved effectively in children through science education.
- Science education contributes to the holistic development of the child by facilitating the progress of cognitive, conative and motor skills.

3.3.3.Middle stage

- The Middle level science education will hone the child's sensorial skills and help it to manipulate its surroundings.
- With an established sensory perception, the child tries to acquire a scientific method to differentiate between perception and reality through an exercise of measurement (eg., determining dimensionality, hot and cold, short and tall etc.,)
- Science education at this stage acquires a disciplinary approach. Science as a subject starts getting differentiated into branches.
- The child will show readiness in learning defined concepts.
- The learning process includes assimilation of information and experiencing convergence. This develops problem solving abilities in the child.
- Performing experiments reinforces learning and provides joy of discovery.
- An integrated approach to science learning, wherein experimentation and learning of multiple concepts helps in retaining the curiosity of the child.
- At this stage, the child's well-developed brain is able to assimilate and validate concepts by following a scientific methodology

3.3.4.Secondary stage

- In the beginning of the secondary stage, students are capable of forming defined concepts. During the first two years (9th and 10th), students learn the principles related to the concepts in all branches of science in an integrated way. Hence, 'basic sciences' help the students to develop principles during this phase of learning.
- Students who are interested in pursuing higher education in science should be motivated towards learning advanced principles and advanced process skills of science.
- During the next two years (11th and 12th) students move from conceptual learning to formal learning of science. Every subject (Physics, Chemistry, Biology) has its own process skills. Students who choose to pursue their higher education in science and technology areas should be given opportunities to study various branches of science more formally.
- Secondary stage should prepare students to pursue higher education in their chosen areas.

4. Objectives of Science Teaching

4.1. General Objectives of Science Education

1) Cognitive Development
2) Enhancing satisfaction in daily life through a better understanding of scientific and technological applications
3) Capability to think logically and critically about everyday events
4) Creative thinking (divergent thinking)
5) Problem-Solving and critical thinking skills
6) Cause and effect relationship
7) Development of scientific attitude and rational thinking.

It’s important that these points are considered while preparing the learning outcomes of any chapter. In addition to the concepts, learning outcomes should also include specific about the process of science and attitude of science that a lesson plans to inculcate

4.2. Specific objectives for science education at different stages of school education

4.2.1. **Foundational stage**

“Children can surprise us with their perceptive observations. Yet, in the early years of school we adults systematically underestimate their capabilities.” The school curriculum forces them to attend selectively to a few simple, almost trivial, facts and generalisations.

1. To provide the child opportunities where they can observe different things, which trigger their curiosity to ask questions.
2. A child can then be motivated to classify, compare and contrast; and ask further questions based on the observations. This will also help in enhancing their communication skills.
3. To bring a child closer to the environment through observing nature, encouraging their imagination
4. To enhance their perception, gross motor skills and creativity through guided activities in an intellectually motivating, open and free environment

4.2.2. Preparatory stage

To develop concrete concepts through sensory experiences only

1. To develop processes of science like observation, classification, communication, inquiry, logical explanation, inferring and prediction based on simple logic
2. To develop attitudes of science only with the development of conceptual understanding and through the development of process skills of science. Attitudes of science include curiosity, openness to new ideas, independence in thinking and satisfaction of learning

4.2.3. Middle Stage

The specific objectives at this level are to enhance the competencies of the child obtained at the preparatory level. These are-

- To develop both concrete and defined concepts
- To make students experience the process skills of science along with the concepts of science
- Able to connect different concepts and understand a phenomenon
- Able to perform experiments and derive joy of discovery
- To retain high curiosity levels in children and enable them to move away from just remembering and understanding
- Emerge to a level where a child tries to acquire skills of identifying a scientific challenge and makes an attempt to hypothesize, either as an individual or in a group
- To encourage inquiry-based learning and understand reality through perception

with an unbiased approach

4.2.4. Secondary Stage

4.2.4.1.Classes 9 & 10

Objectives at this
stage are

- To enable students to apply concepts in science and understand the natural world around them
- To develop scientific temperament and ability to apply the science principles they have learnt in daily life
- To be able to critically analyse experimental observations.
- To develop process skills of science to pursue vocational courses related to science, after 10^{th} or 12^{th}.
- To be able to make an informed career choice about choosing science based subjects in higher education.

4.2.4.2. Classes 11 &12

Objectives at this stage

- To develop formal thinking and formal methods of scientific process
- To develop advanced skills to enable them to pursue science as a profession
- To understand the multidisciplinary nature of science and its importance in the developments of human beings
- To help children coexist in harmony with nature

4.3.Implementation of NEP 2020 recommendations related to science education

4.3.1.1.**Foundational Stage**

Recommendation from NEP 2020 for Foundational Stage: Play based learning, learning of good behaviour, practices to maintain hygiene, ethics, teamwork, cooperation

Implementation Plan Foundational stage

- The environment is rich in opportunities for learning. At this stage, more focus should be given on open or guided observation, sensory stimulation, playful activity, encouraging children to ask more questions (and more open ended questions like why, how, etc).
- There can be small components of age-appropriate thinking and creativity.
- The teacher (facilitator) can trigger curiosity and encourage students' questions about nature. A non-judgemental and mistake-friendly environment will help in free expression of thoughts by the child.
- Simple real world challenges can be given for proving solutions. They can create simple cars, houses, boats, toy's etc. using simple materials like paper, cardboard, thread, cotton, waste items. This helps in encouraging creativity whilst developing gross motor skills.
- Science need not be a separate subject and can be part of an integrated learning in the

form of different themes.

- Students can collect things, compare and contrast, count and measure things, make qualitative observations, organize collections and observations, discuss findings, etc. (Example- distinguishing seeds from sand particles.)

4.3.1.2.Preparatory and Middle stage

Recommendation from NEP 2020:

- The Preparatory Stage will comprise three years of education building on the play, discovery, and activity-based pedagogical and curricular style
- Introduction to formal classrooms but interactive classroom learning
- Experiential Learning
- Holistic Development
- Focus on reading, writing, and speaking skills

Implementation plan for Preparatory Stage:

- The classrooms should be well equipped to help children play with the learning materials
- Every learning activity should enable a child to explore, inquire and discover
- There should be teacher-guided discovery approaches where the learning happens through sense experience only
- The experiences should be direct, contrived or those involving the use of two or more senses
- Every classroom instruction can be divided into two parts
    - where the activities for exploration, interaction, play and discovery are adopted. This may be inside the classroom or in the natural setting.
    - verbalising the discovery/learning that has happened through activity. The verbalisation can lead to development of writing skills. Verbalisation can also develop logical thinking, presentation and language skills.
- The experiences should be from the child's surrounding and familiar to the child
- The interaction of the child with its surroundings should enable learning of Concepts of science and Process skills of science.
- The experiences should also develop creative expression, aid in fine motor skill development.
- The experiences should be concrete and help in sensory perception of the concept being developed.
- Direct experiences of living and non- living objects and materials only can help in learning of science at this level.
- Activities which help develop reversibility of thoughts and actions should be included.
- The experiences provided should involve classification, decentration, Conservation
- The classroom (verbalisation) should develop verbal association, skills of description or explanation, verbal mediation of thoughts to understand the process of a child's thinking.
- The writing skills can be gradually developed where the child uses written text to represent its learning.

- Introduction of stories, anecdotes or trivia to the child related to its learning will improve reading skills and imagination.
- Integration of subjects-Science education should be based on the everyday life of a child at the preparatory level. Therefore the integration across the subjects is necessary. Science can be incorporated with social entities of a child's life. (Ex: concept of Family, Concept of garden, etc.).
- Physical activities as part of science learning can enhance motor skills in children. (Ex: Exercising makes us sweat, which helps the body to cool down. It helps our body to be healthy)
- Science education contributes to the development of cognition, emotions/conation and psychomotor skills. The concepts of science help in cognitive development. The process skills of science help in both cognitive and psychomotor development. The attitudes of science help in conative development.

4.3.1.3.Middle stage

- While the preparatory stage Science learning happens by learning with examples and sensory perceptions, the middle stage requires deliberate experimentation to help develop defined concepts.
- At this stage, utilization of instruments and equipment become necessary. For this reason, each school should possess a laboratory space to implement experiential learning of science. Simple exploratory materials should be provided to each school which students can use for classroom explorations, facilitated by a teacher. In cases where the schools in rural areas are unable to create such an infrastructure, cluster of schools should create a central facility where experiential learning is provided, with the help of corporates (through their CSR) or through government funding. This helps sharing of resources.
- The curriculum on experiential learning and the mode of teaching should be aligned to achieve the objectives.
- The teachers should be empowered with the new pedagogy as well as utilization of the new content and materials associated with it. This can be acheived with the help of centers where training programs can be organised (eg., district science centers and IISERs identified).
- Any rote memorization is to be avoided to enable children to explore and learn.

4.3.1.4 Secondary stage

Recommendations of NEP 2020

- High school (secondary stage): Multidisciplinary study. Subject oriented pedagogical style with greater depth, critical thinking, attention to life aspiration, flexibility and choice
- Reduce the content of each subject to core essentials to make space for critical thinking, deep learning. Move towards less content and more thinking and problem solving.
- Move towards Experiential learning
- Subjects to be offered in two levels-'standard' and 'higher' level
- Earlier policies focused on access and equity, now we have to move towards emphasis on quality of education

- Discontinue Rote learning
- All aspects of curriculum and pedagogy should be revamped and reoriented to achieve the said goals

Implementation plan for Classes 9 & 10

- Subjects at 'standard' (or basic) level and 'advanced level' to be offered. Choice is to be provided at advanced level
- Pedagogy must be experiential at standard level and formal at advanced level
- Advanced level has to be at greater depth of content.
- Multidisciplinary thematic study to be introduced from class 9 itself
- Three pronged approach to be introduced to enhance quality of education
- Teacher's training should enable teachers to deliver higher quality teaching. This can be done by incorporating technology. Teacher's training should happen throughout the year continuously through technological platforms using resource persons who are intellectually endowed in the related field.
- Assessment style should be completely changed to incorporate testing the competencies rather than testing just the memorized information. A combination of 'Assignments', 'Open book tests' and 'closed book objective tests' is recommended with higher weightage on the first two.

Implementation plan for Classes 11 & 12

- Subjects to be offered at class 11 and 12 are Standard level-Basic physical sciences, Basic Life sciences
- Subjects to be offered at Advanced level-Advanced Physics, Advanced Chemistry, Advanced Biology
- Subjects to be offered at Interdisciplinary-A list of subjects like Climate science, Computer science, Electronics, Industrial chemistry etc,
- Both standard level courses are mandatory for every science stream student. She/He has to choose one subject at advanced level and one interdisciplinary course. Choice of Interdisciplinary courses can be from outside the science also.(History, economics etc,)
- Quality of education can be improved by following methods

    - Enable teachers by online courses and seminars.
    - Improve pedagogy by making the standard level more experiential and advanced level more formal in terms of thinking.
    - Students should be encouraged to design and conduct experiments in groups.
    - Revamp assessment by introducing Assignments and Open book examinations. These should assess the competencies and not memory. Also, the goals of assignments are mainly learning the concepts, process skills and developing attitudes of science. Assessment is a secondary goal for assignments.

5. Natural and other disasters: Impact on teaching-learning in schools

Natural disasters like cyclones, floods, earthquakes and droughts which are the conspicuous manifestation of nature's fury, have the ability to adversely affect the educational domain. Usually due to these disasters, transportation and communication in the affected areas are severely disrupted. In severe cases, except for drought, school buildings are damaged or destroyed and the mobility of students and teachers to reach the schools through normal transportation means becomes next to impossible. At the same time, communication with the outside world also gets cut off. Water borne diseases further enhance the adverse impact. All these will definitely affect both teaching and learning process as both the teachers and the taught will be equally affected and will not be able to communicate in person or through communication devices like phones, laptops or desktop computers.

In today's Internet era with web-based education becoming ubiquitous, communication systems relying on terrestrial devices like telephone cables and microwave towers stop working due to the severing of telephone cables, damage to telephone exchanges and collapse of microwave towers. Thus, as in the past, the educational system will become a victim of natural disasters even when web-based education is being successfully imparted to the pupils. Besides the threat of diseases, natural and other disasters will affect the psychology of the stakeholders too with the morale of teachers and students suffering severely and predominance of distractions adversely affecting the interests of students and teachers. This will inevitably have both short- and long-term undesirable effects on teaching and learning.

5.1. Strategies adopted for teaching-learning in schools during situations of disaster

Though the effects of natural disasters cannot be totally negated by forewarning, actions like through advanced planning, choice of proper strategies and their timely implementation can go a long way in mitigating the adverse effect of natural disasters. Natural disasters like floods, cyclones and earthquakes throw a severe challenge to the logistics and communication domains. Thus, attendance of both students and teachers in schools becomes extremely thin. Even tele education or web-based education also suffers due to the collapse of terrestrial communication network. In such cases, provision of connectivity through satellites becomes the most appropriate action to sustain teaching-learning process on a skeletal or tending towards a regular basis. With the launch of more and more sophisticated communication satellites and due to competition, broadband Internet is getting more and more affordable. For ensuring satellite broadband connectivity, private sector industries may be persuaded to make significant contribution as part of their Corporate Social Responsibility programme. Similarly, assistance of NGOs also may be sought vigilantly to enable proper utilisation and sustenance of satellite connectivity.

6. No hard separation in subject areas as per NEP 2020

6.1.1. Classes 9 & 10

At this stage all students have to study science at 'standard' level. There would be one integrated subject called 'basic sciences'. This subject integrates three parts.

Part 1: *Physical science*: The content of the course relates to physical inanimate objects around us. The subject matter revolves mostly around physics and parts of chemistry (General chemistry, physical chemistry and inorganic chemistry)

Part 2: *Life sciences*: The content relates to the life forms around us. Aspects of biology and organic part of the chemistry are to be included in this.

Part 3: *Interdisciplinary Subjects*: All areas of science and knowledge outside what is traditionally called as science, but where science can be integrated, can be considered as interdisciplinary subjects. Social aspects, ecological problems, new age modern technological ideas, etc., are covered in a thematic fashion.

First two parts provide integration within the sciences and the last part provides integration of subjects outside the definition of science disciplines.

6.1.2. Classes 11 & 12

Formal learning of subjects starts at this stage. Hence at this stage formal learning is introduced for the 'advanced level' subjects. At the 'standard' level, subjects are integrated within the boundary of science. The complexity of subject matter varies between 'Standard Level' and 'Advanced Level'. In the advanced level students are provided with in-depth content related to one specialized area.

Interdisciplinary subjects introduced at this stage offer opportunity for students to pick and choose subjects from outside of science.

6.2. Different levels within subjects at the secondary stage

Different levels of subjects are recommended both at 9th and 10th level and at 11th and 12th level. In first two years basic sciences is to be mandatory for all students however they can choose one of advanced subjects as well. Even at 11th and 12th level subjects are offered at both standard and advanced levels.

Here is the summary of subjects offered and a recommended model for choosing the subjects

Stage	Offered subjects	Possible model to choose advanced subjects
Class 9 and 10	**Standard level**: Basic Science	Basic Science + Quantitative Physics or Basic Science + Advanced Chemistry or
	Advanced level: Quantitative physics, Advanced Chemistry, Molecular Biology	Basic Science + Molecular Biology

Class **11 and 12**	**Standard Level**: Basic Physical Science, Basic Life Science **Advanced level**: Advanced Physics, Advanced Chemistry and Advanced Biology **Interdisciplinary**: Climate science, Computer science, Electronics, Industrial chemistry. Forensic science etc.	• Both basic physical science and basic life science are mandatory • Choose one subject at the advanced level • Choose one interdisciplinary subject either from the subjects offered within science or from outside science

7. Basis for identifying core competencies

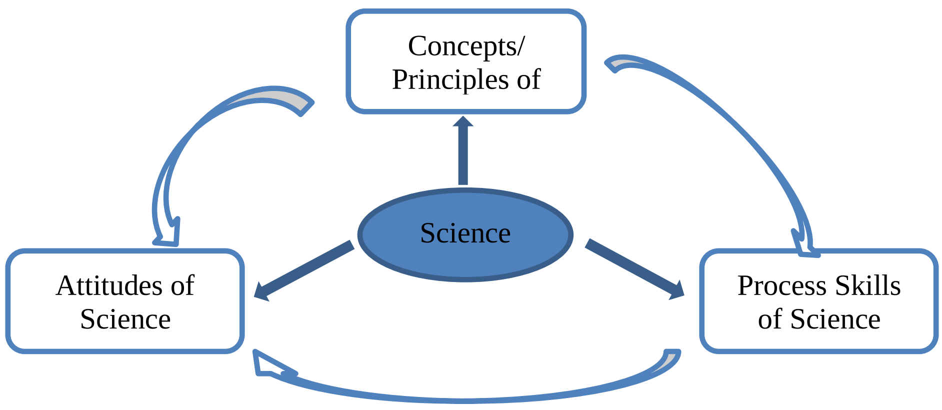
7.1. General Competencies Developed through Learning of Science

Concepts/Principles of science that the child explores in its surroundings through experiences. (Cognitive Aspects)

The process skills developed through science education at different levels are observing, classifying, quantifying, measuring, using apparatus, communicating, inquiring, inferring, predicting, hypothesizing and problem solving. (Psychomotor/Cognitive aspects)

The attitudes of science (not to science) like curiosity, openness to new ideas, respect for evidence, independence in thinking, satisfaction of learning, skill of inquiry are developed through science education. (Conative/ Affective Aspects) [*These are not to be mistaken for attitude towards science.]

Learning activities have to be chosen to aid the development of the above processes rather than the building only the body of knowledge of science. The purpose of selection of content is to help in the development of cognitive processes and equip them to 'Learn how to learn'



7.2. Proposed core competencies at different stages

7.2.2. Foundational stage

- Basic introduction to the **Concepts** of everyday life that the child explores in its surroundings through sense experiences, observations and explorations. (Cognitive Aspect)
- The **process skills** developed through science education at the foundation school level are observing, classifying, questioning, and communicating.
- The **attitudes of science** like curiosity, openness to new ideas, feeling connected to the environment and basic skills of questioning are developed through EVS education.
- Finger dexterity, the basic functions of daily life like eating, washing hands, use of toilets, wearing clothes, greeting others and following simple rules are to be developed in children of pre-nursery, LKG and UKG.
- Competencies of behaving in a group, working in groups during activities, fine motor skills, and sense of hygiene are to be developed in children of 1st and 2nd grades.

7.2.3. Preparatory stage

- **Concepts** of everyday life that the child explores in its surroundings through sense experience. (Cognitive Aspects)
- The **process skills** developed through science education at the preparatory school level are observing, classifying, communicating, enquiring, inferring, predicting, hypothesizing, and problem-solving. (Psychomotor/Cognitive aspects)
- The **attitudes of science** like curiosity, openness to new ideas, respect for evidence, independence in thinking, satisfaction of learning, skill of inquiry are developed through science education. (Conative/ Affective Aspects)

Types of learning that occurs at the preparatory stage

i. **Verbal Learning-** Verbal learning happens in two stages i.e. a. **Verbal Association** (Presentation of object and *observing* the object, this *Observing response* results in internal stimuli and hence verbal response; b. **Verbal/Pictorial Mediation** where there is *Talking to oneself/ picturing the object*, (which the teacher can ask them orally or ask the child to express in its own way).

ii. **Concept Learning-** Concrete concepts are to be developed at the preparatory level. Concept learning should happen through interaction of the child with the examples. Concept to be taught through the listing of dominant attributes during concept formation and secondary attributes at the stage of concept attainment. Three types of concepts can be taught, Conjunctive, Disjunctive and relational concepts

iii. **Psychomotor Skills**- involve Motor Response, Movement coordination and Response patterns, which can be developed through science activities.

7.2.4. Middle Stage

- At this stage, the learnings will involve both experimental and experiential predominantly or verbal classroom learning. Science is best learnt this way.
- **Concepts of science** are developed in children through the process of experimentation
- **Attitudes of science** that are developed involve diverse curiosity, passion for reliable and diverse facts.
- The laboratory method introduced as a formal class at this stage enable the progress of **Process skills of science** like observation, classification, decentration, critical enquiry, hypothesising, etc.
- This stage lays the foundation for real science that becomes the critical requirement during the secondary stages as there is the onset of development of defined concepts.
- While knowledge gives confidence, science creates doubts in the mind. This will be the true representation at this phase. The real difference between an ideating mind and competency to convert an idea into reality will form the basis for classifying students for pure sciences or applied sciences at or after the secondary stage.

7.2.5. Secondary stage

Classes 9 & 10

- At the beginning of secondary stage the core competencies described above have to increase in depth
- **Concepts**: Students learn to generalize and students can now form abstract or defined concepts and principles are developed through the internalization of concepts.
- **Process skills**: At this age their fine motor skills would mature and they should be capable of doing more precise measurements. Cognitively, they can now hypothesize and test their hypothesis. Towards the end of this stage (10^{th}) they should be really good in their analytical abilities. The students develop cause and effect relationship at this stage. They develop formal operational competencies like inducto-deductive reasoning, hypothesising, selection of alternatives, etc.
- **Subject specific process skills** will start to take shape at this stage. Students who are interested in quantitative understanding begin to like subjects like physics and math. Students who have the ability to make detailed observations and connect with life forms will start to like biology. Students who are hands-on show interest in building and manipulation of things (engineering aspects) etc.
- **Attitudes of science**: At this age students start to develop their own identity. Curiosity, openness to new ideas, evidence seeking etc., should form the core of their identity. At this stage, they start to apply the attitudes of science to social scenarios. The learning of attitudes of science eventually leads to the development of favourable attitude towards science if the experiences have been favourable during the learning processes. One important aspect of this is to question fundamental beliefs respectfully and find rational basis for these. Values related to science are acquired by the end of this stage.

Classes 11 & 12

- In addition to above skills students develop subject specific core competencies at this stage
- Quantitative reasoning, objective analysis, critical reasoning, hypothetico-deductive

reasoning, problem solving skills, experimentation skills, measurement skills, pattern identification skills are some of the higher order skills that are to be developed at this stage.

- The students express higher cognitive abilities in experimenting, hypothesising, analysing, abstract thoughts and problem solving. Their ideas are more formal in nature.

8. Time allocation for science in the school timetable

Science is an integral part of our daily life. Knowing the world around us becomes inevitable for us to improve the quality of our lifestyle. Science develops competencies that are essential for continuous learning in all dimensions of life. Science learning also scaffolds the learning of other disciplines. These competencies are essential for the holistic development of personality. This makes science education a necessity as a part of schooling where the basic personality is formed. In order to cater to the development of specific competencies that science develops, science education should be given preference in the school timetable equally with other core subjects at all levels of schooling.

8.1.2. Foundational stage

Science is interdisciplinary at the foundational level. It is inclusive with other subjects and the curriculum is theme based. The exploration of the environment around the child becomes a part of the science that the child learns. Therefore science cannot be separated as an individual subject but the experiences of science should be incorporated into all activities of learning. Therefore the timetable should concentrate on providing experiences of science through explorative and discovery methods.

8.1.3. **Preparatory stage**

Science is incorporated into the formal timetable as environmental science. As per the NEP 2020 recommendation the science education should be interdisciplinary in nature. Science class should be divided into two parts-one where the activity for exploration, discovery and experimentation are done to develop process skills of science, the second part where there verbalisation of learning and expression of concept formation happens. Therefore science education should be allotted time in the daily timetable. (daily two classes). There should be time allotted to promote language skills through science and attitudes of science through extended activities of reading, visits to places of scientific importance, libraries, etc. For development of interest in science these extended activities should be provided a dedicated time.

8.1.4. Middle stage

A formal laboratory period should be incorporated into the school timetable along with the classroom learning. Science project should also be allotted time in the timetable. For the development of scientific skills and attitudes, suitable pedagogy should be adopted and time should be provided for such pedagogical practices along with extended activities. This shall enable the selection of science as a vocational subject at the secondary level for the students who have an inclination towards the study of science. Total time allocated for science learning is one day in a week.

8.1.5. Secondary stage

This is similar to the middle stage. There will be more time requirement for the laboratory practical work and project related activities.

9. Pedagogy of science

9.1.2. Foundational stage

Pedagogy can include play/activity based learning but instructing the child should be avoided and more of exploratory activities are to be provided. A mistake-friendly environment should be created. Some aspects of inquiry based learning (interactions) can be used. The approaches where there is open ended questions are asked are to be employed in the class. There should be acceptance of all answers without being judgemental about the answers. Teaching-learning process should be learner centric. It should be free-flowing as long as the objectives at this stage are accomplished.

It is important to minimise information/instructions that is given to a child. This will maximize observations, imagination and explorations.

9.1.3. Preparatory stage

Pedagogical practices that can be employed are

a) *Constructivist Approaches*- Constructivist principles can be applied to the teaching as the students are at a stage where they can be oriented towards 'learning to learn'. Construction of learning happens through interaction, activity or exploration.

b) *Reflective Practices*- reflections from students help them as verbal mediators of learning. They also help students to logically analyse their learning. It enables students to express their satisfaction in learning.

c) *Experiential Learning*- contributing to development of observation, classification and inquiry skills which leads to formation of generalization.

9.1.4. Middle stage

Any pedagogy adopted should be under the umbrella of experiential learning. An inquiry based (open, guided etc.,) learning built on constructivist principles is to be applied to the process of learning. A good combination of a classroom learning along with laboratory learning will help in the development of concepts, process skills and attitudes of science. The pedagogy and content should emphasize on the teaching of process skills of science rather than rote memorization.

Information seeking exercise should be considered as an assignment and the class time should be utilized more for experiential learning. This will enable the learners to feel the joy of discovery. Experiments may either be conducted independently or in groups. The wonderment of science combined with the joy of discovery will keep the curiosity of the students at a high level and ensure a clear transition from Nature-friendship at the preparatory stage to nature-knowledge at this stage. This has to transform into nature-science levels at the secondary stage. Constructivist approaches, reflective practices, guided discovery, methodology for development of concepts through examples can be employed to aid optimum learning.

9.1.4 Secondary stage

In summary, facts are ‘generally known information’ about the world around us while concepts are the understanding retained in the mind. Concepts can be either concrete or defined. Principles (or a law) are the fundamental truth or proposition that serve as the foundation for a system of belief or behaviour or for a chain of reasoning. Theory is similar to principle but is yet to be proved using a sequence of logical steps (or math) or evidence.

Science education has to follow the method of science itself. The method or process of science like Experience, conceptualize, search for the principles, make theories, make predictions based on theories, design experiments/observations to test the predictions, conduct experiments prove / disprove a theory, help in learning science.

A student has to go through the above process in order to realize the true nature of a principle / law of science. This is the reason; we need subject specific and topic specific pedagogy at higher stages. Though initial concept formation is similar for all concepts and principles, gaining better conceptual understanding and application of principles requires different kinds of pedagogical techniques.

Systematic approach is needed to study any science. As described earlier, method followed to study all sciences is same. However, during class 9,10, 11 and 12 students need to formalize the developed concepts. Method to be adopted for this is different for different kinds of sciences. This is because the focus of study for every sub-stream of science is different.

Broadly, Physics deals with the motion of inanimate objects, chemistry deals with the interaction between objects (materials) and Biology deals with how life works.

Focus of study in physics is to unify laws of nature and arrive at minimum number of laws to explain nature. Since physics deals with simple objects whose behaviour can be modelled strictly, mathematics becomes important tool for understanding physics. Pedagogy of physics should focus on developing mathematical models, visualizing them and solving them.

Focus of study in chemistry is to explain and predict the interaction between various substances (molecules). Conducting experiments carefully and arriving at right kind of inferences is crucial in chemistry pedagogy. Making a theory about interactions and testing the theory also is central to chemistry. Reaction mechanisms form the basic principles of chemistry. Pedagogy of chemistry should focus on experimenting with chemical reactions (including chemical reactions that are taking place all around), qualitative and quantitative experimental techniques and inferring methods.

Focus of study in biology is to explain life and its processes. Life processes are very complex and human understanding is still at nascent stages. It is very hard to rigorously model the life processes using math. Also, it is not possible to minimize the number of laws to define life. Biology focuses on observing and understanding the processes in a very detailed way. It is also important to classify and categorize. Pedagogy should focus on these aspects of biology.

In addition to the above, solving complex problems which are spread across sub-streams of science is an important competency the students need to develop.

9.2. Strategy for holistic assessment

The outdated system of assessment/evaluation, especially at the board level has contributed significantly to several of the challenges that we face in the implementation of some of the finest policies in the past. Similar assessment system unfortunately trickles down even at the lower grades in spite of the focus on CCE or formative assessment strategies. The focus has largely been on the product of science, i.e., our knowledge or understanding of nature or at the most on how we can apply it. Given the importance given by the society at large on these examinations, it needs to be addressed on an urgent basis.

It certainly is easy to assess the product however, there are numerous ways and successful examples of assessing the process skills. There can be questions in the board examinations where information/knowledge is already given and focus is more about comprehending/analysing/synthesising that piece of information. Aligning to the pedagogy of developing the scientific process skills, assessment should also be able to assess the scientific process skills. This can be done in multiple ways like allowing them to figure out the answer to a phenomenon and observe them or even using summative text questions. Multiple ways should be tried out.
The internal assessment can be completely replaced to look for the process skills. Once it starts at the board level, the preceding grades will start taking the processes and attitude of science more seriously.

With such restructuring of assessment strategies, the learning outcomes for a teacher will change phenomenally that will further impact the pedagogy. Assessment should be focused at all the 3 levels:

- Summative assessments or assessment of learning
- Formative assessments or assessment for learning
- Assessment as learning which incorporates students reflections too

9.2.2. **Foundational stage**

Throughout this stage, assessment of facts can be reduced to a great extent and the formative assessment systems can assess the different skills and attitude mentioned above, but shouldn't be in the form of tests.

The assessment at this level should be continuous, informal, based on the students' process skills like observations and participation in discussions and activities. In addition, their regular drawing and writing in their notebooks might be taken into consideration for the assessment of gross and fine motor skills. Assessment of communication and ability to find similarities and differences should be regarded to understand the cognitive development of the child. This type of assessment will inform the teacher about the students' progress and potential. More importantly, it will provide feedback to decide what to teach and how to teach it. This feedback should be utilized to continuously revise the teaching-learning process. The grades allotted should not be considered as criteria for the promotion of child from one class to a higher class.

9.2.3. **Preparatory stage**

Assessment of Content/Concept of Science have to be through Oral, Practical and Written Assessment. The assessments should focus on the objectives of Science education

In assessment of Processes of Science, Attainment targets are to be fixed, wherein the teachers assess students for the attainment of process skills through activities (laboratory experiments, in class activities, group projects which are done under the supervision of the teacher etc.)
Attitudes of Science can be assessed through observation of students by the teacher and through oral assessments.

Assessment should be both Continuous and Comprehensive. Schools should maintain a cumulative record of each student. Assessment should be made once in three months (trimesters) to avoid over burdening of students. The obtained marks should not be the main criteria for the promotion of students from one grade to another.

The assessments should include 40% Verbal/ Oral Test, 30% Written (match the following, picture questions, filling the blank, multiple choice based), 30% process skills (observation of the child by the teachers) and Attitudes.

9.2.4. **Middle stage**

The strategy for the holistic assessment include constantly evaluating students over the years for the developing competencies in the students and to get a head start for identifying them to be inclined to basic science or applied (engineering, medical or vocational) sciences.
Rote learning is to be avoided. The evaluation should not be based on mere knowledge but is on the combined skills and competencies.
In middle school years, process skills should be given much higher priority over the knowledge or understanding as this is the age where the control and coordination between body and mind start to attain precision. The assessment should be a combination of verbal, written, continuous monitoring and evaluation of the process skills, project work and assignments. The weightages for verbal and written skills are to be given lesser importance compared to the process skills. Moral obligations such as ethics and integrity are taught at this level.

9.2.5. Secondary stage

At secondary stage, to avoid rote learning and coaching for the sake of examinations, following methods of assessment are proposed.

Assignment: This method is practiced internationally. Students are given certain assignments which they need to complete in prescribed number of days. This method of assignment is primarily meant 'for learning'. Assessment is a by-product.

Following types of assignments can be given

- *Case study:* A real world natural phenomenon or a new technology is to be studied. Students need to present their process and final outcome. Presentation to be assessed by the teachers. Presentation can be recorded and stored in student database.
- *Experiment:* Simple experiment with scientific rigour can be the assignment. Demo can be done in front of teachers. Viva on processes of experimentation can be done to assess the student.
- *Problem solving:* Simple 'Real world problem' to be given as assignment. Proposed solution can be either presented or documented which the teacher will assess.

Care should be taken not to repeat the same assignments every year. Every year new list of assignments can be given to teachers who can select a few of them and assign it to students. Some assignments can be given to groups of students rather than individual students.

Open book exam: This exam is intended 'for learning' and for assessment. Students have to be give a few hours to complete the exam in the school itself. Students can be asked to bring their text books and are allowed to refer them. Questions have to be of related to application of the concepts learnt by them.

Some examples of questions in an open book exam are Concept explanation, Phenomenon description, Problem solving, Mathematical derivation and Reasoning.

Closed book exam: This exam tests detailed memory, conceptualization and application. Subjective questions and objective questions can be included in this assessment.

Assignments, open book exams and closed book exams have to be spread throughout the year. Weightage for the closed book exam should be minimal (<25%). The cumulative record of the students have to be considered for the promotion of the student from one class to a higher one and also for enrolment of students for higher education.

9.3. Integration of Science with other disciplines

- **Arts integration**
  - Sharing observations in the form of sketch- eg: a plant growing at different stages or in different conditions over days, types of leafs, etc.
  - Enacting and role-play can be used for many different concepts
  - Music and musical instruments, sound, geographical diversity
- **Math integration**
  - Simple counting
  - Collecting data and doing statistical calculations
  - Physics and chemistry equations
- **Sports and Science**
  - Different types of joints and their usage in sports
  - Sports and health
- **Social Sciences**
  - Prevailing social situations that led to the discovery of various concepts in Science and Engineering

    - Some unifying concepts like biological evolution vs civilizational evolution
    - Historical and geographical contexts in which scientists worked and led to the discoveries
    - Social biases/prejudices and their role in scientific discoveries

- **Environment**
    - Pollution
    - Renewable/non-renewable
    - Climate change
    - Evolution and how do we cope with environmental issues
- **Science and Commerce**
    - Commerce in industries
    - Science and economy
- **Science and Industry**
    - Pharmacology
    - Metallurgy

9.4. Guidelines for curriculum developers

9.4.2. General Guidelines for all levels

- Spiral Arrangement of topics with increasing complexity in terms of concepts/principles, process skills of science and attitudes of science
- Subject matter of science should have suitable and sufficient illustrations known to the child
- Curriculum should provide for experiential learning
- The curriculum should specify the attainment targets for concepts/principles of science, process skills of science and attitudes of science
- The curriculum should provide options for extension activities (field trips, science visits, projects, etc.)
- There should be a teacher resource book providing guidance for the experiential learning and options for activities under different topics. The teaching sequence to achieve attainment targets should also be prescribed.
- Role of Indian Scientists/philosophies (ancient, medieval and modern) and its relevance in today's time. These should not be taken as pieces of history, but rather a child should experience the circumstances which led to the development of these disciplines. Moreover, their relevance in today's time needs to be brought out explicitly

9.4.2.1.**Foundational stage**

- Curriculum should promote process skills of observation, classification and inquiry about the child's immediate surrounding.
- These early years are important too for the development of social awareness and social skills. Topics like, "My Family", "People at Work" and "Festivals" focus specifically on social awareness in the later half of the foundational stage. The overall approach

continually encourages meaningful social interaction in and outside the classroom.

- Activities that connect the child to nature should be included in the curriculum stressing on aspects of weather, plants, and animals in the surrounding.
- The curriculum should include examples and activities from the known environment of the child.

9.4.2.2.Preparatory stage

- Spiral arrangement of subjects: The complexity of the topics of study should increase both in terms of concepts and processes of science.
- Subject matter should be selected from the child's immediate environment
  - The subject matter should contain illustrations from the immediate environment of the child.
  - The subject matter should be presented from simple to increasing complexity of cognitive processes
  - The subject matter should be logical and concrete in nature.
  - Observable phenomena and processes that the child can experience should be taught.
- The curriculum should stress on the aspects of experiential learning, keeping in mind the aspects of implementation strategies discussed earlier.
- The objectives of science, i.e., concepts of science, processes of science and the attitudes of science are to be stressed in all the areas of the subject matter. The curriculum should prescribe the attainment objectives keeping the three core objectives in focus for every unit. The learning activities have to be chosen to aid the development of the above processes rather than the building only the body of knowledge of science. The purpose of selection of content is to help in the development of cognitive processes and equip them to *'Learn how to learn'.*
- Curriculum prescription should contain closely knit activities under the heads of Concepts of Science, Processes of Science and Attitudes of Science.
- The curriculum should enable construction of knowledge by the learner.
- To overcome the risks of only achieving Concept/Content related objectives, a separate set of defined objectives may be provided as *"attainment targets"* with the science curriculum specifying the activities under concepts, attitudes and processes of science
- A textbook integrated with workbook to be created for children
- A teacher's resource book to be provided. Suggestions for activities for each topic have to be provided to the teacher.
- The teaching sequence to be prescribed along with the attainment targets, year wise.
- The teacher should be provided with detailed directions in the teacher's guide and materials required to accomplish the attainment targets.
- Provision should be made where teachers will be given flexibility to choose between activities to ensure that the objectives are achieved.
- Theme based learning can be extended to this stage too to provide sufficient scope of integrating science learning with other disciplines
- Extension of activities to bring the child closer to environment and all its components

must be part of the curriculum

9.4.2.3.Middle stage

- The complexity of the topics of study should increase both in terms of concepts and processes of science. Subject matter should extend from the child's immediate environment to a global trend.
- The subject matter should contain illustrations from the immediate environment and a possible visit to the local site should be considered. This helps in the practical deployment of science being studied in school.
- The subject matter should be presented from simple to increasing complexity of cognitive processes. The curriculum should be mainly devised for enabling experiential learning. As indicated earlier, the process skills of science take the centre stage rather than teaching the products of science. The curriculum should prescribe experiments to aid development of process skills.
- The content should consider incorporating all branches of science for a particular topic. Eg., the physics, chemistry and biology of water should be included in the chapter on Water in an integrated or theme-based approach.
- Efforts should be made for integration of science specific disciplines and also integrating science learning with other disciplines, including arts, sports, etc.
- Curriculum must have an important aspect where a child realises the importance of protecting the environment not for others but for our own self.
- Similarly, when different possibilities exist for the description of a particular aspect, the student should preferentially be given the local example. For eg., For students studying near Mysore area, Shimsha (hydro power plant) can be easier to access than a student in Raichur area (thermal power plant). NCERT and other organizations involved in content creation should be provided with the freedom to provide suitable examples.

9.4.2.4.Secondary stage

Class 9 and 10:

Basic Sciences: Basic Sciences consists of 3 parts. Guidelines for each part is as follows

- The course content and pedagogy at this stage should give students an opportunity to study science in all its splendour so that they can make an informed choice about their higher education.
- At this stage, the content should also provide opportunities to hone certain skills that are based in science. This would help students who want to pursue vocational courses after 10th.
- They must have enough flexibility to choose certain subjects at a basic level and certain other subjects at an advanced level depending on their interest in specific subjects.
- **Part 1:Basic physical science** is needed for every student to understand the world around us irrespective of the career path one chooses later in life. Highly mathematical approach to physical sciences need not be enforced on all students. Conceptual understanding is necessary and sufficient for most career paths. Most part of physical and inorganic chemistry basics have to be covered here.
- **Part 2: Life Sciences** Understanding the variety of living beings around us is

important for everyone to know, what are we made up of and how do we function and how do we get sick and how to be healthy? Answers to these questions are essential knowledge for everyone.

- **Part 3: Interdisciplinary** (Phenomena, human endeavours, engineering and technology): There should be a thematic curriculum for the interdisciplinary subject. This should provide a foundation for scientific discovery, Engineering, inventions and vocational skills. This has to be truly interdisciplinary spreading across physics, chemistry, biology, geology, space etc., but also touches humanities, history etc
- Should provide a scientific foundation for value development.

Advanced level (optional) science subjects

- **Quantitative Physics-** Quantitative analysis in addition to simple causal analysis has to be made central in every topic. Quantitative connection between the laws of physics and corresponding mathematical methods has to be made intuitive for children. Plotting graphs and visualizing the connections between parameters as graphs has to be learnt.
- **Advanced Chemistry-** Focus should be on observing various kinds of reactions and learning the principles of chemistry. Formal methods of chemistry to be used as the instructional style in text books. Original methods of discovery used by scientists have to be introduced.
- **Molecular Biology-** Function to structure mapping and drilling down to molecular level should be the approach in the curriculum. Understanding basic organic chemistry and bio molecules should be the focus of the curriculum. Conceptual Connection has to be established between the above in the biological processes.

Class 11 and 12:

- Students must be able to choose certain subjects at 'standard level' and additional subjects at 'advanced level' depending the choice of their career path
- Standard level should provide an opportunity for students to learn the basic minimum concepts very easily for everyone.
- Advanced level introduces formal methods so that students can get prepared in the subjects of their choice for their higher education.
  - **Basic Physical Science**-Curriculum must be suitable for students pursuing pure science, engineering or medical professions. It must be mostly qualitative in nature. Highly rigorous. Mathematical treatment to be avoided. 50% of the learning has to happen through conducting experiments. Applications of the concepts have to be introduced
  - **Basic Life Science**-Curriculum must provide a sufficient foundation for students who like to pursue higher education in pure biology or applied biology (medicine etc). The curriculum should indicate a major amount of time dedicated to conducting experiments related to life science to help students develop concepts and process skills with precision.
  - **Advanced Physics-** Curriculum must give basic quantitative foundation for learning higher physics or applied physics. The stress should be more on

learning of higher order principles and development of analytical skills required to understand advanced physics. The curriculum should focus on application of principles.

- **Advanced Chemistry**- Curriculum must provide basics for higher studies in pure and applied chemistry, chemical engineering, pharmacology, bio chemistry etc. The understanding of cause and effect relationships and their application to solve higher order problems, critical analysis, and precision in conducting experiments should be the focus of the curriculum.
- **Advanced Biology-** Curriculum must provide a good foundation for higher studies in different branches of Biology and Applied Biological sciences like medicine, Ayurveda practice or agricultural sciences, etc. The focus of the curriculum should be on development of understanding of life processes and their relationship with various molecules of life. The curriculum should develop cause and effect relationship, problem solving abilities and analytical are critical skills.

10. Role of stakeholder in implementation of NEP

10.1. Students

- Students are to become active participants in experiential learning and not passive observers.
- The learning of concepts should yield to the learning of process skills of science.
- The role of students should shift from rote learning to the level where the learner takes the responsibility of his learning in the presence of teachers as facilitators.

10.2. Teachers

In order to help implementation of NEP recommendations in science education, the following requirements are to be met by the teachers-

- The teachers must themselves experience and be empowered with process skills to enable them to perform/demonstrate experiments in science.
- The teachers should be trained in the pedagogical skills to help them adapt required pedagogy as per the demands of the curriculum.
- Teachers are to be engaged in continuous training to help them learn new innovations in the field of science and education.
- Teachers have to apply innovative evaluation methods to help them reflect and improve their practice. Novel methods of evaluation also aids in monitoring the student progress and maintenance of cumulative record.
- Teachers should be given only academic work to improve the efficiency of teaching-learning process.

10.3. Parents

Parents as stakeholders are required to play the following role in the successful implementation of science education as per NEP 2020

- Parents are recommended to be active participants in their ward's education through providing encouragement to the child in learning.
- The motivation from the parent in pursuing science as a subject and regularly informing the development of the child to the schools.
- The parents have to create a learner friendly environment at home to aid continuous learning. They have to permit the expression of process skills with an open mind at home where continuation of learning happens.
- The parents are to respect the role of teachers in shaping the child's personality based on the competencies and interests of the child by taking advice from the school regarding the choice of specialization at the secondary level.

10.4. School heads

The schools heads play a prime role in monitoring of the implementation of NEP 2020. The school heads

- Are required to be equipped with the changes that are recommended by the NEP 2020.
- Should ensure that the implementations of recommendations are happening at every stage.
- Should encourage teachers to use innovative approaches of teaching science keeping in view the development of concepts of science, the process skills of science and the attitudes of science in students.
- Should aid in creating a non-threatening, non-judgemental, mistake friendly school environment where a child is free to express oneself and teachers is encouraged to try creative teaching practises
- Should engage themselves as a support system in empowering teachers with the advanced pedagogical approaches.
- Should organize programmes related to science for the benefit of students and teachers of their schools
- Keep in contact with the school complex and the district centres of science to organise programmes, visits and events related to science.
- Should enlighten parents about the progress of their wards with respect to science and
- Take measures to improve the performance of students in terms of science education.

10.5. Teacher educators

Teacher educators become important stakeholders as they are required to train science teachers in pedagogy and content of science.

- Teacher educators are required to actively participate in the curriculum development, research and innovation in science teaching and in devising new methods of pedagogy to enable effective teaching of science.
- Teacher educators are to become the source of pedagogy content knowledge, and empower the entrant teachers in science pedagogy.
- It is important that teacher educators have experienced science process skills and imbibe the attitude of science deeply in them. It is only then that they can make the pre-service teachers experience the processes of science which they are in turn expected to implement in the classroom
- They have to be a motivational source to teachers both in-service and pre-service and help teachers to enjoy their profession by equipping them with the professional skills. These

professional skills should enable teachers to overcome difficulties and problems in their profession and help them to progress.

- Teacher educators should take up the responsibility of arranging science educational activities in school complexes to enable regular training and development of science teachers.

11. Role of Various Agencies in the promotion of Science Education.

11.1. Local organisations

The organisations which are locally active in areas of science are to be considered for the teaching of science. Organisations like local small scale industries, primary health centers, local artisans, science laboratories of higher education institutions, farms, sericulture and horticultural centers, etc. can be considered to contribute towards science education. These organisations can be used to provide information and resources- both human and material resources. The local organisations can be utilized to help teaching of science process skills in students. They can also be used to empower teachers with the skills required to teach new ideas in science. They can also contribute in the finances required to develop and maintain laboratories and teaching-learning resources in schools. They also act in motivating the students in considering science as a vocational option. The schools are to organize a visit to such local organisations at least once a month to help students explore the science in their surroundings, which helps them relate classroom learning to real life situations.

11.2. State-level organizations

Collaboration with state level organisations help in development of research and development of science teaching. Such state-level organisations help as resource centers of science. They can contribute towards providing human and material resources to school complexes in turn aiding the science teaching at individual school level. The science personnel working in the various state-level agencies can become patrons to school complexes. The state-level organisations can adopt school complexes to help provide specialized vocational training in certain areas of science. Some state-level organisations that can be considered for collaboration include state-universities, industries (pharmaceutical, iron ore, power plants, mines, research institutes, etc.)

11.3. National-level organisations

National Institutes of science and technology along with large scale industries, botanical gardens, zoological parks can be considered to help the schools in science education. These organisations can be considered for school visits for the promotion of science education. These organisations help in providing direct experience of science to students. They can also be considered as centers to encourage research and development in school science education through offering multidisciplinary researches to teachers of science. National level science competitions can be organized by these organisations to promote science aptitude as well as find and encourage students interested in science. These organisations can provide scholarships and financial support to the students with high aptitude in science.

12. Requisites for the implementation of NEP Recommendations with reference to science education

In the implementation, there are some basic requirements without which science education cannot be achieved as per the recommendations of the NEP 2020. Right from the classroom to the state level facilities all these resources are to be made available at all times to help teachers and students achieve experiential learning. The objectives of science education require the provisions for providing experiences of science in a deliberate setting. These requisites support and scaffold the learning process.

12.1. School complex- Science Education Centre

Requirements

Content Creation: An alternate Experiential Learning of Science content in line with the syllabus for the appropriate levels is to be created. NCERT/DSERT to take Centre stage and work with NGOs in the space to get this ready.

Pedagogy: The learning and teaching method should align with the aspirations of NEP 2020. The experiential learning of Science is the best way forward as a sense of discovery remains for a longer period of time. Pedagogy to focus on content learning, process skills of science and attitudes of science.

Empowering Teacher/ Facilitator: The Centre should hire research oriented faculty to facilitate learning of process skills by teachers. The teachers in turn teach the process skills to students in laboratory experiments to develop process skills of science.

Infrastructure- The following infrastructure are required to be established and maintained by the school complex to promote experiential learning in science.

a**. School cluster science education centres**

The cluster of schools together should form a Science Centre in one school belonging to the cluster. Laboratory infrastructure accommodate at the maximum 30 to 40 students of a class or combine students from different schools. The ideal ratio is 1 lab for 10 schools. Resource person appointed at the Centre will assist the Teachers from the Schools. This arrangement of cluster science education centers will reduce the burden on limited resources. Materials and equipment needed to conduct experiments are to be supplied and managed only by the professional researcher. The responsibility of maintenance can be outsourced through CSR of corporates. The corporates can also maintain quality and accountability of laboratories. School teachers should perform experiments for the students using the laboratory facilities available in the science centers. Teacher’s role is only to ensure the quality and content of the class is adhered to and the students have performed the desired experiments. It is the responsibility of the teacher to develop attitudes of science and process skills through experiments and not perform mechanical experiments for the completion of the tasks.

b. Lab on wheels

A new, innovative approach to enable all schools to perform laboratory experiments. The laboratory on wheels can help by visiting half a day to each school for 5 days a week.

Hence catering to 10 schools per week. The lab on wheels shall be equipped with apparatus and requirements as per the curriculum prescribed. The experiment kits with a trained personnel shall visit schools to provide opportunity for experiential learning. The teachers utilizes the kits/apparatus to perform experiments/demonstrations and also help students to perform experiments. The lab on wheels can be funded through CSR funds and the quality and maintenance can be the responsibility of corporates or state-level science organizations. The industries can also adopt school cluster science educations centers and maintain lab-on-wheels.

C. School Laboratory

Every school should have a laboratory for providing experiential learning. Laboratory should accommodate at least 15 students at once. The laboratory can be supplemented with materials (both consumables and equipments) from lab on wheels or science centres. A compulsory formal laboratory period has to be accommodated in the time-table from 6-12 grade. Every science lesson should enable students to explore through laboratory.

Process skills, concepts of science and attitudes of science are to be developed through experiencing and exploring by conducting experiments rather than mechanically performing experiments.

12.2. Human Resource

The teachers are central to the education system who are the flagbearers of learning. But due to the circumstances of managing the education systems, teachers now are playing multiple roles as managers, co-ordinators, assistants, technicians, counsellors etc. This is leading to the fall-back in the teaching-learning process. To relieve teachers from the burden of non-academic and administrative work and enable them to be effective in teaching-learning process the following human resources need to be provided to carry out dedicated work.

- **Experts and resources persons** for orienting teachers with innovative pedagogical approaches, conducting training programs related to science teaching, initiating interactive sessions for helping teachers to solve problems. From a survey conducted across the different districts of Karnataka State, it was revealed that 37% of the science teachers admitted that they were not trained in innovative pedagogical practices and 32% of the science teachers admitted that they did not know adequately about NEP 2020. About 56% of the teachers were enthusiastic to learn more about scientific processes. This shows that there is a need for conducting continuous training programs for the teachers.
- **Co-ordinators for school complexes, Cluster science centres, labs and district science centres-** The co-ordinators are to be employed to co-ordinate activities of science centres schools and laboratories. The duties involve co-ordinating and organising programmes of science, co-ordinating the time-table for different science classes and co-ordinating between schools for providing facilities of lab-on-wheels ad cluster science centres.
- **Quality Management Teams-** The quality of the science laboratory and centres have to be managed and maintained from time to time, to ensure proper usage of resources available for promotion of science education. There should be check of quality and

quantity of equipment and consumables supplied supplied to various science centres and laboratories. The team should also evaluate the functioning of the laboratories and science centres. They are also responsible for the evaluating the quality of learning activities and experiments conducted in these science centres and laboratories.

- **Technicians and lab personnel-** are to be appointed to assist teachers in the laboratories. Their duties include setting up of laboratory equipment before the commencement of laboratory classes, recording the data of students and their performance in the laboratory, assisting the teachers in the experiments, keeping stock of the consumables and the equipment. Supervision of cleanliness in laboratories, assisting co-ordinators in organising programmes of science.

12.3. Teaching-learning materials

These are the materials used in the class as well as laboratories to the teachers and students to provide learning experiences. The teaching learning materials are not the laboratory equipment, but supportive learning materials like charts, models, manipulative objects, assistive technology materials of differently abled, real specimens or samples which help as learning experiences. Teaching-learning materials are to be provided to the schools as per the curricular demands to ensure experiential learning. Materials should be of use to each student and not just a display model. Materials should develop skills of manipulation, exploration, inquiry, etc. in children. These materials should be age appropriate, affordable, safe, eco-friendly and preferably commonly known to the child. Teachers should be oriented with the use and maintenance of such materials. Teachers can improvise and develop aids to help teaching. Teachers should be encouraged to use locally available and easily accessible materials for classroom explorations. Science centres should conduct programmes to help teachers in improvisation of teaching learning materials so that they can be produced with minimum expenditure. They should also develop learner friendly materials for schools to use in science teaching utilizing locally available resources.

12.4. Use of Technology in science education

As there is a great surge in the technological advancement in education after the pandemic of COVID 19, use of appropriate technology in different areas of education has become inevitable and convenient. Science is a discipline where technology adaptation in education is seamless but the use of technology should be meaningful and help in providing a wholesome experience. The science centres should take responsibility by collaborating with local, state-level and national science centres in developing appropriate technology for science education. The centres are responsible for organising programmes for teachers to help use technology in science teaching. Technology can be incorporated at various stages of teaching like- planning of lessons, classroom experiences, evaluation, assignments, and action research, cumulative records of students and also in learning through distance mode during natural disasters.

Students are to be equipped with the technological advances as a learner to avail resources of learning. Schools should equip classes to enable use of appropriate technology. At least one smart class should be available in each school.

Apps, Web resources, moocs, moodles, software, videos, simulation, etc. are to be made ready at affordable costs for school science education; these should be developed or adopted with recommendation from NCF/SCF.

12.5. Open Science Laboratories

The lab should be established and maintained with seamless collaboration between the government, Department of state education, corporates, and industries related to science. At least one open laboratory for 50 schools should be made available all throughout the state.

A governing body consisting of able and qualified persons in the field of science and education should be formed to help the proper functioning of the labs. The governing body should avail funding and materials (equipment, human resource and consumables) from the collaborators by presenting the budget once every year. The governing body must be organise financial aid/ material aid to help in the functioning and maintenance of the lab. The governing body must be audited regularly for proper functioning by the collaborators. The governing body must appoint resource persons, teachers, guides, and technical assistants to help students to perform experiments.

Goal of open laboratories
To work towards basic and applied researchers in science.
To help students who are science enthusiasts avail free laboratory facilities.
To encourage creativity and enthusiasm related to science.
To promote innovation, experimentation, and scientific attitude.

Functioning of open laboratories
The lab must be available to the students on all days of the week to help them access during the time available. The lab should be supervised by trained personnel at all times appointed by the governing body.
The students interested in performing innovative or novel experiments should submit a proposal of their idea or purpose in brief to the governing body. The request of the students is to be considered and processed within a time period not exceeding 3 days.

School ID card of the student should provide access to the labs if the purpose is to practice science experiments. The open labs should provide guidance for students in both innovation and practice.
The open labs should organise special programs in fields of science with the help of state-level agencies or industries. One such programme should be organised every month for both teachers and students.

12.6. District Science Centers

District science centers are the focal points in a district for the promotion, status and improvement of science education of their respective districts. The district science centers are to be established and maintained by each district individually. A separate financial facility should be given for each district to maintain the District Science Centers. The state and DSERT should be responsible for the proper functioning and maintenance of the science centers with the help of industries, scientific organisations and agencies.

Role of District Science Centers

- To promote science education in the district.
- To facilitate teacher training regularly throughout the district.
- Quality and Maintenance of school complexes, open labs, cluster science centers
- To ensure programs on science are conducted regularly in school complexes for both students and teachers.
- To appoint human resources for school complexes and cluster science centers.
- To promote and guide research in science and science education in the district.
- To maintain records of scientific agencies and involving them in the process of science education throughout the district.
- To promote students and teachers who are science enthusiasts by providing required opportunity and publicity to their novel work.
- To provide scholarships and aids for the students who are meritorious in science and promote them to pursue higher education in science.
- To establish quality control team within the quality control cell to scrutinize the different science educational institutes of the district.

Units of the District Science Centers

The District Science Center should be constituted with the following units to help them become independent functioning bodies to promote science education in their districts.

a. A Science Library
b. Material Resource Center
c. Well-equipped laboratory
d. Science Teacher Resource Center
e. Science Museum
f. Quality Control Cell
g. Information and Technology Cell

Functioning of District Science Centers

District Science Centers must function regularly taking up different roles as mentioned above. The human resources must be provided to the District Science Centers for all units. Trained and experienced personnel must be employed to establish quality of the District Science Centers.

The district Science Centers should make it mandatory for the individual schools to visit their centers once in a semester along with their students. The district Science Centers should be given the authority to fix visits for schools, conduct training program for science teachers and technicians and maintain records of experiments that are being conducted in the open labs across the district.

Broadcasting the latest innovations in science and technology worldwide to the schools and school complexes will be the responsibility of the District Science Centers. The district science centers can create Apps, blogs, websites and forums for science enthusiasts and make available resources to such groups to promote science in their districts from their information and technology cell.

District Science Centres also should organised demonstrations, talks and discussions which can be telecasted to the schools live. They have to understand the demands of the schools and the society and form a liaison between them.

The quality control cell must visit and inspect schools, school complexes and open laboratories once in a semester to ensure the quality of the programs, maintenance if the facilities and proper functioning.

13. Guidelines for Teacher Education – Pedagogy of Science

As teachers form the centre of the education system, the teacher education takes a prime position in the process of developing teachers to adapt to the new challenges of education. As per the recommendations of NEP 2020, the teacher education should undergo restructuring to train teachers to implement the new ways of education.

Teacher education requires restructuring of science pedagogy content knowledge at the foremost. Innovative approaches to teaching have to be introduced to science teaching concentrating on experiential learning, constructivist and reflective approaches. The former teacher-centred approaches in the teacher education curriculum like the lecture method, lecture-demonstration methods, etc. should be replaced with student-centric approaches of teaching which are psychologically meaningful.

Teacher education should develop research skills in all entrant teachers at the pre-service level to help them evolve their scientific temper. Action-research should become a part of teaching profession to solve problems that are encountered by individual teachers.

Regular training for in-service teachers should be designed by the teacher education to empower teachers with new pedagogical practices and to enable contact between higher education and school education.
Teacher education should help teachers to redefine teaching objectives keeping in mind the content, process skills and attitudes of science. They should help teachers structure their lessons according to the framed objectives and attainment targets.

The teacher education should make entrant teachers to evolve instructional strategies to solve their classroom problems. The teacher education curriculum should focus on the development and use of cognitive strategies required for teaching in their entrant teachers rather than feeding them with factual information.

Separate teacher education specialization for each levels i.e. foundational, preparatory, middle and secondary levels should be provided where teachers will thoroughly understand their target learners well. The appointment of teachers to the different stages should be based on their specialization at the pre-service levels. All the stages of specialization should be treated with equal importance.

The practical areas where experiential learning in science is involved, teachers should be given special training at the teacher education institutions. Laboratory skills of the teachers are to be honed keeping the curriculum of schools in mind at the pre-service education level. Regular workshops are to be conducted for in-service teachers to qualify them with the process skills and laboratory skills.

14. Indian Contribution to Science

The Indian contributions are now mentioned as facts which are just memorized by students. Instead of fact presentation, the inclusion of the way of logical thinking and how the concept was deduced as a process should be included in the curriculum. The way how Indians thought to infer the laws, concepts and principles of science should be taught rather than the facts of science.

Day to day use of science in our culture should be highlighted wherever appropriate. How our culture respects science and scientific basis for our cultural practices should be incorporated with the content. Misconceptions about scientific phenomena and blind beliefs have to be clarified through experimentation or exploration. Scientific notion behind such practices should be incorporated into the curriculum along with appropriate content. The children should appreciate and value the Indian scientific processes that are around us in our diverse culture.

Topics like Science in our kitchen, science and our religion, science of magic etc. have to be introduced to children at the middle and secondary stages to help them understand the world we live in more rationally.

Tribal Knowledge system can be incorporated into the teaching of science wherever the concepts are related. Transdisciplinary universities where there is study of the tribal knowledge can be associated with the district science centres to organise programs regarding science in tribal practices as a part of science teaching and learning. Communication of ideas related to tribal knowledge and its practices can be encouraged in schools from the community.

15. The development of science textbooks and other material bilingually

The materials like text books, workbooks, teacher resource books, evaluation sheets and question papers must be developed bilingually. Separate text books and work books of science are to be made available to students. The English textbooks have to incorporate the illustrations, phrases and words of importance in Kannada next to the English terms to enable the child to relate to the new English words. Similarly the scientific terminologies and definitions in Kannada text books have to be provided with English terms and phrases to help the child learn English language. This helps the children studying in Kannada medium to comprehend scientific terms if he/she opts for Science as a discipline at higher education. Illustrations in both Kannada and English texts have to provide the local Kannada names to help the child to comprehend. This also promotes learning of uniform Kannada names apart from the known local dialectical terms.

The text books should maintaining quality by providing high resolution, colour images and illustrations, where colour is more realistic. Good print and paper quality (min. 80 GSM) should be ensured. The content should be accurate and activity based. Anecdotes related to science content should form part of the text book.

16. Making Science Education More Inclusive

Children with disabilities are often overlooked in policymaking, limiting their access to education and their ability to participate in social, economic and political life. Worldwide, these children are among the most likely to be out of school. Most of these children are differently abled but some can function normally along with the others if provided with opportunities to develop their special abilities during schooling. Such children are often isolated from normal school system as it is assumed that they require special care and aids to help them learn. In the process of educating these children, the social component of education, where the child is made 'society ready' has been neglected. They are constantly taught in an isolated learning environment entirely conducive to their special abilities but are not introduced to the normal societal life, where they are required to co-exists and thrive. It is true that not all the children who are differently abled can be fit for normal school education, but children with milder disabilities can be considered.

16.1. The Curriculum and Classrooms for Inclusive Education

- The curriculum cannot be changed entirely to accommodate children with special needs, but the curriculum framework should provide flexibility to frame objectives based on the individual differences.
- The curriculum should recommend alternate activities or support for children with special needs that can be accommodated in regular classrooms.
- The resource rooms need to be replaced by special educators in regular classrooms.
- For children who are mildly autistic structured activities that involve a set of repetitive stimuli, denoting a pattern are to be introduced so that they are trained to respond in a particular way.
- For children who are visually compromised (complete blindness) tactile aids which are very near to accuracy are to be used by a co-teacher who is thoroughly trained during the teaching learning process.
- Children with auditory disabilities are to be made sensitive to mild vibrations of sound wherever necessary.
- 16.2. Conceptual Development in Children with Special Needs
- During the foundational and preparatory stages, where the sense experience plays a very important part in learning, children with special needs form their own experiences based on their abilities. Hence there is definitely a difference in the conceptual development among these children.
- To help them with concept formation, experiences should be provided based on their special abilities which can help them in forming near to accurate mental models. Here assistive technology, tactile experiences and special aids are to be used carefully under special supervision.
- In the later stages, such children will always face difference in the concept attainment when compared to normal children.

16.3. Teacher Training for Inclusive Science Education

- Co-teachers and Special Educators are mandatory to make education more inclusive.
- Teacher education should provide a specialization at both bachelor and master degree level as an option to make special education a mainstream programme.
- The training should be more practical in nature and should be divided into two stages, i.e. Pre-inclusive stage-where they learn in a simulated environment; Inclusive stage –where they are trained as interns in inclusive schools under the supervision of senior educators.
- Training for each type of disability should be provided separately wherein special skills of structuring classroom learning catering to individual needs and strategies to overcome possible difficulties are the focal points in the specialization subjects.

- At the master degree level of teacher education, a case study involving one particular type of special need can be the practicum.
- In-service teachers need to be provided opportunities to take up special education as an add-on course (but the course should be more practical in nature)

16.4. Implementation of Inclusive Education

- As per the expert opinion, only children with mild to moderate disabilities can be accommodated into the normal school education.
- Extreme sensory disabilities can be managed with the help of co-teachers who are experts, teaching along with the regular teachers in the class.
- Each school can specialize in a few areas of special needs for the start and share the co-teachers.
- District wise model schools (2 to 3 per district) can be made inclusive in the phase 1, later extending the facilities to the other schools.
- Physical disabilities can be managed by making infrastructural adaptations and changes.
- Children with mild learning disabilities or cognitive disabilities (like Asperger's Syndrome, ADHD) where they are socially conducive can be accommodated into regular schools. Such children may need extra break hours during the class, the teachers should be considerate to be more democratic with them.
- Children with special needs can be made to attend school for half-a-day, to help reduce their stress.
- Considering children with special needs, only a few can develop to attain problem solving and complex cognitive processes (hypothetico-deductive reasoning). But most children with cognitive and learning disabilities can be trained to do repetitive, sequential work. They can only be trained to make a living in certain areas of vocation. Hence science education at a higher level can be provided to children with physical disabilities (where they can be mobilized) only. Mild sensory disabilities can also be provided science education as an option at a higher level but with support during the process of learning.
- Children with extreme learning disabilities, sensory or physical disabilities cannot be accommodated into mainstream education and require special centres for their education.

17. Specific recommendations for the state/national curriculum frameworks

- The curriculum should be drafted in such away that the activities are joyful, engaging, and enterprising whilst allowing democracy and freedom to express emotions. The curriculum should be student-centric, and should lead to a pedagogical approach that focuses on exploration and experiential learning. The focus of the curriculum should be on discovery rather than traditional teaching.
- Activities for experiential learning related to different topics have to be suggested in the framework.

- The framework has to specify objectives keeping in mind the concepts of science, process skills and attitudes of science for each topic. The assessment strategies for the above objectives should also be specified.
- Conceptual understanding should be promoted using local exemplars.
- The curriculum should consider Indian knowledge system and its contributions in promoting conceptual understanding.
- The curriculum should also recommend development of vocational skills. The curriculum and evaluation should be designed in such a way so as to differentiate students based on their vocational abilities and help them to choose a career out of choice.

17.1. Specific recommendations for NCF/NCF-Adult Education

- The adult education curriculum framework should focus on inculcating scientific temper and scientific attitude. The framework should recommend objectives that are related to day-to-day practices of science that can be incorporated into their vocation.
- The vocational training in adult education should lead to a certification that enables them to pursue higher education or specialization in that area of work as a human resource. These vocational skills should be valued equal to the graduate level qualifications.
- Adult education curriculum should also develop understanding of the scientific phenomenon that surrounds the daily life of an individual (health, hygiene, science behind culture, safety, ethics, environmental awareness etc.)

18. Challenges and Mitigating Strategies

This section deals with the challenges that we are likely to face in implementing **science** education as per NEP 2020. NEP 2020 emphasizes the need of experiential learning which is at the core of effective science education. The key challenge is to transition the education system from 'rote learning' based system to 'experiential learning' based system. This involves changes in content, pedagogy and assessment methods. NEP 2020 envisages teacher's role to be central in making this transition.

NEP 2020 based pedagogy and assessment would be very new to in-service teachers. Imparting the methods of 'new way of teaching' to in-service teachers is one of the mammoth tasks involved in implementing the NEP successfully. Current training methods involve one or two yearly workshops where state level resource persons train district level resource persons (teachers) who will go back to their districts and impart the same training to other teachers in the district by conducting week long workshops. Most of the training imparted is based on following assumptions.

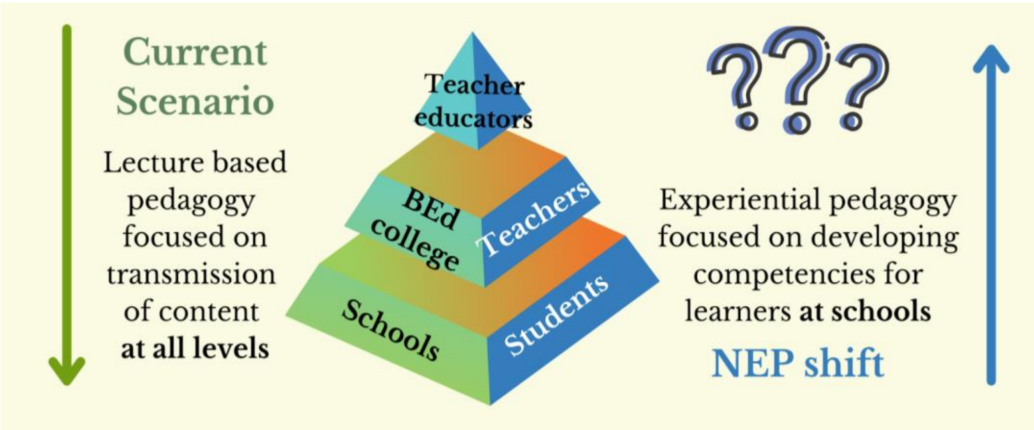
1. It is possible to explain teachers about how to teach well in the new paradigm within a week.
2. District level resource persons can carry and deliver this 'new paradigm' of teaching to other teachers faithfully at 100% precision.

One can instantly see why both the assumptions are fallacious. Following are the reasons why such training is ineffective in the case of complete shift in the pedagogy and assessment.

1. The new pedagogy needs a deeper understanding of the concepts by the subject teacher

2. Teacher should know how multiple concepts are connected to each other and connected to the world around them.
3. A dry run for the teachers where teacher experience for themselves the implementation strategies is mandatory.
4. Teacher should know how to make children experience every idea before it becomes a scientific concept in their brain. Text books and teacher manuals are necessary but are never going to be sufficient to transform the teachers.
5. One time training is never sufficient to change any habit. Continuous training is needed on daily basis for teachers to align themselves to the new ways..
6. Good teaching is an art. Reductionist methods of splitting this art into small parts and hoping that addition of these small parts will give a whole good teacher is a commendable exercise but would not yield great results. Instead, Indian way of learning from a 'Guru' by watching and imitating how an expert teacher teaches is considered a much more effective way of learning for the teachers.

Considering the above aspects a new strategy for in-service teacher's training is proposed below

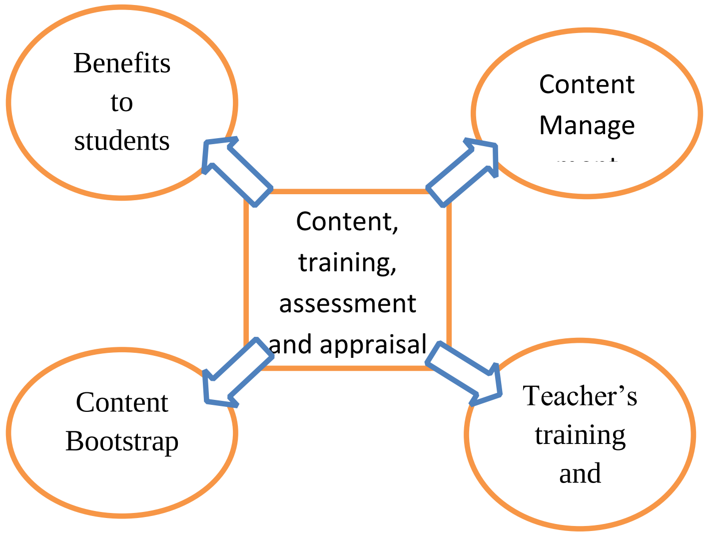


18.1. Proposed Solution

Following are the features of the proposed solution.

1. In-service teacher's training will happen continuously throughout the year.
2. Teacher will be given help in teaching every chapter when she is ready to teach that chapter
3. Training will be imparted by expert teachers both from inside and outside the system. International expert teachers can also be utilized to train our teachers
4. A digital platform to be built (or existing platform like 'Diksha' can be leveraged) that can serve as both the delivery mechanism and a repository for the training material
5. Good teachers will get opportunities to train other teachers by contributing to learning material repository
6. Teacher evaluation can be made in an unbiased way and completely based on the competency and effectiveness of teachers.
7. Leverages existing digital infrastructure at schools
8. Highly scalable model

A technology platform is proposed to stream-line teacher's training, content management, teacher-assessment and teacher-appraisal systems. It will be a web-based LMS (Learning Management System) like platform. It would host teaching videos, lesson plans, activities and other content that are needed for teachers. Most of the content is contributed by the in-service teachers. Initially, content can be bootstrapped by a set of external / designated expert teachers (including international). Gradually the content on the platform grows and evolves through student preferences and expert selection mechanisms. These are explained briefly below.



18.1.1. Content Management Highlights

- Separate teacher training channels for 5+3+3+4 stages. Each stage teachers are to be trained separately.
- Access to repositories should be specific for each class and subject
- Contributed by expert teachers / good teachers within and outside the system
- Graded by experts and students providing a 'combined score'
- Can be sorted based on rating.

18.1.2. Teacher's training and evaluation

- Teachers have to watch the videos / read before teaching a lesson
- Lesson plan should involve what is learnt through the content
- Contribute to the content repository by uploading the teaching content (video, lesson plans, etc.)
- Conduct experiments based on the learnt content
- Contribute to the content by uploading the videos of experiments conducted by them
- Evaluation committee at local and state levels to evaluate and give 'expert rating'
- School inspection can validate the learning as documented by lesson plans
- Students' 'view data' provides "student rating"
- "Combined rating" is calculated by considering 50% from "expert rating" and 50% from "student rating"
- Teacher's salary increments and promotions are dependent on their rating.

18.1.3. Benefits to students and their role

- The videos from the repository cannot be used as a replacement to the classroom teaching.
- Typically students are not compelled to watch the content
- However they have an option to watch whatever content they like
- Number of views provide a base for "student rating"
- Students participate in club activities
- They can watch additional content from here

18.1.4. Content bootstrap

- Initially content should be created by expert teachers
- It would be an yearlong effort
- Expert teachers can be part of the assessment panel later
- Experts can be chosen from outside the system
- Care should be taken to choose expert teachers so that students can understand the videos
- Bootstrapping is the most important aspect of this strategy, if not done well quality will be compromised.

The above model, if implemented well can be scaled to national level and also for the other subjects as well. Digital platform has to be designed well such that it can be expanded to include different facets of imparting education at a national level into it.

Core principle of the above model is taken from our traditional wisdom that a 'Guru' is needed to teach well even for the teachers. Learning through imitation is central to human development. This fact, coupled with the power of digital technology can transform our in-service teacher training and can enable teachers to bring the changes mandated by NEP 2020.

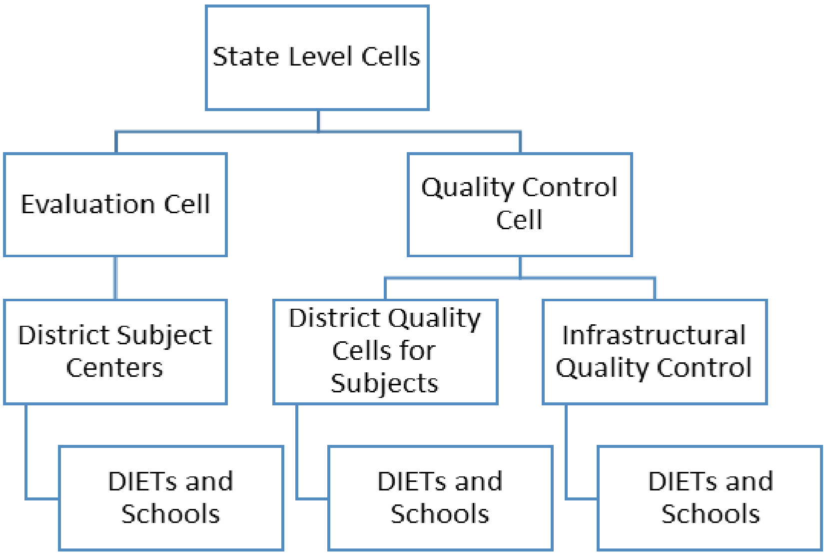
18.1.5.Assessment of Students and Teachers

The assessment and evaluation of a child is only on the "remember and understanding" what has been taught rather than testing the higher order thinking skills of the children with capabilities to analyse, apply, evaluate and create. The practical aspects of learning is never part of the evaluation process.

Students should be evaluated for process skills, verbal skills and attitudes of science. Evaluation should not be restricted to annual examinations. The evaluation tools and training to use these tools should be provided by the district science centers. An expert committee should prepare the evaluation tools and oversee the process of its implementation and completely be accountable. A cumulative record for all the children through the different stages have to be maintained by their respective schools and data should be maintained by the state cells..

For the control of quality of evaluation system, a state level evaluation and assessment cell should be formed. The functions of the cell are to keep track of the evaluation of students and teachers through district science centers. It is also responsible for the development of different evaluation and assessment tools to assess both teachers and students. The evaluation cell directs the teacher training programmes required for the use of these evaluation tool. The cell also maintains records of students and teachers and monitors their progress. A research team under the cell is responsible for the innovations in the field of evaluation based on the data to help improvement of teaching-learning process. In the different districts, the district subject centers take the responsibility of conducting programmes directed by the state evaluation cell. The district science centers maintain records of the students in the field of science from the different schools.

The quality of pedagogy and content is monitored by separate cell called the state cell for quality control. The cell functions under two heads; a. to monitor subject quality and the other to monitor quality of infrastructure. The quality is maintained by continuous supervision of pedagogy, classroom practices and infrastructure through district subject centers. The quality is maintained through thorough supervision and maintenance from district science centers which work in co-ordination with the diets, BRCs and the school. Training programs directed by the state cell are conducted at different levels under the leadership of the district science centers. This process of supervision and quality control helps in the effective implementation of the Strategies and helps overcome the challenges.



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Annexure 1

General questions

1. Please respond to the NEP points above on science education, including any suggestions you may have regarding additions or modifications.

2. What are the problems currently faced in the curriculum and pedagogy of science?

NCF 2005 clearly mentions the need for experiential learning but the curriculum and the textbooks still follow the same old method of delivering information.
Science processes were not given importance when compared to facts of science
In-service teacher's training was archaic and could not enable the teachers to shift over to experiential and inquiry based teaching methods. Upgrading the existing teaching community to experiential learning of science should happen at a feverish pace and they should be delegated with authority and responsibility for successful implementation. Creation of facilities and provision of materials through public/private partnerships will provide quality inputs. The teachers should not be burdened with any administrative/ other jobs and more than 90% of their time spent on teaching/ facilitating science learning and evaluating the students on their performance and growth.
Science lab infrastructure and regular maintenance was poor.

3. How can we ensure in the new curriculum and pedagogy that the problems listed in #2 are addressed/overcome?

The solutions to the above problems are explained in detail in the science position paper. The summary is as follows.

Science position paper gives guidelines to curriculum developers about bringing in experiential learning as a part of the curriculum. Also, it is suggested that "expert teachers" from within and outside the system have to be involved in preparing the curriculum and textbooks.
Objectives for every chapter have to be defined in terms of the science processes & skills children need to learn and NOT in terms of the information that they need to remember. This is made clear in the position paper
A suggestion to overhaul the in-service teacher's training program is explained in detail in the position paper. Technology will be effectively used in the new training methodology and the training happens throughout the year. Even the teacher appraisal mechanisms are suggested so that the best teachers are rewarded. This can lift the quality of education to a new level
'School complex' can provide better infrastructure because of the integration of multiple village schools into one complex. In the meanwhile, till all the schools are integrated into complexes, 'mobile lab' solution is proposed in the position paper. This mobile lab also provides periodic supply of lab materials to schools. These labs are supposed to visit every school once a week and either supply the materials or allow teachers to conduct experiments inside the lab itself. One such mobile lab for 10 schools is proposed.

4. What is currently being done well in science education, and how can these present good practices/innovations/initiatives be strengthened/scaled up?
Nothing is being done well on a large scale. However, some good science teaching is happening in pockets mostly because of the initiatives of some individual teachers or initiative of some smaller institutions.
It may be worthwhile to study these small pockets and understand their methods and find ways of scaling them up.
It is also important to provide autonomy to such teachers and schools so that they can be encouraged to innovate.
The district level science centre is a great concept but only 2 being functional out of the 26 centres indicates a dismal performance of them. If accountability is established, it can be a great source for deployment of the envisaged NEP implementation, effectively.

5. How will the new science curriculum be reoriented towards developing holistic learners? What would be the horizontal connections that the science curriculum will have with other curricular areas for such

holistic development?

The learnings are, in part, culture specific. The students should be exposed to their surroundings and the connect with their immediate neighbourhood should be made deep and a blend with the prevailing culture in the locality is established. This means, the concept taught will have a global connect but the examples (materials) will have to be local. This will not only help students to care for the locally available resource and its preservation rather than not have a connect with the surrounding. It has been adequately described in the position paper that the examples cited should enable deep understanding of a concept and it is better understood through locally available materials and examples. For example, concept on energy generation can be understood through many different examples (hydraulic/thermal/solar/tidal etc) and students who belong to different regions can experience it by visiting the nearest power generation centre. Similarly, a school in a tribal region should consider teaching noise and sound by taking the examples of birds, animals rather to quote an example of an aeroplane. The science education is not to isolate the child from its surroundings to learn science, but incorporating all other aspects of the environment into the understanding of the science. The objectives of science education involve all the three domains of the personality i.e. the cognitive aspects, the affective and the skill development to aid holistic development of personality. The pedagogical processes adopted to teach science shall cater to the expression of not only cognitive achievements but also thoughts and emotions to help balance the personality during the formative years.

6. What would be the approach to science education that would respond to the requirement for reduction of content in science to its core essentials, in order to make room for deeper learning and greater creativity, problem solving, discussion, and critical/analytical thinking?

The integrated learning of themes can reduce concepts learnt in Silos. As an example concept on water can be learnt as physics, chemistry and biological functions of water. This will not only reduce the content of the subject studied, it will make a deeper understanding of a concept. As the individual grows, it will become adequately clear that a wholesome, interdisciplinary approach for the understanding of a particular topic is critical to finding an optimal solution to a scientific challenge.

7. How would the science curriculum and pedagogy move from an "Impression Model" where the emphasis is on remembering scientific facts, to a "Process Model" where the emphasis is on developing scientific temper and evidence-based thinking?

The entire experiential learning of science is on "process model." In the inquiry-based experiential learning, the student is asked to think about the process needed to arrive at a conclusion rather than remembering the information provided to them, as in the current practice. The process of science becomes more important than the product of science. It is important that the entire student community gets exposed and continue to practice science through activity-based learning rather than rote learning. Over the middle and secondary science learning the sensorial perception based understandings will get slowly converted to fact (evidence) based, unbiased scientific evaluation leading to validated conclusions.

8. How would the skill of communicating science be incorporated in the curriculum?

Effective communication is key to getting across how the students have understood science. The evaluation of students studying science is not just through written tests conducted periodically, the ability to communicate and the skill sets required for performing experiments are considered important evaluation criteria for the holistic evaluation protocol. Communication on the science projects undertaken by students during an academic year, either individually or in groups will help them develop skills of expressing the work done by them. Group discussions, elocution and seminars on a particular theme can help students express themselves. While knowledge acquired gives confidence, the repeated experiential learning gives them prudence to use the choice of words which will enable effective communication.

9. How will Indian knowledge systems be incorporated in an accurate and engaging manner into the science curriculum?

Day to day use of science in our culture should be highlighted wherever appropriate. How our culture respects science and scientific basis for our cultural practices should be incorporated with the content. Misconceptions about scientific phenomena and blind beliefs have to be clarified through experimentation or exploration. Scientific notion behind such practices should be incorporated into the curriculum along with appropriate content. The children should appreciate and value the Indian scientific processes that are around us in our diverse culture. Students at Secondary level should be allowed to make experiments to understand the scientific basis for the cultural practices prevalent in the cultural system.

10. How would the work and contribution of Indian scientists be included in the curriculum?

The Indian contributions are now mentioned as facts which are just memorized by students.
Instead of fact presentation, the inclusion of the way of logical thinking and how the concept was deduced as a process should be included in the curriculum. The way how Indians thought to infer the laws, concepts and principles of science should be taught rather than the facts of science.

11. How will local and relevant tribal knowledge systems be incorporated into the science curriculum?

Tribal Knowledge system can be incorporated into the teaching of science wherever the concepts are related. Transdisciplinary universities where there is study of the tribal knowledge can be associated with the district science centers to organise programs regarding science in tribal practices as a part of science teaching and learning. Communication of ideas related to tribal knowledge and its practices can be encouraged in schools from the community.

12. How can scientific temper be incorporated in curriculum and pedagogy from the Foundational Stage itself?

Scientific temper refers to logical and rational thinking. The distinct advantage of developing scientific temper at the early age is to eliminate superstitions and irrational practices. Both curriculum and pedagogy play a critical role. If the concepts can be enabled by activity filled curriculum, appropriately designed, it will significantly reduce the perception-based inferences by the students. Similarly, the inquiry (questioning) based experiential learning as a pedagogy leads to conclusions drawn through scientific experiments.

13. How can the science curriculum be made more engaging, multidisciplinary, and its learnings relevant to the child and help in developing 21st century skills? What are other subject areas under the Sciences that should be introduced at the secondary stage to fulfil present day demands and needs and provide appropriate linkages with higher education? How can this be implemented?

The Science curriculum in the present situation translates to passing on information from the books to students with the help of teachers. With the advent of electronic media and resources available readily, the students are in a better position to access to information. What is grossly missing is the excitement of acquiring knowledge through experiential learning. The joy of discovery by making/seeing experiments is completely lacking. It is desirable that this situation changes. In the competitive world the student is exposed, it is critical that the concepts are made absolutely clear to the students and they are equipped with different skill sets (oral, written and practical) to cope with the ever-demanding situations. As mentioned earlier, the concepts should be taught through a multi-disciplinary concept driven approach.
Some of the major things which are left out conveniently in our curriculum on science are food and wellness associated with food. While there is enough information on plants and agriculture in the texts, there is nearly no information on the wellness contribution and the nutritional value of the food the regional foods offer. What are the important contributing factors for someone to remain a healthy individual and what constitutes a healthy regime is missing in the current curriculum!
There is a wealth of information available especially in the sub-continent, on the natural materials acting as health promotors. It is important to guide the younger generation an exposure to this treasure trove (this kind of information also resides in many tribal areas) and scientifically validate a particular plant extract for a medicinal use through project works, particularly, the secondary level. Exposure to research at a secondary school level should be encouraged and exposure to practical works should be made mandatory. It is absolutely necessary for students to be hands-on by the time they leave the secondary school system

both for higher science studies or vocation training.

Annexure 2

Types of learning that occur at the preparatory stage-

1. **Verbal Learning**

- Verbal Association
  - Presentation of object and observing the object
  - Observing response results in internal stimuli and hence verbal response
- Verbal/Pictorial Mediation
  - Talking to oneself/ picturing the object, (which the teacher can ask them orally or ask the child to express in its own way).

1. **Concept Learning**

- Concrete concepts to be learnt at the preparatory level. Concept learning should happen through interaction of the child with the examples.
- Concept to be taught through the listing of dominant attributes during concept formation and secondary attributes at the stage of concept attainment.
- Three types of concepts can be taught, Conjunctive, Disjunctive and relational concepts.

1. **Psychomotor Skills**

- Motor Response
- Movement coordination
- Response patterns

Pedagogy of science (Preparatory Level)

Steps to initiate verbal learning

1. Describing the student what one is expected to learn.
2. Examining the instructional task and the material for their meaningfulness
3. Assessing Entering Behaviour
4. Provide appropriate classroom condition for practice
5. Provide Knowledge of Correct responses (Prompting, Confirmation, Reinforcement)
6. Provide conditions to reduce distractions.
7. Use suitable methods for assessment of learning.

Steps in Concept Teaching*

1. Describe the expected learning outcomes
2. Highlighting dominant attributes
3. Providing useful verbal cues to think
4. Providing positive and negative examples and helping the child to label the positive ones. (Examples should be realistic and known to the child. They should be concrete in nature and the child should be allowed to explore the attributes)
5. Presenting examples in close succession/simultaneously
6. Encourage students to respond and reinforce their behaviour (even when they are partially wrong)
7. Assess the learning of concept

* The concept objectives are related to the subject matter of the activity and can be expressed as a body of knowledge. These can be achieved through one or more activities.

Instruction of Skills

1. Analyse the Skill.
2. Assess the entering behaviour of the student
3. Arrange for the Training in the Component Units/Skill/Abilities
4. Provide for contiguity, practice and feedback

*The process skills do not always have a direct relationship with the content of activities. Its development requires a wide range of activities over a period of time. (Therefore the content related objectives risk undue attention rather than the attention received by the broader process objectives that the science education should receive.)

Secondary Level

Some definitions:

The words Facts, Concepts, Principles, and Theories in Science are defined as per the publication mentioned in the reference section at the end of the document.

In summary, facts are 'generally known information' about the world around us while concepts are the understanding retained in the mind. Concepts can be either concrete (about a thing) or abstract (an idea). Principle (or a law) is a fundamental truth or proposition that serves as the foundation for a system of belief or behaviour or for a chain of reasoning. Theory is similar to principle but is yet to be proved using a sequence of logical steps (or math) or evidence.

However, the word 'concept' is also used in its general sense where anything that is a mental construct is a concept. For example, when a 'principle' is well understood, it becomes a mental construct and can be called as a concept.

Science education has to follow the method of science itself. Following is the method or process of science

Experience, conceptualize, search for the principles, make theories, make predictions based on theories, design experiments/observations to test the predictions, conduct experiments prove / disprove a theory, theory becomes a principle if proved.

A student has to go through the above process in order to realize the true nature of a principle / law of science. For example, though Newton's second law is a proven law (principle), for a student, it is still a theory till she realizes it herself through the above process. She has to push a lighter (small mass) and heavier object (higher mass) and experience the fact that the heavier object requires higher force. Only then, Newton's law gets conceived in her mind and becomes a concept. This concept gains depth as more and more observations are made about the law. For example, when a student observes that the when the mass doubles, force needed also has to double, she will add another attribute to the relationship between force and mass (directly proportional). Gaining depth requires ability to conduct structured experiments and more precise measurements.

If we consider another example 'theory of evolution', basic pedagogy to form the concept (of the evolution principle) requires the above mentioned stages, however, gaining depth requires addition biology specific observations and processes.

Classes 9 & 10

Steps for basic concept forming (of concepts and principles)

1. Enable students to experience: This can be done by
    a. observation of the natural world around us
    b. observing a natural phenomenon related to the topic
    c. conducting a magical experiment in front of the child to increase curiosity about the topic
    d. Simulate the experience through a thought experiment or computer simulation
1. Discuss about the experience and make sure that the intended experience has taken place
2. Nudge the students to reason out through discussions and seeding some existing theories
3. Help them to arrive at some candidate theories.
4. Suggest experiments to test the theories and discuss the outcomes and corresponding inferences.
5. Conduct experiments and understand the principle

Some ideas can be simpler and may need a subset of the above steps; however, maintaining the sequence is important.

Steps for advanced learning of complex content

Physical sciences and life sciences need slightly different kinds of pedagogy to gain depth. Even the topics within these sciences need specific techniques to gain depth. Some example are mentioned below

Quantitative physics: Experience, Generalization, Concept formation, Experimentation and measurement, plotting graphs, forming equations (mathematically modelling), Quantitative understanding of laws.

Life processes in Biology: Observation of function, investigation of structures, building causal connections between processes. Investigation process can also have a specific defined pedagogy

Classes 11 & 12

Systematic study is needed to study any science. As described earlier, method followed to study all sciences is same. However, during class 11 and 12 students need to apply the formed concepts and principles. Method to be adopted for transfer of learning is different for different kinds of sciences. This is because the focus of study for every sub-stream of science is different

Broadly, Physics deals with the motion of inanimate objects, chemistry deals with the interaction between objects (materials) and Biology deals with how life works.

Focus of study in physics is to unify laws of nature and arrive at minimum number of laws to explain nature. Since physics deals with simple objects whose behaviour can be modelled strictly, mathematics becomes important tool for understanding physics. Pedagogy of physics should focus on developing mathematical models, visualizing them and solving them.

Focus of study in chemistry is to explain and predict the interaction between various substances (molecules). Conducting experiments carefully and arriving at right kind of inferences is crucial in chemistry pedagogy. Making a theory about interactions and testing the theory also is central to chemistry. Reaction mechanisms form the basic principles of chemistry. Pedagogy of chemistry should focus on experimenting with chemical reactions (including chemical reactions that are taking place all around), qualitative and quantitative experimental techniques and inferring methods.

Focus of study in biology is to explain life and its processes. Life processes are very complex and human understanding is still at nascent stages. It is very hard to rigorously model the life processes using math. Also, it is not possible to minimize the number of laws to define life. Biology focuses on observing and understanding the processes in a very detailed way. It is also important to classify and categorize. Pedagogy should focus on these aspects of biology.

In addition to the above, solving complex problems which are spread across sub-streams of science is an important competency the students need to develop.

Example of content, Curricular Principles and pedagogy for Secondary School Stage.

Parts	**Example content**	**Curriculum principles**	**Pedagogical approach**	**Science processes**
Part 1: Physical Sciences	• Physical and chemical properties of matter and its interactions • Mechanics • Energy (both physics and chemistry) • Waves, modern physics	• Basic physical science is needed for every student to understand the world around us irrespective of the career path one chooses later in life • Highly mathematical approach to physical sciences need not be enforced on all students. Conceptual understanding is necessary and sufficient for most career paths • Most part of physical and inorganic chemistry basics have to be covered here	All concepts have to be taught through the following sequence Experience Generalization Law of physics (concept) Wherever real world experience is not feasible, corresponding simulation has to be provided	• Generalizations and forming the concepts • Understanding various laws of physics conceptually • Develop quantitative methods in experimentation

Part 2: Life Sciences	• Plants and Animal kingdom • Basic cell theory • Life processes • Organic chemistry	• Understanding the variety of living beings around us is important for everyone to know • what are we made up of and how do we function and how do we get sick and how to be healthy? Answers to these questions are essential knowledge for everyone	• Diversity to be taught through exploration (visiting places with plants and animals) • Cell theory through discovery method - from function to structure • Molecular mechanisms throug h discussions	• Introduction to technical terms of what they have observed • Ask and get answers to 'how' and 'why' questions • Develop concepts through generalizations
Part 3: Interdisciplinar y (Phenomena, human endeavours, engineering and technology)	• Climate changes • Space travel • Water cycle • Energy Chains • New age machines • Making	• Thematic curriculum • This part provides a foundation for scientific discovery, Engineering inventions and vocational skills • This has to be truly interdisciplinary . It not only spreads	• Main approach is exploratory. Every theme has to be explored by students •Some of the themes are hands-on and hence they are learnt through practical classes. Group activities and projects	• Connecting cause and effect • Determining the influencing factors from data •Experimentati onModel making Presentation of the outcome

	things using chemis try • Foren sic science • Sound enginee ring Health and lifestyle	across physics, chemistry, biology, geology, space etc., but also touches humanities, history etc. • Should provide scientific foundation for the value system		

Advanced level (optional) science subjects

Subject: Quantitative Physics

Example content	**Curriculum principles**	**Pedagogical approach**	**Science processes**
• properties of matter • SHM and waves •Energy • Light • ato mic mode ls • Electricity and magnetism	quantitatively. Quantitative connection between the laws of physics and corresponding mathematical method has to be made intuitive for children. • Plotting graphs and visualizing the connections between parameters as graphs has to be taught	graphs forming equations (mathematically modelling) Quantitative understanding of laws	

Subject: Advanced Chemistry

Example content	Curriculum principles	Pedagogical approach	Science processes
• Atomic models • Periodic table • Types of reactions • stoichiometry • Titration and other quantitative methods •Organic chemistry basics	• Focus should be on observing various kinds of reactions and learning the principles of chemistry • Formal methods of chemistry to be used as the instructional style in text books • Original methods of discovery used by scientists have to be introduced • Safety aspects	Pedagogical path of learning must be a follows. Conducting experiments specific inferences Generalisation and learning principles quantitative methods and qualitative methods Applications of chemistry	• Keen observation of reactions • Quantitative methods • Theorizing and testing the theories • Qualitative analysis

Subject: Molecular Biology

Example content	Curriculum principles	Pedagogical approach	Science processes
• Cell theory • Cellular mechanisms • Organic chemistry basics • Biological processes • Bio molecules • Genetics basics • Micro biology	• Function to structure mapping and drilling down to molecular level should be the approach in text books • Understanding basic organic chemistry and bio molecules can be done from bottom up • Connection has to be made between the above in the biological processes	Pedagogical path of learning must be as follows. Observation Classification, Observation of function □ investigation of structures building causal connections between processes	• Very detailed observation • Classification • Microscopic observations • Building causal connections and testing them • Understanding biological processes through reductionist approach

●.15.4.1 Guidelines for Class 11 and 12:

- Students must be able to choose certain subjects at 'standard level' and additional subjects at 'advanced level' depending the choice of their career path
- Standard level should provide an opportunity for students to learn the basic minimum concepts very easily for everyone.
- Advanced level introduces formal methods so that students can get prepared in the subjects of their choice for their higher education.

Subject	**Curriculum principles**	**Pedagogical approach**	**Science Processes**
Basic Physical Science	• Curriculum must be suitable for students pursuing pure science, engineering or medical professions. It must be mostly qualitative in nature. Highly rigorous	All concepts have to be taught through the following sequence Experience Generalization Law of physics (concept) Experimentation inference Firming up the law Modelling the real world phenomenon mathematically Solving them mathematically	• Generalisation and concept formation • Developing a theory and testing a theory • Conducting experiments without error
Advanced Chemistry	• Curriculum must provide basics for higher studies in pure and applied chemistry, chemical engineering , pharmacology, bio chemistry etc	Conducting experiments specific inferences Generalisation and learning principles quantitative methods and qualitative methods Applications of chemistry	• Quantitative analysis • Salt analysis (qualitative methods) • Methods of preparing chemicals in lab • Methods of metallurgy • Safely conducting reactions in lab
Advanced Biology	• Curriculum must provide good foundation for higher studies in different branches of Biology and Applied Biological sciences like medicine, Ayurveda practice	Observation Classification, Observation of function investigation of structures building causal connections between processes	• Microscopic observations • Building causal connections and testing them • Understanding biological

	or agricultural sciences etc		processes through reductionist approach