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INTRODUCTION

1.1. Introduction

Scientific and technological development in the recent times has and will continue to transform lives of humanity. The role of science in the modern technological world needs no deliberation. All nations big or small are significantly affected by science and technology. Only scientific development can respond to the needs of the modern society. The potential of science in the school curriculum is wholly acknowledged as having a strategic role in the process of adopting education to the needs of rapid social and technological changes in the society. Science not only fires the imagination and curiosity of young minds about the natural world, but also brings about the capability and confidence to engage in the world of scientific and technological ideas. It is imperative that science curriculum at any level provides learning opportunity to acquire scientific knowledge, develop the abilities of scientific inquiry and apply the abilities of science to personal decisions and social challenges.

The role of science within the school curriculum has been redefined in the recent past with the rapid explosion of scientific knowledge, and widening expectations of the society. New goals in science teaching are being identified globally to help produce scientifically literate citizens who understand how science, technology and society influence one another and who know how to use the knowledge in personal and social decisions. In addition, the research in science education and curriculum has influenced and been greatly influenced by research in other areas of education – be it cognitive science or instructional technology, than any other subject. The conceptions of the learner, learning process, society and the nature of knowledge itself have changed much to result into large scale reforms in science education (Fensham, 2001).
Science being a compulsory subject till the secondary stage in India indicates the national concerns that all students should leave school with a basic understanding of the ideas and procedures of science. Yet there is a decline in young people taking up science at tertiary level. Students are reported to find their school science not relevant or interesting to them. Even if it is their perception, they do not seem to be able to link between their science activities and the world around them. Surely many do not see the point of studying things that appear as a series of disconnected facts to be learned.

Ideas to be learned at secondary stage do become more abstract than those encountered in the primary stage. The course of learning science needs to be progressive grasp of ideas or evolution that has wider application and more abstract (Harlen, 2010). Problems of understanding arise when abstract ideas are not connected to concrete experience from which they should be built. At the primary level, activities begin with objects & events around them; the context gives them reality and is of interest to children. There is relevance in what children learn at the primary level, but the problem lies with the relevance of what they learn to build for rest of their lives. So the question is- should the science curriculum be of relevance and interest to students or curriculum should present progressive grasp of ideas? Or is there a functional solution with both elements organised systematically?

Improving curricular practice is the primary aim of science education research. Therefore science education must provide answers to such a curricular issue as this. Science education is genuinely inter-disciplinary studies. Though science is a major reference discipline, there are competencies in other allied disciplines like history of science, philosophy of science, psychology, pedagogy; linguistics which are also needed (Duit, 2007). To improve practices, science must derive from all these disciplines. There is a need to bring science content related issues and educational issues into balance when teaching and learning sequences are designed that aim at the improvement of understanding science and hence may foster the development of sufficient levels of scientific literacy.
Many science educators and teachers think that the content structure for instruction has to be “simpler” than the science content structure in order to meet students’ understanding. Accordingly, they call the process of designing the content structure for instruction “reduction”. However, this view misses the point. In a way the content structure for instruction has to be much more complex than the science content structure in order to meet the needs of the learners. It is necessary to embed the abstract science knowledge into various contexts in order to address learning potentialities and difficulties of the learners.

Analysis of content structure includes two processes which are closely linked, clarification of subject matter and the analysis of educational significance. Clarification of subject matter draws on content analyses of leading textbooks and key publications on the topic under consideration but also may take into account its historical development. Taking students’ pre-instructional conceptions into account that have often proven not to be in accordance with the science concepts to be learned contribute to more properly understanding the science content in the process of subject matter clarification (Driver, & Erickson, 1983). Research shows that the surprising and seemingly “strange” conceptions students own may provide a new view of science content and hence allows another deeper understanding (Duit, Komorek & Wilbers, 1997). Traditionally, science content denotes science concepts and principles. However, recent views of scientific literacy (Bybee, 1997) claim that science processes, views of the nature of science and views of the relevance of science in daily life and society should also be given substantial attention in the science instruction (Osborne, Ratcliffe, Millar & Duschl, 2003; McComas, 1998). All these “additional” issues also need to be included in the process of educational reconstruction. From the vantage point of educational reconstruction it is important to bring science-oriented and student-oriented issues to balance (Jenkins, 2001).
1.2. Evolution of Scientific Knowledge

Popper and Kuhn contributed models concerning the nature of science and the way in which scientific knowledge evolves, though they were driven by different questions. Popper (1934) sought to spell out difference between ideological and scientific theories and to explain why knowledge generated by scientific theories is cumulative. For him scientific theories were not merely instruments nor logistic devices (as the Logical Positivists would claim) but genuine conjectures about the world. Popper maintained that only falsification can ensure reliability and validity of any scientific theory. The more a theory survives attempts to refute it the more corroborated it becomes. It is thus increasingly reliable as a guide to future events and to some degree it reflects the regularities out there. But there is no guarantee that it is complete and true reflection.

Thomas Kuhn (1954) inspired by Popper, studied the actual historical development of science and sociological processes influencing it. The earliest roots of science by Greeks had the tradition of explaining observed phenomena and the cultures prevailing cosmology was founded on these explanations. In modern culture, explanations are the foundation stones for imaginative conceptual (schemes) which define not only the pursuit of knowledge, but the very way people perceive and experience reality. These schemes stand or fall on the basis of (their adequacy as devices to summarize bits of information for generating predictions of additional observations) their effectiveness as guides to research and as frameworks for the organization of knowledge. In case of the changeover from Ptolemy’s geocentric model of the universe to that of Copernicus; the hypothesis generated by old theory turn up evidence that undermines it and reveals anomalies. Science evolves because each new conceptual scheme embraces the phenomena explained by its predecessors and adds to them. Though the achievements of Copernicus and Newton are permanent, the concepts are not permanent. As science progresses, its concepts are repeatedly destroyed and replaced (Kuhn, 1957). According to him a single incompatible observation by a scientist might be sufficient to raise grave doubts about a theory and its unfitness may be demonstrated soon. So both Popper and Kuhn recognized importance of contending hypothesis in scientific development.
According to Kuhn, different set of rules apply in case of scientific revolutions like those of Copernicus and Newton where a major aspect of reality is at stake and hence, necessitates a revolution in philosophy and morality. A lengthy period of conflict within community following a break through may elapse before the new world-view dominates as the Darwinism has exemplified.

Kuhn put forward that attainment of a common “Paradigm” by the community of scientists distinguishes science from other forms of study. The paradigm is defined by four defining characteristics of a uniquely scientific conceptual framework: (1) a set of shared symbolic generalizations (2) a common model of reality (3) shared values as to standards and legitimate procedures and (4) shared examples in the form of concrete problem-solutions typical of the approach of the relevant scientific community. He explained that it is assimilation of these standards and exemplars, rather than the conscious acquisition of formal rules that a student becomes member of professional scientist community.

1.2.1. Science ‘Concepts’ and Nature of Science Concepts

Science is often presented as a collection of facts & theorems that have proved to be correct. The word ‘objective’ is frequently used to describe ‘the scientific method’ implying that there is a single approach’ and that it is somehow independent of human judgement and values. By contrast, the current view of science is that science is not static; theories are dependent on available evidence and may change as new evidence emerges. Science is seen as the result of human endeavour, involving creativity and imagination as well as the careful collection of data and interpretation of data to generate evidence. Science as a body of empirical, theoretical and practical knowledge about the natural world has a long intellectual and social history. The history of science provides many examples of change in how things, for example, the solar system, are understood. Looking back, knowing the evidence that eventually supported the new ideas, these ideas may seem obvious, but at the time they often required a leap of creative thinking that led to the collection of supporting
evidence – a mixture of inductive and deductive reasoning. Ideas supported repeatedly by evidence acquire the status of facts but their stability depends on extensive evidence. Science, seen as a creation of understanding about the world is more likely to excite learners than what is seen as a set of mechanical procedures and established ‘right answers’.

Scientific activity and thinking, whether by scientists or learners, aims for understanding. In developing understanding the ultimate judgement of scientific validity is evidence from the physical world. In comparison to mathematics, science may not seem as precise, but this is so because science depends on evidence which may be uncertain or open to interpretations, not because science is a matter of opinion or unvalidated belief. For progression towards important concepts, ideas need to be achieved at various points. For the same, careful analysis of concepts as well as analysis of current research and understanding on how learning takes place is needed.

Children bring to school ideas formed about the world through their actions, observations and thinking in their daily lives. These are the starting points for the development of the understandings, capabilities and attitudes that are goals of science education. Identifying the course of progression requires logical analysis to find the simpler ideas that are needed as a basis for more complex ones (e.g. Ideas about mass and volume before density) and empirical evidence from research on how thinking develops.

Scientific ideas are often complex and progression about them depends variously on expansion of experience, development of reasoning and access to different ways of explaining phenomena, properties and relationships. Progress will vary from student to student. A precise description may be unrealistic, but the common trends are:

- Increasing ability to consider that properties may be explained by features that are not directly observable.
- Greater recognition that several factors need to be understood if phenomena are to be explained.
- Greater quantification of observations, using mathematics to refine relationship and deepen understanding.
- More effective use of physical, mental and mathematical models.

Recognizing and applying such general trends supports a more flexible approach to progression than does a prescribed sequence of activities which may not match the needs of all students. The science curriculum should be of relevance and interest to learners.

1.2.2. Concepts and Conceptions

The nature and scope of the terms ‘concepts’ and ‘conceptions’ have been discussed variously in education literature. Bruner et al (1956) defined a concept as ‘the network of inferences that are and may be set by an act of categorization’. Therefore concepts can be seen as deductions that are made as a result of making sense of and grouping actions and experiences. Smith and Medin (1981) suggested that concepts are critical for ‘perceiving, remembering, talking and thinking about objects and events in the world.’ In other words, concepts can be considered as multifaceted and are used in different ways. White (2002) stated that concepts are ideas that we have in our heads that we express with words: it is the ‘expression of ideas’ that is important. One description forwarded by Treagust and Duit (2008) is that conceptions can be regarded as the learner’s internal representations constructed from the external representations of the entities constructed by other people such as teachers, textbook authors and software engineers. One may extend the notion of ‘external entities’ used in this description to include real world entities and experiences. Larsson & Hallden (2010) explicitly distinguishing between ‘concept’ and conception’ say that ‘concept’ is used to describe a grouping of objects or behaviours on the basis of certain common features arrived through research or wide spread use while ‘conception’ refers to the way an individual thinks about that grouping. Dykstra, Boyle and Monarch (1992) use the term ‘conception’ to refer to students’ knowledge about how the world works or how it is constituted which is operative in different situations.
Science is a human construct and a human activity which involves exploring the world around us in a particular way, so as to increase our understanding of the phenomena we observe, to explain and describe phenomena in the natural world. By experiencing phenomena, we all begin to make rules and generalisations or concepts. A concept is, thus, an idea, or a set of interlinked ideas, which a person uses to explain, categorise, and predict observations and experiences. In our daily life, we encounter new experiences and according to our previous experiences (knowledge) we try to “assimilate” or “accommodate” these new experiences in our existing “schemas” as Piagetians would explain. As we learn more about the world, the concepts are reshaped, extended to make it more useful and even in some occasions discarded in favour of a completely different explanation.

The behaviourist notion of considering the child as ‘tabula rasa’ has been gradually replaced by a constructivist approach which views learner as the one who brings to class, a complicated body of personal knowledge and understanding (Ausubel, 1968). Piaget emphasised that children build knowledge internally by interacting with the world to learn how it works, and to make meaning of it. By the time the child enters the elementary school, he has already constructed initial conceptual structures about the physical world. As the child learns more about the world around them, they tend to interpret any new information from the viewpoint of these existing intuitive ideas and beliefs. These existing ideas and beliefs however may be significantly different from accepted scientific viewpoints, often referred to as ‘alternative conceptions’ (Palmer, 2001). The term ‘alternative conception’ refers to reasoning which allows them to interpret a scientific concept or phenomena which are alternative to the conceptions held by scientists. Misconceptions are alternative understandings about phenomena that learners have formed which are scientifically incorrect interpretations.

It has been found that students have alternative conceptions of various concepts in science like air, light, living and non-living things, gravity etc. It is important for teachers to explore students’ prior knowledge before introducing
any new concept in the class and to deal with children’s alternate conceptions or teaching for rectifying some of their misconceptions in a developmentally appropriate manner as they interpret new concepts in relation to their existing ideas and beliefs.

The Alternative Conceptions Movement (ACM) from 1980s to the present, prompted studies that employed both nomothetic and idiographic methodologies. The nomothetic studies are more typical of the ‘quantitative’ researcher, which employ an experimental approach, usually using a written survey on large samples and inferential statistics and compare students’ conception to those currently held by scientific community. Idiographic studies, more typical of the ‘qualitative’ researcher, employ ethnographic research methodologies like clinical interviews on fewer participants and report rich understanding of these few students’ conceptual frameworks regarding the phenomena under study rather than comparing to the scientifically held view. They adopt the position that personal, idiosyncratic views of the reality are the norm and that they evolve. The ACM has involved researchers operating at many points on the qualitative/quantitative methodology spectrum.

Henriques (2000) claims that children have their own understanding of many scientific concepts prior to receiving formal science instruction. Children’s conceptions are personal constructions which arise from everyday experiences and are often stable and resistant to change (Driver, 1985). Children develop alternative understanding about phenomena that are scientifically incorrect and represent explanations of the phenomena constructed by a student in response to the students’ prior knowledge and experience. These misconceptions, linked to intuitive ideas are held for a long time and it is not simple for teachers to bring about a conceptual change. Conceptual change in science has been defined as changes in scientific theories that occur when new concepts are proposed and old concepts must be radically changed or replaced to accommodate concepts (Dunbar, 1997). This notion of conceptual change, at the scientific theory level, has been used as an analogue to describe student’s learning of scientific concepts. Hence, learning from a conceptual change
perspective is thus understood as the result of interaction between what a student is taught and his or her existing ideas or concepts.

1.2.3. Conceptual Change

Conceptual change is the process whereby concepts and relationships between them change over the course of an individual person’s lifetime or over the course of history. Research in three different fields – cognitive developmental psychology, science education, and history and philosophy of science - has sought to understand this process. The convergence of these three fields, in their effort to understand how concepts change in content and organization, has led to the emergence of an interdisciplinary sub-field, referred to as “conceptual change” research.

Within cognitive developmental psychology, the interest in conceptual change was motivated by problems identified in the stage theory of cognitive development proposed by Jean Piaget. Piaget claimed that the developing child passed through a series of four distinct stages of thought and that concept development reflected these broad transitions between stages. However, it increasingly became apparent that children’s conceptual development was best described in terms of distinct developmental trajectories for each conceptual domain considered (e.g. knowledge about number, knowledge about the motion and interaction of inanimate objects, and knowledge about goal-directed intentional entities). The term “conceptual change” was increasingly used as work on these distinct developmental trajectories led to the discovery that a variety of types of changes occur in the content and organization of concepts.

In parallel, researchers in science education were learning that one of the main reasons students often found scientific concepts like force and energy difficult to understand was the intuitive concepts about the natural world that students brought with them to the classroom. It became clear that students were assimilating the scientific ideas presented to them in the classroom into their existing concepts, resulting in what came to be referred to as “misconceptions”. Researchers in science education turned to the task of identifying these pre-
instruction ideas and sought instructional strategies that would succeed in helping student transform their intuitive concepts into more scientific alternatives.

These developments in cognitive developmental psychology and science education were influenced by developments within the history and philosophy of science (HPS). HPS had novel approach as to how scientific concepts and theories change over the course of history. In his book “The Structure of Scientific Revolutions”, Thomas Kuhn (1962) argued that changes in the scientific understanding of the natural world should not be seen as a gradual, incremental progress toward ever better understanding. He pointed out that it is sometimes very difficult to characterize how a more recent concept is better than a predecessor. The reason for the difficulty is that the successive concepts are embedded in a distinct set of relationships with other concepts and investigative techniques. Thus, the content of the two concepts and relationships to others can be so different that it is inappropriate to compare the two successor concepts directly with one another. An important concept to emerge from this reasoning was the idea of a “paradigm.” Commentators have noted that Kuhn used the term in a number of different senses. However, one sense seems to have had the most influence on what came to be referred to as “conceptual change research.” That is, the idea of a “paradigm” understood as an integrative set of theoretical concepts and methods taken for granted by a particular research community. According to Kuhn, most of scientists’ work is conducted within a paradigm (what Kuhn called “normal science”). Occasionally, however, insurmountable problems lead scientists to question the paradigm’s assumptions, and a new paradigm emerges (what Kuhn called “a paradigm shift”).

Kuhn’s work, and that of other philosophers and historians of science, had a substantial influence on cognitive developmental and science education research. Increasingly, children and students’ concepts were seen as embedded within their own set of relationships with other concepts and the developmental or learning task came to be seen as a kind of paradigm shift.
1.2.4. Knowledge as Theory vs. Elements

There are two parallel views about the cohesiveness of learners’ alternative knowledge. One view is that the naïve ideas are coherent, cohesive and form a well integrated network. This resonates with Kuhn’s notion of ‘paradigm’ which advances the idea of knowledge as a ‘set’ of beliefs that govern our world view at that particular point of time (Kuhn 1962). Carey (1985) and Keil (1994) also showed through their work that young children’s thinking in biology is logical and systematic and that a well formulated ‘children’s biology’ existed. McCloskey (1983) did a series of studies and advocated that learners entered Physics with a coherent alternative theory to Newtonian Physics. Au (1994) suggested that children as young as 3 years of age demonstrate an evidence of possessing well-established theory like knowledge of substances but the extent of organization may depend upon contextual differences and amount of experience.

The other point of view rejects the universal systematicity and coherence of knowledge viewing it instead as a collection of ideas or strings of thought that work in a particular context but may not cohere. Toulmin (1972) advocates a clear anti-Kuhn position rejecting a global framework the idea of ‘conceptual ecology’ vs. Kuhn’s logical system’. This viewpoint is endorsed by Minstrell (1992) who looks upon learners’ alternative knowledge as elemental beliefs and instructionally relevant ideas that students have upon entering instruction and suggests describing such knowledge of a situated nature in terms of ‘facets of knowledge’ which represent cognitive unit of reasoning or strategy applied by students when addressing particular situations. Disessa (1993) also propagates an essentially fragmented view of knowledge, though also referring to a loose systematicity and uses the term ‘phenomenological primitives’ (p-prims) to describe the knowledge system of novices. P-prims are unstructured collection of simple elements that originate from superficial interpretations of reality. P-prims appear to be organized in a conceptual system and are activated through recognition. The process of learning in science entails organization and systematization of knowledge pieces into complex wholes. As this happens, p-
prims also change in nature from being isolated self explanatory entities to complex knowledge structures. Tytler (1998) who examined the nature of students’ informal science conceptions by studying a range of conceptions relating to air pressure reported a lack of coherence in primary school children’s conceptions. It was concluded that children are extremely fluid in the way they construct explanations of a phenomenon and primitive conceptions can coexist alongside more advanced conceptions even within the same context.

Ozdmir and Clark (2007) draw out three important points of agreement between knowledge as theory and knowledge as elements stances i) learners acquire knowledge from their daily life experience. ii) learners’ naïve knowledge influences their formal learning and iii) much naïve knowledge is highly resistant to change.

We find that current understanding supports and leans more towards considering naïve knowledge as a collection of independent ideas that do not cohere into an organized theory.

1.3. Evolution and Learning Progressions

Science ideas are evolutionary. There is evidence that understanding in science is a gradual process and that at certain ages children seem to have similar misconceptions regardless of where they live. In making sense of ideas in science, the learner is involved in an evolutionary process requiring constant refinement, redefinition and interpretation. The evolution of ideas is a core element of teaching and learning of science.

Learning Progressions (L.P) depict successively more sophisticated ways of thinking about an idea that might reasonably follow one another as students learn. They describe in words and examples what it means to move over time toward more expert understanding of big ideas of a domain. The big ideas like Evolution, Kinetic Molecular Theory, and Energy etc in science are the foundation for the concepts, theories, principles, and explanatory schemes for
phenomena. LPs have been referred to by different names, progress variables, learning trajectories, progressions of developmental competence, and profile strands (Nichols D.Paul, 2010).

Learning progressions are description of the successively more sophisticated ways of thinking about a topic that can follow one another as children learn about and investigate a topic over a broad span of time (6-8 years) (Duschl, Schweingruber and Shouse, 2007, Smith, Wiser, Anderson and Krajcik, 2006). They are dependent on instructional practices (Stevens, et al 2010)). They provide a promising means of organizing and aligning the science content, instruction and assessment strategies to develop deep and integrated understanding of relatively small set of big ideas of science over the broad span of time. The move towards greater expertise may be sequential in nature such that understanding of one topic is required before students can develop understanding of another topic. Alternatively, an LP may describe how students develop a more complex model, where knowledge of a topic becomes more sophisticated by incorporating more ideas and connecting to ideas of other related topics (i.e. developing a more scientific accurate model). Stevens et al. (2010) defined upper and lower anchors in the following way. A description of the knowledge held/needed by students prior to developing understanding of concepts provides the lower anchor and the knowledge and skills of the students are expected to have at the end of LP is the upper anchor. The upper anchor is decided by the societal expectations or the curriculum standards. LPs describe the different levels of understanding as student’s progress to the upper anchor.

Progression in scientific ideas in elementary students may be viewed in 3 ways:

- From description to explanation: The ideas of older children are more related to explanation while those of younger children are related to gathering information, i.e. What is happening or what is there etc. An explanation is the result of combining intellectual activity with discrete facts gathered through enquiry (Hubert Dyasi, 1999). The development of explanations is an essential component of science inquiry activity.
- From small to big ideas: Each experience leads to a small idea that helps to make sense of specific observations. It is transformed to a bigger idea when it is linked to other ideas. This is an important dimension of progress since the formation of widely applicable ideas or concepts is essential if we are to make sense of new experience.

- From personal to shared ideas: Younger children look at things from a point of view of their own. These are based on their experience and their interpretation of it. Older children's ideas are influenced by those of others and their teacher. Thus ideas are constructed on basis of social and educational interactions as their own thinking. Through becoming aware of others ideas and sharing their own, children negotiate meaning for their experiences and for the words that are used to communicate to them. It is central to learning in science that children have access to the views of others and to the scientific view, but at the same time retain ownership of their own developing understanding.

LPs provide a promising means of organising and aligning the science content, instruction and assessment strategies to provide students with an opportunity to develop deep and integrated understanding of a relatively small set of big ideas. Ideally, LPs should be based on research about how competence develops in the domain. Using research on children’s learning, LPs can be identified that trace the path that children might follow as they move from naive ideas to more sophisticated understanding. Research points to many challenges in indentifying LPs. Competence may develop along multiple pathways, some being followed more often than others. These typical paths may provide the basis for developing LPs. Any LP is hypothetical as long term studies of actual children learning a particular concept has not been made.

Assessment Development: LPs can provide clue about the types of assessment tasks that will elicit evidence to support inferences about student achievement at different points along the progression. A multiple stage process might be used for developing assessments to tap into students’ progress along a LP. Such process includes:
1. Translating the big ideas into student performances, tasks or activities etc through which students can demonstrate their understanding.

2. Using these learning performances to develop clusters of assessment tasks or items, including traditional and nontraditional items.

3. Using research on students’ learning as a basis to interpret student responses, explaining how responses reveal students’ thinking with respect to big ideas and LPs.

Progression: Continuity, Curriculum Structure and Sequencing

Progression is applied to something that happens inside a learner’s head; children develop their ideas thinking about experience and ideas. Some aspects of these learning may happen quickly and easily whereas other aspects happen in very small steps, with difficulty and over a number of years (Driver, 1994).

Continuity is something organized by the teacher; it describes the relationship between experiences, activities and ideas which pupils meet over a period of time, in a curriculum which is structured to support learning.

Curriculum continuity should be designed for progression of pupil’s ideas, but it cannot guarantee progression. Several studies highlighted the problem learners have in making sense of the role of plant nutrition in photosynthesis, the role of photosynthesis in matter cycling and of energy flow in ecosystems. Most elementary pupils and also older pupils think matter can appear and disappear in processes such as decay. While planning teaching it is useful for teachers to plan in helping pupils to make a number of small steps towards big ideas. The sequencing of these small steps can be informed by the progression of the children’s understanding (Fig 1.1). Some of these small steps themselves may present learners with difficulties, for example, moving from a view of matter where things can appear and disappear to the idea that matter is conserved is not a simple step.
Sequencing is a very important element of curriculum structure. Sequencing refers to the problem of determining the order of teaching and learning experiences that leads to the acquisition of knowledge, skills etc. Sequencing can be understood as three different conceptions. One is that the learner orders his own learning as he deals with a situation. Another conception refers to the arranging the program of studies in which it is assumed that to maximize learning contents must be ordered in accordance with the developmental stage of the learners. The third conception assumes that for any learning task there are hierarchy existing form very simple to the more abstract and complex elements. The term sequencing assumes importance in different ways to curriculum developers, psychologists, teachers, learners etc. According to Tyler (1951), sequence is building on previous experiences but going more broadly and deeply.

![Diagram of Curriculum Continuity –Designed for Progression](image)

Fig. 1.1: Curriculum Continuity –Designed for Progression

Teaching science with children’s thinking in mind depends on careful sequencing of the curriculum in which continuity is organized by teacher for progression of pupil’s idea as shown in the figure above.

### 1.4. Rationale of the Study

The conceptual structure of a discipline like science is the organized ensemble of the discipline underlying principles and the fundamental ideas of science.
Facts, concepts, hypothesis, rule or principles represents ideas at a lower order of generality. In the middle range, the terms theory and law can be placed. Models or paradigms represent the higher order terms.

School curriculum generally emphasizes lower order level, centering on topics and related facts. As students progress through grades they build conceptual structures in the brain as they relate new examples to past learning. This means that curriculum developers and teachers need to identify conceptual ideas often stated as essential understandings that are developmentally appropriate for the age level of their students. Conceptual understandings become more sophisticated from primary to secondary and post-secondary stages. But most of the alternative concepts formed at early stages are not graduated to scientific conceptions by the time students complete school education.

In the curriculum design and instruction, a major task is to address the key concepts and generalizations (essentially understanding) related to the critical content of science as discipline, such as Matter, Energy, Evolution, Cellular Organisation of organisms, Supply of energy and materials within organisms etc (Harlen, 2010). A coherent curriculum is that which fosters through the grades in the deliberate and systematic design, increasing sophistication in critical content knowledge, conceptual understanding and complex performance abilities. To develop increasing sophistication in critical content knowledge, decision needs to be made as to what is critical, and finally what should students know in order to progress to the next level of learning. Correlating critical content topics at each grade level with key concepts to be developed shows the conceptual structure of science. The content standards must be articulated over time as a sequence of topics and performances that reflect a logical, sequential or hierarchical nature of the disciplinary content from which the subject matter of science derives. This implies that a set of content standards to be coherent must evolve both over time within a particular class level and across the class grades.
Scientific literacy is the term used to express the understanding of important ideas in science. It is widely agreed that elementary students should develop ideas about living things, materials, energy sources, the earth as an environment etc. Science goes beyond description and is concerned with explanation. For example when children explain the phenomena of dissolving in terms of what happens when some solids are added to some liquids. This is on the border between describing and explaining. A more sophisticated explanation is in terms of molecules of one substance being distributed in those of another without chemically combining. There are still further layers of explanation that scientists would use that link the property of dissolving to other properties of substances. Each of these explanations represents bigger ideas than the one before because it links together a wider range of phenomena.

Curriculum statements often do not aim to help primary children develop the big ideas. Statements are often like checklists of items and neglect the links that there may be between the items and leaves children understanding parts but not how these parts link to a larger whole. Curriculum statements set forth a sequence of topics to study rather than progression.

Science curriculum often contains too many disconnected topics that are given equal priority. Less attention is paid to how students’ understanding of a topic can be supported and enhanced from grade to grade. Finding from research about children’s learning and development can be used to map progressions in science at elementary level. Research can describe the successively more sophisticated ways of thinking about a topic that can follow and build on one another for a broad span of 6-8 years of elementary level. Learning progression is a promising direction for organizing science curricula and instruction.

Science learning presents a challenge to educators because on one hand the diversity and complexity of scientific knowledge rests on organized conceptual frameworks and requires sophisticated knowledge construction and evaluation practices; on the other hand children bring different meaning making practices
and concepts to school. One challenge at elementary stage is to identify the core ideas to teach which empowers students for further learning in science. Another challenge is to understand the pathways or progression by which children can bridge their starting point and desired end point. Given the complexity and counterintuitive nature of the end point, curriculum sequences should be guided by a long term vision and understanding about what might be truly foundational and most important to teach. Learning progressions can serve the basis of a dialogue between researchers, assessment developers, policy makers and curriculum developers. ‘Food and nutrition’ is a major concept in science which links the living world with the non-living through energy and matter. ‘Energy’ is a major concept since it explains many phenomena such as work, force, motion, photosynthesis, chemical reactions, chemical bonding etc (Watts, 1983). ‘Matter’ is another very important science concept since everything in this universe is made up of matter. These three concepts are major and foundational concepts of science. This study makes an attempt to trace the evolution of important concepts of science: ‘Food and nutrition’, ‘Energy’ and ‘Matter’ which have implication for curriculum development at the elementary level.

1.5. Statement of the Problem

A Study of the Evolution of Science Concepts among Students at the Elementary Level

1.6. Definitions of the Terms Used

The introductory chapter has dealt with different meanings and connotations in which the following terms have been used in the literature. In this study, the following operational definitions are used.

**Evolution** - The progression patterns among various concept aspects of major science concepts across elementary classes.
**Science Concepts** - The term 'science concepts', refers to those ideas about a particular concept or subject that are presently shared by the scientist community.

**Elementary Level** - Elementary level refers to classes 1st to 8th and students of 5 to 13 years of age.

1.7. Research Questions

1. What are the conceptions of students of age 9 to 13 (class 4th, 5th, 6th, 7th, 8th) regarding food, energy and matter?
2. Do older students within the group have modern scientific understanding of selected science concepts?
3. Is there a parallel between the progression of children’s conceptions and scientists’ conceptions about science concepts throughout history?

1.8. Objectives of the Study

1. To trace the concept progression in the intended curricular content of science at elementary level
2. To collate pedagogical perspectives of major science concepts
3. To trace the trajectory of historical evolution of the major scientific concepts
4. To analyse and map the progression of major science concepts among elementary students from field data
5. To develop a collated learning progression of specified science concepts

1.9. Delimitation of the Study

This study is delimited to exploring the evolution of 3 major science concepts – ‘Food and nutrition’, ‘Energy’ and ‘Matter’ among the students of class 4th, 5th, 6th, 7th & 8th. This study focuses only on the National Curriculum Framework, 2005 developed by the national body, National Council of Educational Research and Training (NCERT) and their textbooks. The study is limited to Delhi only.
1.10. Organisation of the Study

The organisation of the study is as depicted in Fig. 1.2.

**Chapter 1:** This chapter introduces the study and explains the rationale behind selecting the problem. It also includes the objectives and delimitations of the study. The plan of presentation is also included.

**Chapter 2:** This chapter provides the review of the related research studies conducted in the area of elementary students’ science conceptions and learning progression.

**Chapter 3:** This chapter describes the study design and the following: design of the study, development of tools, the sample and the methodology adopted.

**Chapter 4:** This chapter presents the analysis and discussion of evolution of the major concept: ‘Food and nutrition’. The data is analysed by examining each of the investigated science concept. The findings and interpretations are reflected.

**Chapter 5:** This chapter presents the analysis and discussion of evolution of the major concept: ‘Energy’. The data is analysed by examining each of the investigated science concept. The findings and interpretations are reflected.

**Chapter 6:** This chapter presents the analysis and discussion of evolution of the major concept: ‘Matter’. The data is analysed by examining each of the investigated science concept. The findings and interpretations are reflected.

**Chapter 7:** This chapter presents a tentative framework from the findings of the present study to foster progression of scientific conceptions among elementary students.

**Chapter 8:** This chapter summarises the study and includes scope for further research. Finally the thesis includes Appendices with the tools and results tables. Bibliography is given at the end.
Selection of major concepts for this study

- Review of literature to identify methods to study evolutions and arrive at important science concepts
- Analysis of intended Curriculum at Elementary level: Indian
- Analysis of intended Curriculum at Elementary level: International

Selection of Concepts
- Food and Nutrition
- Energy
- Matter

- Studying their Nature and content from History of Evolution
- Developing Pedagogical Perspective of major concepts
- Studying Evolution of the major concepts from primary source

Development of a framework for the Progression of Learning Science Concepts

Fig. 1.2: Schematic Representation of the Study