A STUDY OF THE EVOLUTION OF SCIENCE CONCEPTS AMONG STUDENTS AT THE ELEMENTARY LEVEL

ABSTRACT SUBMITTED TO THE UNIVERSITY OF DELHI FOR THE AWARD OF THE DEGREE OF
DOCTOR OF PHILOSOPHY

BY
BANDITA BALARAM MOHANTY

UNDER THE SUPERVISION OF
DR. T. GEETHA

FACULTY OF EDUCATION
CENTRAL INSTITUTE OF EDUCATION
UNIVERSITY OF DELHI
DELHI-110007
2013
A STUDY OF THE EVOLUTION OF SCIENCE CONCEPTS AMONG STUDENTS AT THE ELEMENTARY LEVEL

ABSTRACT

Introduction

A purposeful science curriculum should aim to sustain and develop the curiosity of young people about the natural world around them, and build up their confidence in their ability to inquire into its behaviour. It should seek to foster a sense of wonder, enthusiasm and interest in science so that young people feel confident and competent to engage with scientific and technological matters. Moreover, science curriculum should help young people acquire a broad, general understanding of the important ideas and explanatory frameworks of science in addition to the procedures of scientific inquiry (Robin Millar and Jonathan Osborne, 2000).

Our emergent understanding of the way young students acquire domain-specific knowledge in the sciences can inform the planning and sequencing of science curricula. Development of science concepts may not be a primary goal of science education. But conceptual understanding may be seen as an appropriate goal of curriculum and then instructional courses may benefit from planning which draws on knowledge of the way, in which understanding of science concepts evolves. A wide range of factors including social and cultural aims, are taken into account when decisions are made about curriculum content in school science courses. If courses are to relate appropriately to learners, curriculum decisions are to be taken on the basis of processes of knowledge acquisition across age.

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. 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.

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.

**Rationale of the Study**

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).

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 these important concepts of science: ‘Food and nutrition’, ‘Energy’ and ‘Matter’ which have implication for curriculum development at the elementary level.

**Review of Related Literature**

A large body of literature now exists on students’ ideas about a range of phenomena relevant to various branches of science. Investigations have been undertaken in the areas of light, density, homeostasis, health concepts, air, gases, heat and temperature, nature of matter, energy, nutrition among many others. The reasons for
selecting the concepts mostly focus on their centrality of them and difficulty students face while understanding such abstract concepts. Food and nutrition, energy and matter are three such major concepts which are foundational; form links with most of the science concepts and are peculiar from pedagogical considerations of elementary curriculum.

Many studies reviewed in this section have analysed conversational interviews between investigators and children about individual science concepts. This approach involves interviews with children (referred to as Piagetian clinical interviews), during which their meanings for words can be explored and/or interviews about ‘events’ (Osborne, 1980) that include practical science demonstrations. As these study-designs involve in-depth and individual taped interviews, the number of participants is usually small in comparison to the research in which fixed or constructed response is collected in surveys designed to indicate the prevalence of conceptions using larger or more representative samples (Bell, Brook and Driver, 1985).

A cross-sectional design is adopted by many researchers studying progression of scientific ideas among learners. However, the predominant focus of these cross-sectional studies has been children’s ideas about individual science concepts or a theme like ecology etc. The most cross-sectional studies reviewed, the youngest children tested were 5 or above. Osborne et al.’s (1990) cross-sectional study on 7 to 11 year olds and Leach, J. et al.’s (1992) study on 5 to 16 year olds were regarding the continuum of ages. Progression of science concepts among learners have been probed through systematic conceptual analysis, assessment procedures and interpretation.

Comparison between theory change in science and conceptual change in children showed that there are strong similarities between these two processes. Anderson and Karrqvist (1983) also drew parallels between the learner’s struggle to understand the nature and propagation of light and the historical growth of ideas about light. Writers from developmental psychology have also proposed an analogy between children and scientists (Brewer and Samarapungavan, 1991; Carey 1985). Brewer (2005) gives examples of why children are not modern day scientists but can be described as, and compared to, pre-Socratic scientists. Ancient Greeks used common sense views to form their theories, as do children. Both children’s and early scientists' views could be described as robust emergent processes. Exploring the analogy between the
development of theories by children and scientists throughout history could provide an increased understanding of the pattern and nature of children’s alternative conceptions about science concepts. The researcher reviewed studies related to students’ understanding of science concepts through a historical lens such as the study of Mas C.J.F., Perez, J.H. and Harris, H. (1987) on adolescents’ conceptions about gases, the study of Coelho R.L. (2009) on children’s energy concepts and that of Noble A.M. (2008) on primary children’s conceptions about light among other similar researches.

The review of literature was summarised from four broad perspectives:

- studying elementary learners’ conceptions,
- studies related to students’ understanding of science concepts across age,
- studies related to students’ understanding of science concepts through a historical lens and
- studies related to progression of science concepts among students.

Statement of the Problem
“A Study of the Evolution of Science Concepts among Students at the Elementary Level”

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
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

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.

Research Design

Evolution refers to the progression patterns among various aspects of major science concepts across elementary classes in the context of this study. Given the complexity and counterintuitive nature of the desired 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. Hence the research design calls for an exploratory approach of finding focus of science curricula, science concepts, original researches, assessment tools and finally emerging understanding from field data.

The study was undertaken in two phases. The first phase was collection and interpretation of secondary data and the second phase consists of data collection from field and its interpretation.

The first phase of the study was carried out in 5 steps:

- A comprehensive analysis of the content material of elementary science curriculum to locate the major concepts for the study
- An analysis of content sequence of those major concepts from the international science curricula at the elementary level.
• Development concept maps of identified concepts from both intended and available international curricula
• Development of timeline from history of evolution of those science concepts
• Collating pedagogical perspective of the identified concepts from different research studies.

The following section summarises the first phase of the study, methodology adopted, tools adopted to collect and interpret data.

The N.C.E.R.T syllabus guidelines for elementary classes for environmental studies (from class 3rd to class 5th) and science (from class 6th to 8th) were looked into. The researcher has undertaken an in-depth analysis of each chapter of all the text books (class 3-8) and syllabus guidelines of elementary classes to categorise the content into major concepts. The purpose of content analysis was to examine the placement, depth and progression of content across the elementary grades. 

Food & its Components, Properties of Material/Matter, Plants, Animals, Characteristics of Living Organisms, Conservation, Measurement and Motion, Light, Electricity and Magnetism, Air, Physical Phenomena, Natural Phenomena, Water, Soil are the 14 major concepts along which the Science curriculum at the elementary level could be classified. The major concepts were identified from the perspective of structure of science as a discipline. Concept maps of these 14 major concepts were constructed to trace the depth of content coverage and how the strand emerges across elementary classes. Many concepts such as Force or health concepts had limited presentation across elementary classes and many concepts were dealt only at the phenomenal level (e.g. Light) for which primary students would not have the conceptual understanding.

Elementary science curricula of USA (AAAS, project 2061, 1993, 2009), Australia (Australian Curriculum, 2008 and P-10 continuum: achievement standards of State Victoria) and National Curriculum, U.K (2007) were sourced from the web and analysed to find the content strands present in them. The key scientific concepts identified in this study are related closely to the science syllabus of elementary classes as prescribed by NCERT but the treatment is different.

Three major concepts identified from analysis of elementary science curriculum of NCERT and other countries were Food and Nutrition, Energy and Energy Sources, and Materials/ Matter. To converge on important science concepts in elementary
science curriculum is not an easy task. These 3 important science concepts were identified after review of related literature, analysis of international science curricula and analysis of syllabus as well as text books for elementary classes of E.V.S. and science.

Concept maps were developed to fulfil the following objectives:

- To understand what the intended curriculum includes in the area of food and nutrition, energy and matter in Indian context
- To identify what constitutes ‘standard’/expected knowledge in these topics from available curricular resources.
- To derive a concept map from the maps mentioned above to form a basis for developing questionnaire

The development of concept maps of Food and Nutrition, Energy and Matter was taken up by analysing (a) the Environmental Science Textbooks (class 3rd to 5th) and Science Textbooks of NCERT (class 6th to 8th) and (b) International standards in science and other curricular material available through web resources.

Collating history of evolution of three science concepts was done to understand the nature and structure of each concept. History of evolution of the selected concepts of food and nutrition, energy and matter has been collated from publications and available web resource to understand the nature of content of these three major concepts.

The pedagogical aspect of content structure of matter would help the researcher to build a perspective on how elementary students understand the three science concepts, whether there are obstacles in understanding it, and to finalise the conceptual statements based on which questions would be framed. This perspective also would provide a background for analysis of primary data. Pedagogical perspective has been collated from the summaries of reviews and other research conducted by nutritionists, physicists, chemists and other researchers from the perspective of science education, cognitive psychology or child development.

**The second phase** consists of data collection from field and interpretation from both primary and secondary data. This section summarises the steps taken to select the
sample, collate and develop tools, data collection and analysis. The purpose of this part of the study is:

- to identify the conceptual ideas of students in the three major concepts from class 4th to 8th
- to explore whether there is progression from contextual knowledge to more scientific understanding
- to explore the trajectory of students from phenomenal to conceptual understanding and macroscopic to microscopic understanding.

A cross age methodology was used in this study. Approximately 200 students each from class 4th to 8th were selected and their conceptual development about three science concepts was explored using appropriate research tool. Three questionnaires were developed to probe children’s ideas about each of the key scientific ideas, one for classes 4th and 5th (Stage1), second questionnaire for classes 6th and 7th (Stage2) and the third one for class 8th (Stage3).

A total of 957 elementary students of five schools of Delhi were administered the questionnaire. The sampling was purposive random sampling (hence non-probability). The participants are most likely to have certain characteristics relevant to the study. Two schools were Kendriya Vidyalayas run by the KVS, an organization controlled by the Ministry of Human Resources Development. Three schools were managed by private managements catering to middle income group of clientele.

The analysis was done at two levels: general analysis of students’ conceptions of stated concepts and comprehensive analysis of students’ conceptions. The responses of students were analysed to see a general picture of elementary learners’ conceptions about food and nutrition, energy and matter and difference amongst stages from mean, standard deviation, and applying one way ANOVA with 3 groups (stage 1, 2 and 3) and chi-square test of significance. Percentage of responses, difficulty value of questions (hence concepts) were analysed to see learners’ progression of concept with the sub-concepts. The comprehensive analysis was done to see learners’ progression of concepts with their various strands for a detailed understanding. Results were summarized for individual questions grouped under relevant strands. Student’s scientific and alternative conceptions were listed and compared with the findings from literature.
Analysis and Major Findings

Food and Nutrition:

The outlines of the food and nutrition concepts were divided into 2 strands such as (i) food and nutrients and (ii) digestion-system and process from the concept map derived from intended curriculum at Indian and international sources.

General analysis of the primary data indicates from the mean that students of Stage3 performed better on the test on the food and nutrition concept compared to the rest of the Stages. Older students understood better, i.e. stage3 performed better than stage2 and stage2 performed better than stage1. The data indicate that as students progress through the science curriculum from primary to middle level, there is a progression in their knowledge about food and nutrition. One-way ANOVA indicated statistical differences between Stage 1 and Stage3; and Stage 2 and Stage 3, but no significant difference between Stage 1 and Stage2. A bigger sample with a full range of questions on food and nutrition may help to make more definitive conclusions.

Students of both classes within Stage1 (9 to 10 years) conceptualised about nutrients in food and digestion in much the same way. Students of class 5th had their exposure to the topic on digestion in curriculum, but it seemed to have marginal effect on them. However, they understand the role of mouth and stomach better than class 4th students. This finding is similar to that of Teixeira (2000) that by the age of 10, the function of the digestive system is explained in terms of functions of organs. The age differences suggest that children’s theory is built on the application of empirical knowledge. The results indicated that the acquisition of the concept of digestion leads to a conceptual revision and enrichment by the age ten.

Similarly if the conceptualisations of students of Stage2 (11 and 12 years) are considered, their conceptualisation about digestion, role of various organs or sequence is better than the students of stage1. They could not identify nutrients in food items which shows their lack of content knowledge about nutrients and hence balanced diet also. Most students do not identify what nutrients common food items have and what is missing in a balanced diet. They identify fats and carbohydrates easily. They know the importance of vitamins, minerals and proteins, but cannot identify in food items. They understand the process of digestion better than younger
students, but most still have to conceptualise the absorption of digested substances from intestines. The physical process of transformation of food during digestion is understood. Chemical transformation process takes place with the help of glands is conceptualised by many, but the absorption and assimilation is not understood by most students.

The students of Stage 3 (13+ years) have conceptualised most concepts related to food and nutrition inquired of them. They did not find most concepts difficult except one concept on the relation between food and growth. Conceptualisation of it will require understanding of particulate nature of matter and conservation of matter. However, around 28% of students intuitively understood the relation between food and growth which shows that students at this age are probably cognitively ready for abstract concepts like particulate nature of matter.

**Drawing a historical parallel between early scientists and students' conceptions:**

- Early understanding of the scientist community was that food has contribution to health without knowing the details; children too understand the various roles of food not knowing the processes.
- Historically, the constitution of food like carbohydrates; proteins being made of Carbon, Hydrogen, Nitrogen etc. were discovered first and later the role and composition of enzymes and vitamins were known. Students understand about carbohydrates and proteins earlier than vitamins and minerals.
- Structures of organs of the digestive system were understood first and later their functions were discovered. Students have knowledge about organs earlier compared to their functions.
- A lot of speculations were made about the function of organs of the digestive system and the process of digestion before it was known finally. Elementary students too have initial ideas about organs like stomach, intestines before progressing to the scientific ideas.
- Around 23.4% of stage 1 and 20% of stage 3 students thought that stomach had a filtering role. Their responses are very similar to the conceptions of medieval physiologists like Galen who wrote that stomach performed a filtering or storing role. Though there was progression in scientific conception
about stomach’s role in digestion from stage 1 to 3, the above said alternate conception persisted and the alternate concept of filtering role decreased considerably.

- From the timeline of food and nutrition, it is understood that evolution of food and of nutrition occurred independently. Evolution in food and digestion stemmed from speculation: speculation about effects of food with health, speculation about role of different organs or glands in the body. Interpretation of observations of experimentations leads to generalisations such as those of Dr. Beaumont. From the study of the evolution of food and nutrition, the implications for school science is that alternate conceptions of students are important starting points for subsequent scientific understandings. Students may comprehend generalisations about food and nutrition from explanation of experiments and subsequent theory-building. Learners would probably understand and describe concepts related to food first, and then understand nutrients of food. Explaining or emphasising the need of including a component or nutrient into diet may not useful for learners till they comprehend the biochemical nature of its transformation inside the body. Hence the attention of students also needs to be drawn to conceptual explanation behind chemical transformation of food, absorption and assimilation.

**Drawing a parallel between research so far and students’ conceptions:**

- Most students of stage1 (percentage around 8-12%) had difficulty understanding that insects and flowers can be food of either humans or animals. Though the topic is part of primary text books in Class III, many did not think that people might be eating flowers or insects. They had human centric viewpoint, did not consider animal nutrition at all. This is similar to the findings of Lee, Y.J. and Diong C H, (1999) with secondary students’ (age 16-18 years).
- Students of stage 1 understand about food from their personal and social construction in their conceptions about seeds, meat and milk easily.
- Around 60% of stage1 students thought water to be food. Above 70% students of stage2 consider water to be food because water is necessary for
plants and animals. Text books present water as a component of food while some nutrition specialists consider that organic substances only can be food. Lee, Y.J. and Diong C H, (1999) too have reported in their study that many students confused the concept of nutrients and water, believing water to be food. Research on Nutrition by Project 2061(American Association for Advancement of Science, AAAS, 1993) report that lower elementary school children may believe that food and water have equivalent nutritional consequences.

- While 56% stage1 think that glucose is food in the classification task, 68% of stage3 students think that glucose is food. The context given for stage3 students is glucose administered intravenously to a patient. For around 15% of older students, glucose is not food and 12% remain unsure whether glucose is food or not. These 27% students may be considering anything taken orally to be food and not intravenously (CLIS summary, 1992).

- Students of stage-1 when asked to answer what happens if one eats only rice for a month, almost equal number of students thought they would grow fat or thin or would fall ill with deficiency(32%). Students do not attribute any particular role to a group of food like carbohydrates, so they are equally divided between all possibilities.

- Students of all stages do not have progression in content knowledge about nutrients e.g. identification of calcium and iron as minerals or proteins, though it is part of intended curriculum, but about 61% of stage 1 identify the element present in bones as calcium. Because of exposure to advertisements about various health foods containing calcium through mass media, students know that calcium is present in bones though the sub concept is not part of their syllabus.

- The common alternate conception about ghee in 20% of our students (stage2) was that fats have all nutrients, suggesting that it is healthy to eat ghee according to them. It is social construction of knowledge for these 20% (72 in numbers out of 360). It is contrary to the understanding of European students (Brinkman & Turner, 1987 and Dixey et al, 2001) who thought fat was not necessary or rather harmful for them.
• A logical conclusion from the above findings is that students do not understand balanced diet and its composition. It is confirmed through primary data with stage 2 group of which around 36% understand the constituents of balanced diet.

• Students of stage 1 were asked about where the digestion process starts. In Yilmaz Cakici’s, (2005) study of Turkish children’s (of the same age) understanding of digestion, only 20.4% children of class 4th and 34.9% of class 5th answered correctly that digestion starts in mouth. In the present study, higher number (54%) of students of the same age has the scientific concept.

• Around 65% of stage 3 identify the sequence of process of digestion correctly, 35% pick incorrect sequence thinking absorption or digestion takes place earlier than ingestion or eating. This alternate conception is similar to the finding of Simpson (1984) who found that at thirteen, children’s ideas of the sequences of digestion are very confused, both in terms of the anatomical route and the processes.

• Around 67% of stage 3 students think that on fasting for 2-3 days there will be fewer nutrients in the blood and seem to understand the relation between food and nutrients, 11% do not understand it and 18% do not foresee any storage mechanism for nutrients in the body. Francisco Nunez and Enrique Banet, (1997) found that only 69% of students of ages 16-17 (who had studied biology) understood the relation between cellular respiration and digestion and that digestion converts complex nutrients into simple substances.

• Only 28% of stage 3 think that particles from food are rearranged in body, 38% think that food accumulates inside the body and 24% think that vitamins and minerals are added to the body unchanged. This finding is similar to the finding by Smith and Anderson, 1985 and Leach et al. 1992 under CLIS project. They found that some students of all ages think food is a requirement for growth, rather than a source of matter for growth. They have little knowledge about food being transformed and made part of a growing organism’s body.
The researcher has attempted to articulate the results of this study by different perspectives on progression from the above understanding.

There has been a progression from phenomenal to conceptual understanding.

- Stage 3 conceptualises glucose as food while stage 1 comprehend seeds and meat as food.
- Stage 3 comprehends about glucose as food better scientifically

There has been a progression from macroscopic to microscopic understanding.

- Understanding of body structures growing from rearrangement of particles (28% of) by stage 3 students while stage 1 students understand that food helps in growth.
- There is a progression in conceptual understanding about chemical transformation of food by digestive juices from stage 2 to stage 3.

There has been a progression in content knowledge

- Stage 3 recalled better about the role of stomach from stage 1.
- Stage 3 knew scientifically about the completion of digestion in small intestines compared to stage 2 and stage 1; stage 2 recalled scientifically more compared to stage 1.

Energy:

The outlines of the energy concepts were divided into 6 sub-concepts such as understanding of fuels, renewable and non-renewable sources of energy, sources of energy and pollution/ environmental consequences and energy in living systems, meaning of energy and energy transformations under two strands: (i) sources of energy and (ii) energy: meaning, forms and transformations.

General analysis of the primary data indicates from the mean that students of stage 2 performed better on the test on energy concept compared to the rest of the Stages.. The overall impression showed that there is trend with a dip at the end of the
progressive line. Stage 3 and stage 2 have similar understanding of the energy concepts asked and stage 2 and 3 have better understanding than stage 1. The pilot study had not accounted for such trend which appeared in the main study.

One-way ANOVA indicated statistical differences between stage 1 and 2; between stage 1 and 3, but no significant difference between 2 and 3. The data indicate that as students progress through the science curriculum from primary to middle level, there is a progression in their knowledge about energy. A bigger sample with a full range of questions on energy may help to make more definitive conclusions.

Students of Stage 1 could conceptualise about sources of energy better than about forms of energy or meaning of energy etc. Students of class 5th identify forms of energy better than class 4 students.

Sources of energy is conceptualised easily by students of Stage 2. Their conceptualisation about sources and forms of energy is better than the students of stage 1. Transformation of energy from one form to another is not understood by most of the stage 2 students. Most students of this stage had conceptualised about sources of energy and thermal (heat) energy well.

The students of stage 3 have conceptualised most concepts related to energy inquired of them. They had difficulty in conceptualising transformation of energy in a flashlight, and nuclear energy. Conceptualisation of it will require understanding of forms of energy in various contexts and the transformation of energy from one form to another. However, around 19% of students intuitively understood the concept of transformation. They could have used their conceptual understanding about conventional sources and answer about nuclear energy. Concepts on forms of energy and sources of energy were easily understood by most of the class eighth students. From the primary data, one may generalise that students of stage-3 i.e older students understand concepts of sources of energy better than junior students, but students’ understanding of energy concepts did not improve in class 8th despite their exposure to energy-related concepts like heat and temperature, combustion, electricity, fuels etc. Students may require direct instruction in the topic energy rather than covertly placed energy topics.
Evolution of energy concepts among elementary students does not happen linearly or incremental always. Students are found to progress towards more scientific understanding. The concepts found difficult by primary students were found easy by middle level students. By the time students complete elementary stage, they conceptualise most concepts except the concepts related to transformation of energy easily. Students conceptualise the concepts related to their social context easily while find the scientific concepts difficult. They find phenomenal concepts easy to understand that concepts which need conceptual explanations.

**Drawing a historical parallel between early scientists and students’ conceptions on energy:**

- The term energy meant activity and had been used with this meaning in the 18th century and in the first part of the 19th century. In 1851, William Thomson, later on Lord Kelvin, used the word to refer to the mechanical activity of a body, i.e., its capacity of doing work. Students too relate to energy through activity easily. The division into two sets – static and dynamical – of the stores of activity available led to the distinction between potential and kinetic energy. From the timeline of energy, individual scientists had understood and coined kinetic energy in the year 1829 and potential energy in 1853. Around 56% of stage-1 understands that moving objects have energy (kinetic energy) (Table 5.15). Though a high percentage 20-26% also thought that there is no energy in the moving objects they could relate to movement and energy conceptually, without instruction in this area. Kinetic energy is related to energy in moving objects and is easily observed compared to potential energy. Historically too kinetic energy was discovered earlier than potential energy. Students seem to understand kinetic & potential energy in a similar sequence.

- Around 37.4% of stage 2 students identify the forms of energy produced in human body as chemical energy (Table 5.10). Students choose friction and pressure both as forms of energy. Students confuse between force, pressure and work. About 63.3% of students of class 8th identify heat energy as the form of energy produced in human body. Though this shows progression compared to the understanding of stage 2 still 21% of stage 3 students
confuse force with energy and have the concept that force is the form of energy produced in human body.

- A question was put to students of stage 1 and stage 2 to identify the definition of energy. About 31.5% of stage 1 and 41% of stage 2 equates energy with force. This alternate conception has been earlier found by Watts and Gilbert (1986) that students use energy synonymously with force or power.

- Many researchers (Viennot, 1979; Watts & Gilbert, 1983; Duit, 1984) have noted that students fail to differentiate between energy and other physical terms, mainly the concept of force. This reflects the confusion between energy and force which scientists had during historical evolution of energy.

Drawing a parallel between research so far and students’ conceptions on energy:

- The concept related to sources of energy are related to the context of students’ experience and easily understood compared to the forms of energy or transfer of energy which requires understanding the energy model conceptually. The science instruction does not prepare most of the students to see beyond phenomena and understand the conceptual explanation of the phenomena. This is corroborated by Papadouris’ et-al (2008) study.

- Students of Stage 1 and Stage 2 were required to identify source of energy for man among water and food including other things (Table 5.9). About 75% of stage 1 and 70% of Stage 2 identifies food as source of energy for man. Around 19% of stage 1 and 18% of stage 2 students have alternate concept that water is a source of energy. Their misconception about water also remains from class 4th to 7th. These findings can be compared to those of Colin Boylan (2008) with elementary students (mainly class 3rd to 6th) of Australia regarding their understanding of energy concepts. About 34% elementary students had the understanding that eating food gives us energy, and 38% of them thought sleeping gives us energy and 28% thought that the energy in our bodies comes from drinking water.

- In the present study, around 19% elementary students have the concept that water is a source of energy for man. So relatively less students (19%
compared to 28%) in our context have the alternative concept and more students (70 to 75% compared to 34%) have scientific concept. This also relates to the previous section on Food and Nutrition where in the classification task, 60% of stage1 and 73% students of stage 2 consider water to be food because water is necessary for plants and animals. Text books present water as a component of food while some nutrition specialists consider that organic substances only can be food. Research on Nutrition by Project 2061(American Association for Advancement of Science, AAAS, 1993) report that lower elementary school children may believe that food and water have equivalent nutritional consequences.

• Around 37.4% of stage 2 students identify the forms of energy produced in human body as chemical energy (Table 5.10). Maximum students choose pressure (32%) and friction (23%) both as forms of energy. About 63.3% of students of class 8th identify heat energy as the form of energy produced in human body. Still 21% of class 8th students confuse force with energy and have the concept that force is the form of energy produced in human body. Students confuse between force, pressure and work (Vennot, 1979; Watts & Gilbert, 1983; Duit, 1984). Upper primary students have not been formally introduced to forms of energy, but 38% approx. of stage-2 and 63% of stage3 understand the forms of energy produced in human body scientifically. Learners typically start with the ideas of energy related to personal experiences of human activities (Solomon, 1982).

• About 21% of stage-3 students confused force with energy. Young students as well as adults like the pre-service teachers have been known to have this intuitive view about energy (Trumper, 1995). Trumper found that pre-service teachers continued to confuse the concepts of energy and force even after instruction for 4 years.

• To the questions whether our energy levels are increased or decreased after exercise, 34.5% of stage 1 students think that energy will be depleted which is scientifically acceptable (Table 5.11). A higher percentage of 47% think energy is increased after exercise. They themselves feel tired after physical work, but here they relate to building up of stamina (or strength over a period
of time) with the increasing energy level. A recent study by Mann and Tregust (2010) with students of 8-12 years in Australia through an open-ended questionnaire also have pointed out that there is limited understanding of energy use, energy conversions and energy transfers in the body. Understanding about role of respiration in conversion of food into useable energy increases from age 8 to age 12 in a progressive way. Judith Barak, Malka Gorodetsky and David Chipman (1997), of Israel studied on misconceptions regarding energy in biological systems and a vitalistic notion of biology in students of 17 years. The results pointed to a strong correspondence between the ability to understand energy in biological phenomena and adherence to scientifically oriented conception of biology.

The language we use in everyday context may be very different from the context in which a term or concept has scientific meaning. Hence everyday language becomes source of alternative concepts built by learners. ‘Building up of energy’ is one such idiom used in common parlance which made 47% of students of stage-1 have an idea that after exercise our energy levels increase.

- About 71% of students of stage 3 have the concept that the form of energy produced while a bell rings is sound energy, but 18% think it is magnetic energy (Table 5.18). Students of class 8th have exposure to the topic ‘Sound’ in class 8th. In Colin Boylan’s study (2008) on elementary students (mainly class 3rd to 6th) of Australia most students identified all forms of energy such as the light energy, kinetic energy, sound energy, thermal energy & solar energy easily.

- The form of energy of sunlight captured in photosynthesis-light or heat-were the two main responses expected of students of stage 2 (Table 5.16). About 62% of them responded correctly as light energy. The concept of photosynthesis is taught in class 7th in detail, still more numbers of students (34% of class 7th) were confused and selected heat energy, 31% of students of class 6th select heat energy. So a large number of students think that heat energy of sun is utilised by plants during photosynthesis. This finding is similar to the findings of Hirca N, Calik M and Akdeniz F (2008). About 60% of
grade 8 students (from 9 schools of Turkey) were able to link that light energy is absorbed by plants during photosynthesis.

• A question was put to find what students of stage 1 and 2 would define energy as (Table5.20). They had to identify the definition of energy among other options like the power of force or something you need to live etc. About 31.5% of stage 1 and 41% students of stage 2 have alternate conception and equate energy with force. This has been earlier found by Watts and Gilbert (1986) that students use energy synonymously with force or power.

• About 24% of stage1 and 19% of stage2 students also have an alternate concept that energy is something you need to live. Anthropocentric viewpoint about energy was listed among many frameworks that students have by Watts, (1983). Many researchers (Viennot, 1979; Watts & Gilbert, 1983; Duit, 1984) have noted that students fail to differentiate between energy and other physical terms, mainly the concept of force.

The researcher has attempted to articulate the results of this study by different perspectives on progression from the above understanding.

There has been progression from phenomenal to conceptual understanding in energy concepts.

While stage 1 understood about sources of energy and fuels used, stage 3 had conceptual understanding of the meaning of fuels.

Progression may also be inferred when students of stage 3 conceptualised the processes by which fossil fuels are formed and younger students are able to identify fossil fuels from other fuels.

Stage 3 students were able to conceptualise environmental consequences of using different fuels and compare them in terms of CO₂ emission.

Students of stage 3 and 2 were able to apply their understanding about forms of energy in human body while students of stage 1 understood about some forms of energy.
Progression within the stage may be inferred to a small extent when students of stage 2 had to identify that a source of energy heats a solar cooker and a gas stove as a common explanation. Around 38% of class 6th and 51% of class 7th understood the common explanation of source of energy correctly (44.4% of stage 2 students). About 24.6% thinks that gas heats a solar cooker as well as gas stove. Papadouris et al (2008) explored primary and middle classes students' (aged 11-14) explanation of changes in physical systems involving energy and the extent to which students drew on energy model as a common framework. They found that 38% of primary and 61.5% of middle students drew on the energy model to explain change in two different instances like in the working of wind mill and electric fan and hence their responses were conceptually oriented. Around 26% of primary and 21% of middle students also gave conceptually oriented responses but were drawing on other concepts of physics like force or electricity. Around 29% of primary and 21% of middle level students had a phenomenologically (at the level of observation) oriented response like attributing the cause for change towards certain objects like electric wire or some processes of the system instead of a concept.

**There has been a progression in the content knowledge.**
Stage 3 knew more about sources of energy compared to other stages.
Stage 3 knew about renewable sources of energy with certainty over stage 1.
Stage 3 identified forms of energy better than stage 2 and stage 1.

**Matter:**
The outlines of the matter concepts were divided into 5 strands such as understanding of (a) Properties of materials (b) Physical processes such as freezing, boiling, evaporation and condensation (c) Conservation of matter (d) Chemical properties and (e) States of matter.
An observation of the mean shows that students of Stage 3 performed better on the test on the matter concept compared to the rest of the Stages. Stage 2 performed better than stage 1.

One-way ANOVA indicates statistical differences between all stages. The data indicate that as students progress through the science curriculum from primary to middle level, there is a progression in their knowledge about matter concepts.
Cognitive maturity of stage 3 appears to shift their understanding about matter towards progression. A bigger sample with a full range of questions on matter concepts may help to make more definitive conclusions.

From this study of students’ conception about materials from age 9 to 13 and above it was found that students of **Stage 1** find 7 concepts out of 13 concepts, difficult. Three of these concepts are related to change of state, one each is related to characteristics of air and properties of material, and two are related to identifying features of solids, liquids and gases. The concepts related to their experience and perception like conservation of mass and freezing, evaporation being faster outside etc was found easy by them.

The students of **Stage 2** found 5 concepts difficult. Both classes found conservation of mass during freezing, chemical change, condensation, and states of matter concepts difficult. Identification of chemical change is conceptualised easily by older students.

The students of **Stage 3** have conceptualised most concepts related to material inquired of them.

**Drawing a historical parallel between early scientists and students’ conceptions:**

About 17% of stage 1 students have the concept that fire is not material. About 30% of stage 2 students understand fire as non-material. Maximum students at 45-46% of these two stages think that CNG is not material. Gases were not considered as material till the 17th century when air was known to have weight and was known to be made up of particles.

From the timeline of matter, it is evident that individual scientists were speculating about the structure of matter for a long time before Dalton brilliantly summed up the previous discoveries to come up with atomic theory in 1800. The material properties of gases were discovered before that. Elements were known earlier than the atomic structure. Model building by scientists helped to develop particulate nature of atoms from the discovery of various sub-atomic particles.
From the study of the evolution of matter, the implications for school science is that it is difficult to understand particulate nature of matter. They would probably understand and describe phenomena related to matter like evaporation and condensation first, and then explain them scientifically with the particulate nature of matter. Conceptualizing particulate nature of matter would be possible once students are ready to build mental models of matter. The attention of students also needs to be drawn to conceptual explanation behind physical phenomena like evaporation, condensation etc. for a progression.

Drawing a parallel between research so far and students' conceptions on matter:

- More than 40% to 50% of students of Stage 1 and 2 ascribed gas to be a non material (there was no change in understanding gas as a material across stages). Studies (Johnson and Driver, 1991; Piaget, 1929, Sere, 1985, Stavy, 1988) also report students of all ages having vague perceptions of the gas state and not considering gases as substances.

- Only 40% of Stage 2 students consider fire as non-material which is the scientific concept. This is similar to the findings Stavy, (1991) and Lee et al, (1993) that elementary students may consider anything that exists as matter including heat and electricity.

- Students of Stage 1 were asked where the water from wet clothes goes upon drying. As many as 16% just described the event saying water just disappeared. Around 39% students understood that water had gone into the air. Little more than 25% of the group thinks that water breaks into Hydrogen and Oxygen gas; this answer is popular because it sounds more scientific. All these conceptions of children about evaporation have been reported earlier by Bar, 1989; Osborne & Cosgrove, 1983.

- Bar and Travis (1991) found that 70% of a sample of 6 to 8 year olds understood that when water is boiling water comes from it and that vapour is made of water. In the present study only 58% of students of 9 to 10 age could conceptualise that steam is made of water vapours, many students thought water breaks into H₂ and O₂.
• The conception about condensation of Stage 2 and 3 with the findings of previous researchers can be compared by the following table.

<table>
<thead>
<tr>
<th>Concept</th>
<th>Researcher</th>
<th>Age</th>
<th>Scientific Concept</th>
<th>Alternative Concept</th>
<th>Concepts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condensation on-water on</td>
<td>Present Study</td>
<td>11-12</td>
<td>Air-13%</td>
<td>H₂ and O₂</td>
<td>49%</td>
</tr>
<tr>
<td>Cold bottle comes from?</td>
<td>Osborne and Cogrove, 1983</td>
<td>12-15</td>
<td>10%</td>
<td>60%</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>17</td>
<td>55%</td>
<td>30%</td>
</tr>
<tr>
<td></td>
<td>Bar and Travis, 1991</td>
<td>10-14</td>
<td>20%</td>
<td>40%</td>
<td>40%</td>
</tr>
</tbody>
</table>

• In the present study, higher percentage (at 48%) of students of age 11 and 12 compared to Driver’s sample of 15 year olds in 1982 where 33% had scientific idea that mass of solution will be the same as constituents while dissolving.

There has been progression from phenomenal to conceptual understanding in matter concepts.

Conceptualization of non material improved from Stage 1 to Stage 2. More students of Stage 2 could understand that fire is not material compared to students of Stage 1.

Conceptualisation about volume and hence characteristics of the three states of matter: solids, liquids and gases enhances to a marked extent from Stage 1 to Stage 3.

Conceptualisation about solid or non-solid improved within the stage1 i.e. from class 4th to 5th.
There has been a progression from macroscopic to microscopic understanding.

Physical change conceptualization- increases from Class 6th to 7th (36%-51%)

Chemical change- conceptualization improves across classes from Stage 2 to Stage 3

Identification of features of liquids and gases- 18% Stage 1 and 76% in Stage 3

There has been a progression in content knowledge
The properties of metals were better understood by stage 3 students compared to Stage 2.

**Recommendations**

**Food and Nutrition:**

- Considering water as food since it has minerals, some do not since water is not organic a common agreement among scientists, nutritionists, curriculum developers and textbook authors needs to be reached about the scientific meaning food which needs to be conveyed to students.

- The challenge for elementary students is to accept that digestion is not an end in itself but an intermediate stage between eating and releasing energy. The challenge can be tackled at two levels: (1) working and refining everyday words connected with digestion and energy into scientific meanings. (2) for a deeper level understanding, developing the concepts of conservation of matter during digestion and role of respiration in energy release in the body.

- The challenge to understanding the role of nutrients in our body for elementary students is in understanding the groups of materials, such as carbohydrates, proteins etc and that food materials consist of molecules/particles of chemical substances. In treatment, the role of nutrients and the deficiency thereof need to be dealt together by textbook authors and teachers.

- The particulate view of matter and conservation of matter can be important pre-requisites for grasping the digestive process from elementary students’ point of view. This view should be given due consideration.
• Students need to have the conceptual resource of conservation of matter and matter being rearranged to accept that digestion is an intermediate stage between eating and building new body substances. Further, understanding of digestion depends on previously established concepts of solids, liquids and solubility. This would be progression of learners towards sophisticated/integrated food and nutrition concepts which seems difficult at the elementary level without pedagogical efforts directed towards that end. The implications are for curriculum developers to take a decision regarding introducing particulate nature of matter at the elementary level for a smooth progression in the area of food and nutrition.

**Energy:**

• First, the curriculum planners, physicists and textbook authors have to come to common decision regarding the energy concepts and the breadth of it to be presented to elementary students.

• Elementary students are over generalising the advantages of natural gas not understanding the conceptual explanation behind. Similarly water as a source of energy is a naïve concept poses a hurdle in their scientific progression.

• The attention of students is drawn towards contexts and phenomena related to energy use in the present textbooks, scaffolding needs to done by teachers towards conceptual explanations.

• The concept of energy as an abstract concept may itself present a challenge to elementary students. The concept of energy is simplified in elementary science curriculum, but there seems to be lack of clarity regarding the developmental appropriateness for the concept, as well as correctness of possible simplifications (Trumper, 1990). While the advantages of postponing the introduction of abstract concepts such as energy to a later stage could be safe in terms of curriculum planning (or achievement of learners), postponing building conceptual capacity and concept progression can be to the detriment of science education.
Matter:

- ‘Substances’ and ‘Materials’ are used interchangeably in books and introduced without clarification. Hence students are confused in the semantic meanings of them. Curriculum planners and textbook developers have to take cognisance of this.

- Students had difficulty in understanding changes of state like evaporation, condensation etc. Freezing and identification of condition for evaporation was conceptualised easily by Stage1, but around 60% students do not conceptualize water in vapour state being in air/atmosphere on evaporation. Condensation as a sub-concept under phase change needs to be presented in a pedagogically appropriate way by text book authors and teachers.

- Physical change and chemical change is not conceptualised by maximum students at stage 2 where the topic is introduced. If the view of a particular change is dominated by the apparent disappearance of some material(s), then students are unlikely to understand the conservation of mass. This perception-bound ideas need to be taken care of by teachers and text book authors.

- Traditionally, the nature of matter is a topic that is not addressed in much depth at the elementary school level and part of the reluctance to introduce children to the microscopic worldview is based on a long standing belief that children are essentially concrete thinkers. In this view, the abstract world of atoms and molecules is too far removed from the child’s concrete experiences to be comprehensible. As various research studies with older students shows, the transition to a systematic microscopic worldview is difficult across the entire age spectrum. The world of atoms and molecules are equally invisible or inaccessible through direct experience to high school students and to young children. Understanding the microscopic world required acts of imagination. A recent developmental literature by Metz (1995) suggested that children are capable of fairly complex and abstract scientific reasoning, especially in appropriately supportive instructional contexts. Conceptual change in this area has been historically difficult for scientists, and will be difficult for students as well.
CONCLUSION

Evolution of science concepts among elementary students does not happen linearly. Students are found to progress towards more scientific understanding. The concepts found difficult by primary students were found easy by middle level students. By the time students complete elementary stage, they conceptualise most concepts except a few concepts related to microscopic or particulate understanding. Students conceptualise the concepts related to their social context easily while find the scientific concepts difficult. They find phenomenal concepts easy than to understand that concepts which need conceptual explanations. Items requiring elicitation of single ideas is found easy by the elementary students and items requiring connections among multiple ideas is found difficult. Students have similar confusion regarding science concepts as was found to be held by scientists in history. The various alternative concepts found in elementary students are similar to those held by elementary students as reported widely by researchers. However interviews about tasks/activities elicit different responses about science concepts. The fixed response questions elicit different responses. Even then, many of the alternative conceptions hold true across countries and even age.

Tracing the trajectory of evolution of science concepts among elementary students is challenging. Fundamental ideas tend to be abstract and parsimonious, their appropriateness and usefulness cannot be appreciated by students without the conceptual resources or epistemological commitment of the practising scientific community. Owing to developmental and experiential constraints of students, some of the science concepts may be difficult for students to understand.

At the elementary level, understanding of particulate (or microscopic level) level of matter helps in developing understanding in the areas of energy and nutrition. Teaching & learning at macroscopic level only, limits their understanding at the gross level. Several researchers have attempted pedagogy derived from historical development of the area for improving learner’s understanding. The input may be at the level of text development (for example, understanding Toricelli’s experiment may help learners ‘see’ the material nature of gases) or at the level of experiments designed based on them (examples are: Experiments with air, syringes). Curriculum development need not be limited by children’s naïve or alternative understanding of
concepts. Construction of knowledge is done by individual children in the social setting of classroom, but the scaffolding has to be provided by the curriculum carried out by teachers.

The researcher’s understanding of curriculum organisation in the three areas of food and nutrition, energy and matter was derived from historical evolution of the concepts in three domains, research on children’s understanding about concepts pertaining to the three domains and empirical research on children’s understanding about some of the concepts pertaining to elementary level.

Historical evolution indicates that a cogent development in a domain has not occurred in human history. Evolution is gradual and times sudden, but at all times cumulative adding on to human construction of knowledge in that area and also integrated across domains. More sophisticated and exclusive the knowledge, more integrated it is across matter & energy. At subatomic level the distinction between energy and matter is also non-existent. Scaffolding has to be provided by science education (and hence science teachers) to lead children from their own understanding to understanding evolved in scientific community through a coherent curriculum.