CHAPTER II

SCIENCE PROCESS SKILLS: A THEORETICAL OVERVIEW

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SCIENCE PROCESS SKILLS: A THEORETICAL OVERVIEW

Development of science has been the result of man's inquiry of puzzling natural phenomena and situations with a view to satisfy his innate curiosity and to subdue the environment for enhancing his physical comforts. For this purpose, he built up a body of scientific knowledge by utilising his intellect and applying his ability for engaging in thinking and reasoning. This shows that even in ancient times science was really the product of a precise method of thinking rather than mere acquisition of ready made facts. But when body of scientific knowledge expanded, this spirit of inquiry gave way to mere information mongering in the hands of incompetent teachers. The unscientific system of examination calling for mere reproduction of this information added momentum to this degeneration. Thus the true spirit of science which is built upon the real process of thinking and learning was lost sight of.

It is under these circumstances a rethought of the issue was taken up by modern educationists and those interested in augmenting the quality of science education.

2.1.0 THE SIGNIFICANCE OF PROCESSES IN SCIENCE TEACHING

In many countries attempts have been made to reorient the curriculum so as to give due importance to processes in science education. The major goals of these curricular innovations can be classified as:

(a) the development of curricular materials and science programme that are consistent with current science knowledge
(b) the development of curricular materials and science programmes which provide the student with an understanding of the process of science (AAAS, 1994).

Donnelly (1985) suggests the conditions for having a practical theoretical role for science processes in the science curricula and its implementation. They are:

1) the process must be defined at some minimum level of coherence

2) their connection if any, with pupils’ intellectual skills must be ascertained.

3) methods for the development of the relevant skills must be explored.

National Committee on Science Education Standards and Assessment (1994 draft) advanced inquiry as an important standard for grades 9 through 12. Inquiry in the classroom is a means for promoting and supporting students’ curiosity and questioning spirit. Inquiry is a critical component of the science curriculum at all grade levels and in every domain of science.

It serves four essential functions:

a) to assist in the development of an understanding of scientific concepts

b) to develop an understanding of the nature of scientific inquiry

c) to develop the skills and the disposition to use them necessary to become independent inquirers about the natural world

d) as a model of how we know and what we know in science.
The science criteria framed by the evaluation system of General Certificate of Secondary Education (GCSE 1988) also emphasise the development of skills. They are enlisted below:

a) the relative weight given to skills and methods must increase
b) the relative weight given to facts and terminology must decrease
c) experimental work must be included
d) Everyday life and socio-economic implications of science must be considered (Cooper, 1986).

Bruner (1962) insists that the memorization of facts is not as important as the acquisition of the process of knowledge. “To instruct someone in a discipline is not a matter getting him to commit results to mind. Rather, it is to teach him to participate in the process that makes possible the establishment of knowledge. We teach a subject not to produce little living libraries on the subject, but, rather to get a student to take part in the process of knowledge. Getting knowledge is a process, not a product”.

Some science educators (Simpson, 1987) raise strong arguments for a process-led science curriculum. They question the relevance of teaching of facts in the situation where information is generated in gigantic amount. Learning and education do not involve the passive handling and acquisition of information. Human beings are information processors, rather than information absorbers and active learning involves the processing of new information according to learner’s previous experiences, needs, preconceived ideas, knowledge, and hypotheses. So in addition to the information skills, previous ideas, experiences, and hypotheses should present in the learners’ cognitive structure.
Hence Wellington (1990) substantiates science education should focus on the following equally:

1. Knowledge ‘that’ - facts, happenings and phenomena
2. Knowledge ‘how’ - skills, processes and abilities
3. Knowledge ‘why’ - explanations, models, analogies, theories etc.

The transferable skills deserve the position of basis for science education than the facts, which soon get outdated. Therefore science education should aim at developing the transferable skills.

A critical view on the major curricular innovations reveals that, when processes and attitudes are considered as the main focus, the role of specific content is generally played down. This leads to an inductive view of learning science. The generalisations formulated by using the process skills add to the children’s conceptual knowledge of the world around them.

The alternative school of thought regards the teaching of concepts as significant for children’s understanding of the environment. Even though they use process skills during teaching and learning, the focus is upon product. The underlying approach to learning is deductive. Children learn the generalisations and then they will use them in understanding things around.

For effective teaching and learning of science a learning approach in which the processes and products are needed rather than the process-product polarization. Modern educators are of the opinion that content of an activity influences children’s use of process skills. Any activity will have some content, which influence the thinking and exploration.

The process approach has many-sided significance. It stimulates autonomous recognition of relationship, broadens background knowledge for
current and future use, reinforces the skills and motivates the pupils towards self education.

The National Council of Educational Research and Training, (NCERT) while planning the integrated science curriculum for the middle school students, identified the process approach as one of the core elements of the course. While discussing the philosophy of the integrated curriculum, the document Integrated Science Curriculum - an introduction (NCERT, 1982) states: "...a science curriculum must stress more on... these processes than the products of science. The knowledge of the product is useful in understanding the processes of science and for concretizing the processes for pedagogical use. But understanding of the processes are useful both for daily life as well as in furthering scientific knowledge".

2.2.0 PROCESS Vs PRODUCT APPROACH

The body of scientific knowledge, which is the result of the quest for comprehension and explanation through the development of fundamental principles, is called the 'content' or 'products' or 'major concepts' of science.

The body of knowledge may be seen as a collection of knots. When the little knots are tied in the bigger ones, making generalizations, science begins to make sense. The method used by scientists for acquiring the body of knowledge is known as the scientific method or method of inquiry or processes of science. The scientists use experimentation and observation as the basis of developing conceptual schemes. The development of conceptual schemes by experiment and observation and the premise that these conceptual schemes lead to further experimentation and observation are considered as the fundamental aspects of the nature of science.
This cyclic nature of the genesis of conceptual schemes from observation and experimentation and the use of them to stimulate further observation and experimentation is also found extensively in the writings of scientists and philosophers of science.

From the regularities found in the experiment, conceptual structures are evolved. The value of these conceptual structures depends on its effectiveness to predict further behavior of nature. These predictions serve as the basis for further experimentation and observation. And so the scientific edifice appears to be a self-renewing, never ending one which continuously builds new conceptual structures through experimentation on, and analysis of the environment.

2.2.1 SCIENTIFIC PROCESSES AND SCIENTIFIC METHOD

The most distinguishing characteristic of science is the way it finds knowledge i.e. the method it uses for exploring the universe. It is an activity that takes place in the minds of men as a result of certain intellectual processes. These intellectual processes are the means by which one can examine the unknown, explore and investigate, through experimentation on, and analysis of the environment.

Science processes are quite different from the popular notion of scientific method. Some science educators are against the notion of the existence of such a 'special method of science', in the sense that, if a particular method is followed, discoveries will be made. (Thier, 1973). According to them there is no one scientific method, but there are certain general principles which govern the work of all scientists. The often-mentioned scientific method is the manner
in which they report their findings, and not the way they gain knowledge. The actual work of science is much less formal. It requires critical and creative thinking.

But these science processes characterize the activities of scientists, the way to locate and gather information, explore, search, and discover the truths of nature. These processes of science need not necessarily be a part of scientists' behaviour or activity.

Woolnough (1985) suggests that the scientific method can be split up into its various component parts. This implies that when the students acquire mastery over the component skills, they become competent in scientific method. This way of gaining proficiency in the scientific method, however, is not feasible in science. Scientists do not work according to such a mechanical process of ordered steps. According to Medawar (1969), what passes for scientific methodology is a misinterpretation of what scientists do or ought to do, and hence scientists are completely indifferent to scientific methodology.

Karl Pearson’s (1937) steps of scientific inquiry include many of the science processes. They are listed below:

a) the problem is identified
b) observations pertinent to the problem are gathered
c) a hypothesis based on the observations is developed and stated
d) testable predictions of other related observable phenomena are developed from the hypothesis
e) the hypothesis is tested through observations
f) as a result of empirical observations, the hypothesis is supported, rejected or modified.
The terms such as, thinking skills, scientific thinking, reasoning skills, cognitive development, critical thinking and logical thinking have been considered as related to science process or processes of scientific inquiry. Upon examination, these terms contain some common elements. The Secondary Science Curriculum Review (SSCR, 1987) identifies skills as being separate from processes. A skill is seen as a specific activity which a student can be trained to do. But a process is seen as a rational activity involving the application of a range of skills. But it is unquestioned that a degree of generalisability can be seen in the human capabilities of this sort.

Gagne (1977) considers these processes as intellectual skills which realise in due course of time. Once they have been generalized, they not only help the child in understanding other subjects, but also influence his approach to everyday problems.

Millar and Wynne (1988) do not see any special association between the so-called processes and science. These processes are common to systematic thought in all formal discipline, and to informal common-sense reasoning. That is, they are general cognitive skills which man routinely employs throughout his life without any need for formal instruction.

2.3.0. CLASSIFICATIONS OF SCIENCE PROCESSES

A Process is a series of activities or operations performed to attain certain goal or product. Science Processes are the inter-linked activities performed by any qualified person during the exploration of universe. The Science process outcomes are the intellectual skills needed for scientific investigation attained by student as a result of learning of science. In order to get a better insight into
the nature of processes the investigator examined some of the important classifications attempted by top authorities in the field. Some of the representative classifications are given below.

2.3.1. NEDELSKY’S COMPETENCE-ABILITY CLASSIFICATION IN SCIENCE LEARNING

Nedelsky (1965) has classified the objectives of a physical science course in college or high school. They are learning of abilities. Each ability is subdivided into two; those concerned with symbolic subject matter and those concerned with real phenomena. The abilities under these classifications are given below:

Ability 1: Knowledge: verbal and mathematical
Ability 2: Understanding: verbal and mathematical
Ability L2: Intuitive understanding
Ability IL2: Laboratory understanding of phenomena
Ability 3: Ability to learn
Ability L3: Ability to learn from experiment or observation.

(The letters, L denote Laboratory competence and I denotes Intuitive understanding)

2.3.2. SCIENTIFIC THINKING: (SCOTTISH EDUCATION DEPARTMENT- CURRICULUM)

The Scottish Education Department Consultative Committee (1969) on the Curriculum in the “Programme for the First Two Years of Secondary Education in Scotland” elaborates one of its objective as “acquisition of ability to solve problem situations and think scientifically” suggested the kinds of ‘thinking’ which pupil would develop by studying science. They are listed in Table 2.1.
2.3.3. NAY’s CLASSIFICATION OF SCIENCE PROCESSES

Nay, et.al. (1971) identified five steps of scientific inquiry, with seventeen subdivisions and many other minor divisions. Their scheme of scientific inquiry is given below:

I. Initiation

1. Identifying and formulating a problem
   a. speculating about a phenomenon
   b. identifying variables
   c. noting and making assumptions
   d. delimiting the problem.
2. Seeking relevant background information
   a. recalling relevant knowledge and experiences
   b. doing literature research
   c. consulting

3. Predicting

4. Hypothesizing

5. Design for collection of data through field work and / or experimentation
   a. defining the independent and controlled variables in operational terms
   b. defining the procedure and sequencing the steps
   c. identifying needed equipment, materials and techniques
   d. indicating safety precautions
   e. devising the method for recording data.

II Collection of data

6. Procedure
   a. collecting, constructing and setting up the apparatus or equipment
   b. doing field work and / or performing the experiment
   c. identifying the limitation of design (as a result of failures, blind alleys etc.,) and modifying the procedure (often by trial and error)
   d. repeating the experiment (for reproducibility, to overcome the limitations of initiation, design, etc.)
e. recording data (describing, tabulating, diagramming, photographing etc.)

7. Observing and observations
   a. obtaining qualitative data (using senses etc.)
   b. obtaining semi-quantitative and qualitative data (measuring, reading scales, calibrating, counting objects or events, estimating, approximating etc.)
   c. gathering specimens
   d. obtaining graphical data (charts, photographs, films etc.)
   e. noting unexpected or accidental occurrences (serendipity)
   f. noting the precision and accuracy of data
   g. judging the reliability and validity of data.

III Processing of data

8. Organising the data
   a. ordering to identify regularities
   b. classifying
   c. comparing

9. Representing the data graphically
   a. drawing graphs, charts, maps, diagrams, etc.
   b. interpolating, extrapolating etc.
10. Treating data mathematically
   a. computing (calculating)
   b. using statistics
   c. determining the uncertainty of the results

IV Conceptualization of data

11. Suggesting an explanation
   a. for a set of data
   b. deriving an influence or generalization from a set of data
   c. assessing validity of initial assumptions, predictions and hypotheses

12. Formulating operational definitions
   a. verbal
   b. mathematical

13. Expressing data in the form of mathematical relationship

14. Incorporating the new discovery into the existing theory. (developing a ‘Mental Model’).

V Open endedness

15. Seeking further evidence to
   a. increase the level of confidence in the explanation or generalization
   b. test the range of applicability of the explanation or generalization

16. Identifying new problems for investigation because of
   a. the need to study the effect of new variable.
   b. anomalous or unexpected observations
   c. incompleteness (gaps) and inconsistencies in the theory.
17. Applying the discovered knowledge

In this set of skills, many affective attributes and mental operations such as communication, logical thought, critical attitude, creativity etc., seems to be excluded.

2.3.4. KLOPFER'S CLASSIFICATION OF OUTCOMES IN SCIENCE

Klopfer (1971) has given taxonomy of objectives of science education based on knowledge, comprehension, processes of scientific knowledge and methods, manual skills, scientific attitudes, interests, and orientation. They are presented below:

TABLE 2.2. TABLE OF KLOPFER'S SPECIFICATION FOR SCIENCE EDUCATION

A.0: Knowledge and comprehension

A.1: Knowledge of specific facts
A.2: Knowledge of scientific terminology
A.3: Knowledge of concepts of science
A.4: Knowledge of conventions
A.5: Knowledge of trends and sequences
A.6: Knowledge of classifications, categories and criteria
A.7: Knowledge of scientific techniques and procedures
A.8: Knowledge of scientific principles and laws
A.9: Knowledge of theories of major conceptual schemes
A.10: Identification of knowledge in a new context
A.11: Translation of knowledge from one symbolic form to another.
B.0: Process of scientific inquiry I: observing and measuring

B.1: Observation of objects and phenomena

B.2: Description of observations using appropriate language

B.3: Measurement of objects and changes

B.4: Selection of appropriate measuring instruments

B.5: Estimation of measurements and recognition of limits in accuracy.

C.0: Process of scientific inquiry II: seeing a problem and seeking ways to solve it

C.1: Recognition of a problem

C.2: Formulation of a working hypothesis

C.3: Selection of suitable tests of a hypothesis

C.4: Design of appropriate procedures for performing experiments.

D.0: Process of scientific inquiry III: interpreting data and formulating generalizations

D.1: Processing of experimental data

D.2: Presentation of data in the form of functional relationship

D.3: Interpretation of experimental data observations

D.4: Extrapolation and interpolation.

E.0: Process of scientific inquiry IV: building, testing, and revising a theoretical model

E.1: Recognition of the need for a theoretical model

E.2: Formulation of a theoretical model to accommodate knowledge

E.3: Specification of relationships satisfied by a model
E.4: Deduction of a new hypothesis from a theoretical model

E.5: Interpretation and evaluation of tests of a model

E.6: Formulation of a revised, refined, extended model.

F.0: Application of scientific knowledge and methods

F.1: Application to new problems in the same field of science

F.2: Application to new problems in a different field of science

F.3: Application to problems outside of science (including technology).

G.0: Manual skills

G.1: Development of skills in using common laboratory equipment

G.2: Performance of common laboratory techniques with care and safety.

H.0: Attitudes and interests

H.1: Manifestation of favourable attitudes towards science and scientists

H.2: Acceptance of scientific inquiry as a way of thought

H.3: Adoption of 'scientific attitudes'

H.4: Enjoyment of science learning experiences

H.5: Development of interest in science and science related activities

H.6: Development of interest in pursuing a career in science.

I.0: Orientation

I.1: Relationship among various types of statements in science

I.2: Recognition of the philosophical limitations and influence of scientific inquiry
1.3 : Historical perspective: recognition of the background of science
1.4 : Realisation of the relationships among science, technology and economics
1.5 : Awareness of the social and moral implications of scientific inquiry and its results.

2.3.5 GAGNE’S HIERARCHY OF LEARNING TYPES

Gagne formulated a model based on the hierarchy of learning types. On this model, learning of more basic behaviour is a pre requisite for learning of the higher behaviour. This idea has been systematised by Gagne (1977) in the form of a hierarchy of learning types.

1. Signal learning
2. Stimulus response learning
3. Chaining
4. Verbal association
5. Discrimination learning
6. Concept learning
7. Rule learning
8. Problem solving

Gagne later modified this hierarchy of eight learning types. He retain and the first four in the same order, and modified the latter four higher types into five varieties of capabilities, as he called them [Gagne (1985)]. These capabilities are:

1. Intellectual skills: Intellectual skills are the most important types of capabilities learned by human beings. It includes, successful
handling of symbols for communication with environment. The most typical form of an intellectual skill is a rule. Intellectual skills consist the following categories:

a) multiple discrimination
b) concrete concept and defined concept
c) higher order principles or learning of rules
d) procedure.

II Cognitive strategies: Cognitive strategies are internally organised skills whose functioning is to regulate and monitor the utilization of concepts and rules. By acquiring and using cognitive strategies the learners are able to regulate internal processes such as,

a) attending
b) learning
c) remembering
d) thinking
e) problem solving

III Verbal information: The learner has to learn verbal information and retain it, so that, it is immediately accessible. Information is thought of as verbal and capable of being verbalised.

IV Motor skills: Acquisition of motor skills is the organisation of movements to constitute a total action that is in smooth, regular and precisely timed and

V Attitudes
Gagne's hierarchy implies the structure of scientific process. It serves as the background psychological principles for the preparation of innovative curricula—SAPA—which emphasis, science processes (AAAS).

2.3.6. SHEPARDSON'S IDENTIFICATION OF SCIENCE PROCESSES

Shepardson (1990) investigated on problem solving phase, student interactions, and thinking skills. He could identify student behaviour behind each phase of the problem solving. They are presented below:

1. Problem finding and refining phase: In this phase students employ the following skills.
   a) focusing
   b) analysing
   c) evaluating
   d) integrating

2. Research designing phase
   The students use focusing skill during this phase

3. Data collecting phase
   The skills used by the students in this phase are
   a) focusing
   b) integrating
   c) generating

4. Data analysing phase
   During this phase the students use the following skills
   a) remembering
   b) analysing
c) organising
d) information gathering
e) focusing
f) integrating
g) evaluating

5. Evaluating phase

In this phase the skills used are

a) organising
b) focusing
c) integrating
d) information gathering.

2.3.7. UNESCO’s CLASSIFICATION OF SCIENCE PROCESSES

UNESCO source book for science teaching (1992) lists out the indications of process skills. They are summarised and given below:

observing

Using the senses (as many as safe and appropriate) to gather information
Identifying differences between similar objects or events
Identifying similarities between different objects or events
Noticing fine details that are relevant to an investigation
Recognizing the order in which sequenced events take place
Distinguishing from any observations those which are relevant to the problem in hand
raising questions

Asking questions which lead to inquiry
Asking questions based on hypotheses
Identifying questions which they can answer by their own investigation
Putting questions into a form, which indicates the investigation which has to be carried out
Recognizing that some questions cannot be answered by inquiry

hypothesizing

Attempting to explain observations or relationships in terms of some principle or concept
Applying concepts or knowledge gained in one situation to help understanding or solve a problem in another
Recognizing that there can be more than one possible explanations of an event
Recognizing the need to test explanations by gathering more evidence
Suggesting explanations, which are testable, even if unlikely

predicting

Making use of evidence to make a prediction (as opposed to a guess, which takes no account of evidence)
Explicitly using patterns or relationships to make a prediction
Justifying how a prediction was made in terms of present evidence or past experience
Showing caution in making assumptions about the general application of a pattern beyond available evidence
Making use of patterns to extrapolate to cases where no information has been gathered

**finding patterns and relationships**

Putting various pieces of information together (from direct observations or secondary sources) and inferring something from them
Finding regularities or trends in information, measurements or observations
Identifying an association between one variable and another
Realizing the difference between a conclusion that fits all the evidence and an inference that goes beyond it
Checking an inferred association or relationship against evidence.

**communicating effectively**

Using writing or speech as a medium for sorting out ideas or linking one idea with another
Listening to others’ ideas and responding to them
Keeping notes on actions or observations
Displaying results appropriately using graphs, tables, charts etc.
Reporting events systematically and clearly
Using sources of information
Considering how to present information so that it is understandable by others

**designing and making**

Choosing appropriate materials for constructing things, which have to work or serve a purpose
Choosing appropriate materials for constructing models
Producing a plan or design which is a realistic attempt at solving a problem

Succeeding in making models that work or meet certain criteria

Reviewing a plan or a construction in relation to the problem to be solved

devising and planning investigations

Deciding what equipment, materials, etc. are needed for an investigation

Identifying what is to change or be changed when different observations or measurements are made

Identifying what variables are to be kept the same for a fair test

Identifying what is to be measured or compared

Considering beforehand how the measurements, comparisons, etc. are to be used to solve the problem

Deciding the order in which steps should be taken in an investigation

manipulating materials and equipment effectively

Handling and manipulating materials with care for safety and efficiency

Using tools effectively and safely

Showing appropriate respect and care for living things

Assembling parts successfully to a plan

Working with the degree of precision appropriate to the task in hand

measuring and calculating

Using an appropriate standard or non-standard measure in making comparisons or taking readings
Taking an adequate set of measurements for the task in hand

Using measuring instruments correctly and with reasonable precision

Computing results in an effective way

Showing concern for accuracy in checking measurements or calculations

A general discussion of the science processes as given by various experts reveal that, the science process skills have a hierarchical order. Some basic skills are needed for the acquisition of higher order skills. One can infer an overlap of many skills in a specific phase of a problem solving task. There are some commonalities among the various classification of skills, but some of them lacks the high degree of wholeness of the processes. Klopfer's (1971) classification is significant to be mentioned among them, while Shepardson's (1990) contribution signifies the analysis of the different skills inherent in problem solving in definite phases.

2.4.0. MAJOR CURRICULAR INNOVATIONS IN SCIENCE

Since 1960, the teaching of science became a major concern that it received global attention. This period was one that of intense and vigorous development of the science curriculum, marked by the publication of many major projects. The major curricular innovations launched as a revolt against the traditional product-led approach stress the development of processes in science teaching. Physical Science Study Committee (PSSC), Science - A Process Approach (SAPA), Harvard Physics Project (HPP), The Elementary Science Study (ESS), The Science Curriculum Improvement Study (SCIS), The Elementary School Science Project (ESSP), School Science Curriculum Project (SSCP), The Minnesota Mathematics and Science Teaching Project (MINNEMAST), Conceptually Oriented
Program in Elementary Science (COPES), Chemical Education Material Study (CHEM study), Chemical Bond Approach (CBA), Science in Process, Warwick Process Science, various Nuffield courses in the U.K. and ASEP in Australia are some of them. A recurring and significant feature of most of these curriculum proposals was a major shift in emphasis away from the teaching of science as a body of established knowledge, toward science as a human activity with increasing emphasis on the processes and procedure of science. The curriculum projects are framed in such a way that children should enjoy science through direct engagement in scientific activities and gain an awareness of what scientists do and should be encouraged to pursue the study of science at an advanced level. A critical evaluation of them reveals that, the intensity of the role of processes in them are different, but they have some uniqueness. Some of the major curricular studies are reviewed below to illustrate this point.

2.4.1. THE PHYSICAL SCIENCE STUDY COMMITTEE (PSSC)

Physical Science study committee (PSSC) was formed in 1956 and it devised new physics texts, laboratory manuals, films and supplementary reading materials. In its preamble it is claimed that science teaching is made process oriented and due stress is laid on discovery learning and conceptual schemes of science.

The stress given in this programme was

1. on helping children learn science information, skills, attitudes
2. characteristics of science process and products
3. teaching science through discovery approach.
2.4.2. SCIENCE–A PROCESS APPROACH (SAPA)

The Commission on Science Education of the American Association for the Advancement of Science (AAAS) launched a programme named Science–A Process Approach (SAPA), which emphasises the laboratory method of instruction and the learning of scientific processes by children. In SAPA, the processes of investigation are identified and explained in detail. They begin in highly specific and concrete form and gradually generalize by well-planned exercises. The processes are used as guidelines for constructing sequences of instruction. There is progressive development in each process category. As this development proceeds, it comes to be increasingly interrelated, with corresponding development of other processes. Terminal behaviour is specified for each process, and the sequence of tasks that should be completed to develop the terminal behaviour is outlined in detail by means of task analysis. The processes are carefully analyzed into eight basic and five integrated processes. They are given below:

*Basis Processes*

- **Observing**: Using five senses to obtain information
- **Using space/time relationship**: Describing spatial relationships and their change with time
- **Classifying**: Imposing order on collections of objects or events
- **Using numbers**: Identifying quantitative relationships in nature
- **Measuring**: Measuring length, area, volume, weight, temperature, force, and speed
Communicating: Expressing ideas with oral and written words, diagrams, maps, graphs, mathematical equations, and various kinds of visual demonstrations.

Predicting: Making specific forecasts of what a future observation will be.

Inferring: An explanation of an observation.

*Integrated Processes*

Controlling variables: Studying the influence of changing variables, the factors, which influence one another.

Interpreting data: Using data to make inferences, predictions and hypotheses, the statistical treatments given to such interpretations, and the study of probability.

Formulating hypotheses: Making generalized statements of explanations.

Defining operationally: Defining terms in the context of experience.

Experimenting: Larger process of using basic and integrated processes.

2.4.3. THE ELEMENTARY SCIENCE STUDY (ESS)

ESS helps each child to investigate through physical materials, the nature of world around him. Through active participation children acquire useful information. This programme leads children to open enquiry combined with
experimentation. The natural inquisitiveness of children and their freedom from preconceptions to difficulty that ESS tries to cultivate and direct into deeper channels.

2.4.4. THE CONCEPTUALLY ORIENTED PROGRAMME IN ELEMENTARY SCIENCE (COPES)

The Conceptually Oriented Programme Project (New York University, 1969) considered the following sequences of processes as the basic skills:

1) analyzing
2) classifying
3) communicating
4) experimenting
5) interpreting
6) mathematical reasoning
7) measuring
8) observing
9) predicting

2.4.5. COURSE FOR THE JUNIOR FORMS OF NIGERIAN SECONDARY SCHOOLS

A course for the junior forms of Nigerian Secondary Schools (New trends in integrated science teaching, UNESCO Vol. I, (1969-70) included the following skills in the order of sequences given below:

1) Observing - carefully and thoroughly
2) Reporting - completely and accurately what is observed
3) Organizing - information acquired by the above process
4) Generalizing - on the basis of acquired information
5) Predicting - as a result of these generalizations
6) Designing - experiments to check these predictions
7) Using models - to explain phenomena where appropriate
8) Continuing the process - of inquiry when new data do not conform to predictions

2.4.6. SCIENCE CURRICULUM IMPROVEMENT STUDY (SCIS)

Science curriculum improvement study (SCIS) is a research project to develop content-process oriented programme of science teaching for small children. The goals of the programme are:

1) to help the children to learn the fundamental concepts of science
2) to enable them to understand that scientific ideas are based on the observation of natural facts and phenomena and are also the product of human inventiveness and imagination, and
3) to help them to understand that for an idea to be fundamental and persistent, it is necessary that it is tested against further observation and experimentation.

This programme combines content, processes and attitudes. The first step is the selection of content, it is followed by the selection of instructional procedure which enables the children to learn scientific processes. The instructional procedure is centered round exploration invention and discovery.
2.4.7. VARIOUS NUFIIELD PROJECTS

The skills to be developed in children according to the curriculum project Nuffield 11-13 (1986) are:

1) handling equipment
2) observing
3) patterning
4) communicating
5) designing investigations and experiments
6) mental modeling

Patterning includes classifying and predicting. Designing investigations incorporates raising questions, hypothesizing and controlling variables.

2.4.8. WARWICK PROCESS SCIENCE

In the curriculum project Warwick Science Process (Screen 1986), the following processes are made explicit:

1) observing
2) inferring
3) classifying
4) predicting
5) controlling variables
6) hypothesizing

2.4.9. ASSESSMENT OF PERFORMANCE UNIT (APU)

In the United Kingdom, the Assessment of Performance Unit (APU) has established an assessment framework which identifies six Science Activity Categories (SAC) (Murphy and Gott, 1984). They are listed below:
1) use of graphical and symbolic representation
2) use of apparatus and measuring instruments
3) observation
4) application and interpretation of concepts and data
5) planning investigations
6) carrying out investigations

2.4.10. SCIENCE IN PROCESS

'Science in Process' talks about the 'acquisition and use of process skills' and of processes being taught, (ILEA, 1987). It draws attention to the following process skills:

1) applying
2) interpreting
3) classifying
4) investigating
5) evaluating
6) observing
7) experimenting
8) predicting
9) hypothesizing
10) raising questions
11) inferring

The brief discussion made about on the important curricular studies in science conducted in different parts of the world substantiate the point raised...
by the investigator, that the modern trend in science instruction is of stressing the acquisition of the process of learning the subject rather than mere acquisition of the content of the subject.

2.5.0. PROCESS MODELS

Anderson (1970), Wilson (1974) and Rachelson (1977) attempt to describe processes in terms of models. Their models are given below:

Rachelson (1977) gives a model of the process of scientific inquiry. The model illustrates the relationship between testing and generating a hypothesis. It presents scientific inquiry as a self correcting revisionary system. The revisionary element is critical, as it is the unique characteristic of scientific inquiries.

Observable data create a problematic situation

Generation of hypothesis through intuitive acts

Drawing conclusions

Empirical testing of prediction using empirical controls

Hypothesis

Formation of observable prediction

Observable predictions

Result

(R) = revisionary element

*Fig. 1. Process of Scientific Inquiry (Rachelson, 1977)*
Fig. 2. A model of process skills (Anderson, 1970)

- Experimenting
  - Manipulating variables
  - Formulating hypotheses
  - Formulating models
    - Making operational definition
    - Predicting
    - Communicating
  - Classifying
  - Measuring
    - Using numbers
  - Observing
  - Interpreting data
  - Inferring
  - Using space-time relationship
Understanding the world around depends on the development of concepts. The development of concepts depends on the process skills. The concepts and process skills are interrelated. As concepts gradually become more sophisticated, process skills need to be refined and extended.

A format of the science process skills is given by UNESCO source book for science teaching (1992).

Fig. 3 Process skills as part of a whole called Scientific Investigation

(UNESCO Source book 1992)
Carin and Sund's (1970) model of interrelationship between Processes and Products is given below:

Fig. 4. Inter relationship between Processes and Products (Carin and Sund, 1970)

Wilson's model (1974) provides two parallel sets of search processes—the empirical inquiry and the conceptual inquiry. The search process in the empirical enquiry includes observation, classification, inferring, predicting, quantifying, and simplification whereas, conceptual inquiry includes attribute search, symbolic representation, conceptual testing, idealization and analysis for cause. The model is represented in figure 5.
Empirical inquiry:

Discrepant event:
curious events
data gaps
chance observations

Empirical experiments:
observation
classification
inferring
predicting
quantifying
simplification

New phenomena:
objects, events,
observable relationships
 correlated occurrences

Conceptual inquiry:

Discrepant attributes:
contradictory phenomena
limit determination
theory articulation

Conceptual experiments:
attribute search
symbolic representation
conceptual testing
idealization
analysis for cause

New explanations:
paradigms, models
relationships, principles
theories, laws.

Fig. 5. Process Model of Scientific-Inquiry (Wilson, 1970)

The typical development of intellectual skills is revealed by Piaget (1963). It starts from the very concrete and specific to the increasingly abstract and general. Highly general intellectual skills are typically formed over a period of years, and are thought to depend upon the accumulated effects of learning for a considerable variety of relatively concrete principles.

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