CHAPTER II

RELATED LITERATURE

2.1 Introduction

An overview of the present study was presented in Chapter I. This Chapter explores to review the related literature and to develop an instructional strategy based on Gagne's conditions of learning. While discussing the Gagne's conditions of learning which is the focus of the study, here, attention has also been drawn to other theories which have contributed to science instruction in particular. This is also required to create a backdrop for better understanding of Gagne's position. Gagne has immensely contributed to instructional design and as such this chapter has a thematic flavour towards an instructional design. Gagne had essentially focussed his attention on training people to perform complex behaviours that involve high degree of precision and coordination. His contribution to instructional design included task definition, task analysis and sequencing. His concentration was on conceptualizing performance goals or tasks, breaking these tasks, developing g training actitities that ensure mastery of each subcomponent and finally arranging entire learning situation into sequences that ensure adequate transfer from one component to another and achievement of pre-requisite learning before more advanced ones. Gagne has made important contributions to the preactive component or the planning aspect of instruction.

Any discussion on science instruction and instructional design may not be complete without having a few words about the contribution by learning psychologists and educationists like Piaget, Gagne, Brunër and Ausubel. The second section of this chapter concentrates on their contribution. Gagne's conditions of learning has directly or indirectly influenced quite many other developments in instructional psychology. A few notable contributions are discussed in the third section. An overview of Gagne's conditions of learning with a short discussion on its relatedness to science processes and philosophical basis for the same is given in the fourth section of this chapter. Fifth section discusses an instructional design based mostly on Gagne's conditions of learning.

2.2 Contributions from General Theories

Though all learning theories contribute towards instruction, specific attention may have to be given to the work of Gagne and Bruner who have developed the most widely recognised applications of learning theory to instruction. The developmental aspects of learning described by Piaget and the meaningful learning suggested by Ausubel also have contributed immensely towards the development of instruction especially in science.

Gagne (1965) in a work drawing upon principles from both behavioural and cognitive literature described eight different types of learning. Starting with the simplest type of learning, the eight modes were referred to as : (1) Signal Learning, (2) Stimulus-Response Learning, (3) Chaining, (4) Verbal Association, (5) Multiple Discrimination Learning, (6) Concept Learning, (7) Principle Learning and (8) Problem Solving. Again these fundamental modes of learning represented a hierarchy which mandated the occurence of a lower mode in order for subsequent types of learning to occur. Gagne has hypothesised that for learning to occur sequences of instruction should be developed utilizing this hierarchy in combination with a knowledge of the initial state of the learner relative to specific content. Gagne also addressed himself to the issues of student motivation and methods of presenting instruction. However, the focus of his work was clearly to propose a hierarchy of learning types and to demonstrate their implications for instruction. An elaborate discussion on Gagne's work is presented in the later part of this chapter.

Bruner's work in instructional theory has drawn upon researches in the area of concept attainment, human development and acquisition of knowledge. He demonstrated how these concepts might be combined in "Towards a Theory of Instruction" (Bruner, 1966). His theory of instruction was based on the following main points : (1) Experiences which most effectively implant in the individual a predisposition toward learning, (2) Ways in which a body of knowledge be structured so that it could be most readily grasped by the learner, (3) Most effective sequences in which to present the materials to be learned and (4) Mature and pacing of rewards and punishments in the process of learning and teaching (Bruner, 1966, pp 40-41). Although Bruner's work did not constitute a theory of instruction, it did broaden and clarify the concerns of many who were dealing with instructional theory.

Since the goodness of the structure (structured knowledge) depends upon its power for simplifying informations for generating new propositions and for increasing manipulability of a body of knowledge, structure must always be related to the status and gifts of the learner. Bruner thinks that instruction consists of leading the learner through a sequence of statements and restatements of a problem or body of knowledge that increases the learners ability to grasp, transform and transfer what he is learning. In short, the sequence in which a learner encounters materials within a domain of knowledge affects the difficulty he will have in achieving mastery. These have their effects on the organisation of curricular materials.

Piaget, who is clearly a cognitive theorist, uses 'schema' as his key intervening variable. Schemeta, broadly speaking, are the frameworks or organising structures for mental activity. The formation and change of schemeta is the essence of cognitive development. A child, of course, has schemeta relevant to great many topics and the number becomes even greater as one approaches adulthood. Piaget has been particularly interested in those that might broadly be called scientific. The exploration of these schemeta has been Piaget's greatest contribution. Schemeta are changing constantly. Such a change is the essence of cognitive development. The process by which they change is known as accommodation. Piaget identified four stages in cognitive development. The first stage is 'sensory

He is atleast ready to think in the realm of abstract propositions that fit in with varying degrees, the real world that he faces. The key processes in the stages of child development are assimilation and accommodation. Assimilation consists of the filtering or modification of the input from the environment. In this process new knowledge meshes with the child's internal patterns of understanding to fit reality. Through this process of assimilation, the existing internal insights are reconstructed to accommodate new data or information. Piaget's study deals with knowledge acquisition at various stages. Most of the piagetian studies are conducted in the domain of conceptual knowledge. Piagetian studies hold good to the extend of determining to the type of concept which could be taught to a child at a particular stage. Problem solving studies in a Piagetian framework have not been much common in science education (Stewart, 1982). However, the theoretical positions taken by Piagetians as well as the claims made about what should or should not be taught at particular grade levels, are intimately tied to problem solving. This seems from equating thinking with problem solving (Lawson, 1979) and their use of problems (Piagetian tasks) to assess an individual's level of schema development or success in various content domains (Cantu and Herron, 1978; Grant and Renner, 1975; Lawson et. al., 1978; Walker et. al., 1980).

Any comprehensive theory of instruction must be concerned with how to optimize the acquisition, organization, and retrieval of new knowledge. Ausubel recognised as early as 1960, that making new knowledge meaningful to the learner is important for optimizing acquisition, organization and retrieval, and it has become widely accepted that (Ausubel, 1968) this is accomplished primarily by relating new knowledge to what a student already knows. Ausubel stresses the significance of the principle called subsumption in his theory. According to this, meaningful learning takes place when a new idea is subsumed into a related structure of already existing knowledge. This has many implications to instruction. The first principle involved in this is the importance of providing the learner with a meaningful structure before he attempts to learn a new principle. A second principle is that any subject has to be presented by progressive differentiation of content and the most general and inclusive ideas first and the most detailed and specific ones later. The third principle involved in Ausubel's theory is called consolidation. This means the insistance on the mastery of an ongoing lessons before new material is introduced. The fourth principle is integrative reconciliation which means that new ideas, once introduced need to be deliberately related to old ideas, significant similarities and differences pointed out, real or apparent, inconsistencies reconciled.

Ausubel's idea of advanced organisers comes from his view that learning and retention of unfamiliar but meaningful verbal material could be facilitated by advance introduction of relevant subsuming concepts. Ausubel advocates that the organizers appropriately relevant and inclusive introductory materials that are maximally clean and stable - are to be introduced in advance of the learning material itself and are also presented at a higher level of abstraction, generality and inclusiveness; and since substantive content of a given organizer or series of organizers is selected on the basis of their appropriateness for explaining, integrating and interrelating the material they precede, this strategy increases the organizational strength of the cognitive structure. The principal function of the organiser is to bridge the gap between what the learner already knows and what he needs to know before he can successfully learn the task at hand. (Ausubel, 1968). A good advance organizer provides an organised conceptual framework that is meaningful to the learner to relate the concepts in the instructional material to elements of the framework. The development of an organizer depends partly on the nature of the materials, the characteristics of the learner and the mode of delivery. Advanced organizers have turned out to be both good and bad in practice. Unfortunately, it is still not possible to offer a foolproof definition of what constitutes an advanced organizer (R.E. Mayer, 1979). Researchers utilizing the work of Ausubel (Novak, 1977) argue that relevant prior knowledge is the most important factor in learning science content as well as in using that knowledge to solve problems. However, limitations are many. The theories discussed by Ausubel (1968, 115-123) including his own theory of subsumption (1968, Ch.3) does not apply to intellectual skills and they help more for verbal learning (Gagne, 1970). But without any doubt Ausubel has contributed in his own way to the science instruction.

2.3 Recent Contributions from Theories of Instruction

Theories of instruction attempt to relate specified events in instruction to learning processes and learning outcomes drawing upon knowledge generated by research and theory. Often instructional theories are prescriptive in the sense that they attempt to identify conditions of instruction which will optimize learning, retention and transfer. The researches related to this section has generated lot of piecemeal knowledge about method or optimizing desired learning outcomes. What is needed most at this point is the development of an 'instructional science' with a common knowledge base that integrates knowledge or findings from all theoretical perspectives (Gropper, 1983; Reigeluth, 1983).

The Gagne-Briggs (1979) theory of instruction based on the work of Gagne (1977) begins with a taxonomic framework of learning outcomes considered essential for an understanding of human learning as it occurs in instructional settings. These learning outcomes are : (a) verbal information, (b) intellectual skills, (c) cognitive strategies, (d) motor skills and (e) attitudes. The first three of these correspond with those in psychology of cognition and learning. Specifically these events are conceived as taking place in an approximately ordered sequence as follows : (a) gaining attention, (b) informing the learner of the objective, (c) stimulating recall of pre-requisites, (d) presenting stimulus material, (e) providing learning guidance, (f) eliciting performance, (g) providing feedback, (h) assessing performance, (i) enhancing retention and transfer. Several characteristics of this prescriptive instructional model make it distinct from others. The process of learning assumed by Gagne-Briggs theory are those included in the information processing model of learning and memory, as described by Atkinson and

Shiffrin (1968) and employed in essential aspects by several other memory theorists (Greeno and Bjork, 1973). It is the contention of this theory that traditional factors in learning, such as continguity, exercise and reinforcement, although of undoubted relevance, are much too general in their applicability to be of particular use in the design of instruction. Instead, internal and external conditions must be specified separately for the learning of verbal information, for intellectual skill, and for each of other categories of learned capabilities. Instruction is defined as a set of events external to the learner which comprise of five kinds of learning outcomes, including attitudes and motor capabilities. The theory is comprehensive in the sense that it attempts to include all kinds of learning outcomes to which instruction is usually addressed.

Bloom's model of mastery learning (Bloom 1971,1981) which is derived in part from the model described by Carroll (1963) includes major variables: aptitude (time required to learn), quality of instruction, ability to understand instruction perseverance (time the learner is willing to spend in learning) and opportunity (time allowed for learning). In more recent accounts (Bloom, 1976) the theory has come to give primary emphasis to alterable variables for schooling which are : (a) cognitive entry behaviours, (b) affective entry characteristics of students and (c) a number of specific factors making up the quality of instruction. Among the most prominent contributors to instructional quality are student participation and corrective feedback. Bloom's theory also proposes that individual differences in achievement can be reduced, in their amount of variation, over time occupied by successive learning units. The low achievers may be given high quality instruction with corrective feedback and may be permitted to take more time to reach mastery. The method, the theory says, can convert low achievers to high achievers. While each alterable variable is considered to have a causal effect on achievement, the theory puts forward no hypothetical learning processes which seek to explain the action of instructional variables on learning and retention.

Merril and his collaborators (Merril et al 1977, 1979, Reigeluth et al 1978) have tried to give a prescriptive theory aimed at instructional quality. They consider that quality of instruction depends upon the adequacy and consistency with which the instruction is represented in objectives, tests and instructional presentation. The theory holds that there are three levels of representation of what has been learned and what is to be tested :

(a) concepts, (b) principles, and (c) procedures. Within the confines of proper 'presentation forms', suggested by Merril, instructional presentation can be more or less adequate depending upon what strategies are used. Presentation of concepts, for instance, includes the following : (a) providing immediate informative feedback, (b) isolating the presentation form by separating it from other material and clearly labelling it, (c) giving helps such as mnemonic aids, attention focussing, algorithms, (d) providing an adequate sampling of instances, (f) using a range of difficulty levels, (g) arranging instances so as to favour matching of common properties. Some instructional strategies suggested by this theory have been empirically verified by such investigators as Tennyson et al (1975) and Markle and Tieman (1974) among others. While all suggestions appear to be have sound bases when judged against known research findings, specific design of strategies for the three categories of outcomes has not yet been described. But such strategies provides a check list of points while designing instruction.

An Elaboration Theory of Instruction has been described by Reigeluth and his associates (Reigeluth 1979, Reigeluth et al 1978, Reigeluth & Rodgers 1980). While

Merrils instructional theory dealt with 'micro' strategies for the design and presentation of the material within a topic, this theory intends to deal primarily with 'macro' strategies for organizing instruction, those that pertain to the sequencing and interrelating of topics within a course. The general theoretical conception of instruction is compared to viewing a scene with the use of zoom lens. Beginning with a wide angle view, one gradually increases the details and complexity of parts by zooming in on them. Periodic review and synthesis are considered important aspects of the theory. When instructional sequences are being designed, the presentation of an epitome is followed by the teaching of an operation, and this in turn is followed by what is called the "expanded epitome". An instructional sequence is designed in this manner would have the following steps (Reigeluth and Rodgers 1980):
(a) select all the operations to be taught (by performing task analysis), (b) decide which operation to teach first, (c) sequence all the remaining operations, (d) identify the supporting content, (e) allocate all content to lessons and sequence them, (f) sequence the instruction within each lesson and (g) design instruction on each lesson and expanded epitome. Obviously this theory incorporates a number of ideas from other prescriptive models. It utilizes both

information processing task analysis (Merril 1976) and learning hierarchy (Gagne 1977, a,b) and it claims to use to advantage the idea of subsumption (Ausubel et al 1978). It also accepts the idea of micro-strategies in Merril's theory for component lessons. The theories outstanding novel contribution appears to be the prescription of frequent 'zooming' from most general view of the comtent to be learned, to selected specific details, making provision for the learning or recall of prerequisites, returning to the general view once more, with provision for review and practice.

The Neo-Piagetian theory of instruction proposed by Case (1978 a,b,c) is based on the theory of intellectual development which holds that the sequence of behaviour that emerges during each of the major stages of intellectual development (Piaget 1970) depends upon the increasingly complex cognitive strategies. The succession of strategies within each stage depend on acquiring of strategies through experience or through encounters with planned instruction and gradual increase in the size of working memory. Case proposes that this increase in working memory results from automatization of basic cognitive operations of which learner is capable. Implications of this developmental theory for instruction have been phrased in terms of instructional design. The first step is to identify the goal of the task to be performed. Then a series of operations are mapped out by means of which learner may reach the goal; it is suggested that personal introspection or expert protocols may be used. The second step in instructional design is to assess the student's current level of functioning, discovering by clinical method or otherwise how the 'novice' approaches the task. Instructional design is then undertaken including exercises that demonstrate to the learner the inadequacies of his current strategy and providing explanation of why the correct strategy works better. This is followed by presentation of additional examples using the new strategy, and practice with them. Throughout the process of developing instruction, careful attention is paid to minimizing cognitive complexity, in view of learners' memory power as a limiting factor. A distinctive feature of this instructional theory, one which retains the Piagetian tradition, is its proposal that existing cognitive strategies of uninstructed students be discovered, analyzed, and used as a basis for contrast with the more efficient executive procedures to be newly taught.

Collins (1977) describes a theory of Socratic Tutoring which he considers useful in imparting new knowledge to new problems and situations. The theory is conceived to be particularly helpful in developing an intelligent computer assisted instruction (CAI) system (Collins et al 1975). The teaching dialogue of such a system is best characterised as a blend of diagnosis and correction strategies, the tutor probes the student's understanding and uses errors as clues to misconceptions. In this, the tutors questions are guided by a number of rules beginning with "ask about a known case, if it is the start of a dialogue or if there is no strategy available" (Collins 1977). Analysis of these suggest that students learn new information, make functional inferences and learn to reason about the problem presented in tutoring situation. The theory allows the students while doing the routines to practice reasoning strategies relevant to new content being learned.

The theory of instruction proposed by Rothkopf (1981) emphasises empirical variables such as those suggested by Carroll (1963), but in addition provides a theoretical rationale for their inclusion as factors which promote learning. First, there is a disparity between the defined performance outcome and the instruction itself, whether the latter is verbal or in some other form.

Disparity thus describes the kind of transformation the student must perform with the instruction in order to achieve a successful performance. This means specifically that the students must have the ability to engage in suitable mathemagenic activities (Rothkopf 1965, 1971). Second, these activities depend on the learner, but can be modified by various instructional means. A third set of factors consists of the intellectual capabilities of the students. The difficulty of processing instructional information is reduced when the elements of these capabilities are familiar which is derived from the previous instruction - relevant experience of the learner. Rothkopf describes a molar theory rather than a molecular one. The concepts of this theory are not differentially applied to different kinds of learning outcomes; otherwise, they show considerable resemblance tothose of other instructional theories of cognitive variety.

The instructional theory elaborated by Markle and Tiemann (1974) and Markle (1978) is applied to a number of learning outcomes categorized as psychomotor, simple cognitive and complex cognitive. The last of these includes concepts principles (rule application) and strategies. The theoretical concepts included in this theory are primarily three which are familiar in the field of instructional design : (a) active responding, (b) errorless learning and (c) immediate feedback.

Scandura's (1977a,b; 1980) instructional theory called as structural learning theory deals with intellectual competency. The competence underlying any particular problem domain can be represented in terms of finite rules which can be considered to have three features: (a) a set of conditions to be satisfied by inputs, (b) a set of conditions characterising the outputs the learner expects the rule to produce and (c) an operation or procedure which when applied to the content domain generates a unique output. Expanding upon this conceptual basis, this structural learning theory proceeds to deal with the control process called "goal switching" and its application to the utilization of rules and higher order rules. When the learner fails to achieve the problem solution the goal switching process directs the search for higher order rules which generates other potential solution rules. Structural learning theory has particular implications for cognitive processing load and speed, for analysis and assessment of individual learner competence and accordingly for the systematic design of instruction aimed at establishing problem solving capability (Scandura 1977a). This theory filled with examples and predictions in mathematical terms, may best be viewed as a theory of rule learning and rule application.

Landa's (1976) theory on algorithmization of instruction argues for the definition and use of algorithms for the purpose of assuring instructional effectiveness and efficiency. The basic properties of algorithms are : (a) specificity which means that all actions of the user of an algorithm are unambiguously determined by statement of rules; (b) generality implying that the algorithm is applicable to an entire set of problems belonging to a particular class and (c) resultivity indicating that the algorithm is always directed toward achieving the sought after result. These characteristics appear clearly to equate algorithms with rules, or with rule systems embodied in procedures. Landa's model of effective instruction calls for systematic analysis of the learning task, and precise definition of learning procedures (rules) to be taught and the presentation and exemplification of these procedures to the student in the clearest and most direct possible manner. To Landa, algorithms are the basic aspects of instructions, which pave the way for heuristic learning and creative thinking.

While continuing to be cognizant of evidence indicating the gradual nature of intellectual development (Karplus 1980, Lawson 1980) some researchers seek to interpret and apply evidence that will improve students ability to think in ways related to the reasoning exhibited by scientists. Lawson and Lawson (1980) include in their instructional recommendations- (a) testing the truth of categorical propositions, (b) testing hypothetical causal propositions and (c) strategies of hypothetico-deductive reasoning. In general, most investigators of this tradition suggest concrete use of problem solving exercises representing particular kinds of reasoning to support the development critical and creative thinking.

Supes (1978) discusses the idea of "global models" of instruction, so called because they deal with such variables as students mean rates of progress through a topic course. At the same time such models ignore the details of responding that are traditionally of interest to the instructional psychologist. Findings of global studies may be used to indicate, for example, the proportion of time which should be devoted to the teaching of arithmetic at the fifth grade level or within an arithmetic course how much the time should be devoted to computation and how much time to problem solving. The aim of such investigation is to permit the use of the model for optimization of outcomes. For investigators who seek to explore global predictions for optimizing various aspects of instruction and curriculum patterning, these models appear to be of immense use.

The studies reviewed in this section is of very important for any instructional designer. In each an instructional problem existed - how to identify and sequence content for intellectual skills, how to improve the effectiveness of an instructional system or how to enhance the instructional effectiveness of teachers. In each project the investigators drew upon the existing research base in order to develop a solution. Not all the theories discussed above are complete in all aspects; but each one has its own contribution to make towards a general theory of instruction and instructional design.

There are a number of ways in which research findings of the type mentioned so far can influence practice. One can gain some ideas from a particular study from a learning theory or its principles or instructional theory which can be subsequently incorporated into educational practice. Individualized system of instruction, systems design in instruction and more recently computer based instruction have had their roots in these theories. For instance instructional systems design was originated through the working of Gagne (1962), Lumsdaine (1964), Gagne and Briggs (1977a), Branson (1977) which includes process of planning the instructional setting, the delivery system and all the instructional hardware and software including teachers manuals. Whatever be the type of approaches developed in the design of instruction the findings from the theories of learning and instruction have a great deal to contribute. Gagne believed that the best thing an instructional designer can do is to find out the conditions under which learning takes place. In fact that will dictate the ideal situation required for acqusition of various capabilities. To have a better understanding of what Gagne has said an overview of his conditions of learning is presented in the next section.

2.4 An Overview of Gagne's Conditions of Learning

The previous sections of this chapter have highlighted some of main contributions from general theories of learning and a few of the recent contribution specifically applied to instruction. This section is completely dealing with Gagne's conditions of learning in its theoretical perspective and its contribution to the instructional design through task analysis and learning hierarchies. Gagne has immensely contributed to science instruction and as such Gagne's views on science processes are also extensively discussed.

2.4.1 Gagne's Theoretical Position

Gagne's psychological position is slightly eclectic, centred upon behaviourism, somewhat loosely defined, and it contained only marginal overtones gained from Gestalt field family of learning theories. In the development of his psychological position, along with taking major contributions from members of behaviouristic family, Gagne draws from minor contributions from several other psychological approaches. Gagne (1963, 1968) although still working within the behaviourist tradition managed to overcome three major weaknesses of the behaviourist instructional technology. He (1963) reviewed a number of failures of behaviourist technology in military training applications to formulate his own idea on learning.

Behaviourist instructional technology had three major weaknesses (Case,R. and Bereiter, C.,1984) which Gagne tried to overcome or modify. The first was the principle of reinforcement, the most important aspect of behaviouristic technology, although obviously important in human learning, turned out to be less powerful than the behaviourist theory had implied. The second, because the behaviourist theory dealt exclusively with observable behaviours, in some cases it provided a very awkward way of specifying objectives of learning (Bereiter, 1968). They had to rely on verbs describing tests rather than processes. Thus the behavioural objectives many times have turned out to be not really specified behaviour that was intended to be taught but specifications for the tests to be applied (since this could be done without mentalistic terms). The third weakness, however, was that behaviourist technology provided no methods for carrying out a key step in its own programme. How does the educator identify behaviours that are steps in the direction of the desired terminal behaviour and how does the educator determine that these steps are small enough that they can be successfully negotiated by the learner? In practice the behaviourist educators had to rely on conventional instructional wisdom for the design and sequencing of instructional steps.

Gagne concluded from his studies that in most training situations the key problem was identifying in sufficient details what was to be taught. Once this has been adequately determined, the problem of how to induce the desired changes in behaviour are usually minor. Since reinforcement techniques apply only to the how of instruction rather than to what, they cannot deal with the central problem of teaching. Thus, Gagne first shifted the focus from reinforcement to the nature of the behaviours themselves. Second, he recognized a variety of learning which included not only the learning of physical behaviours and S→R connections but also the learning of concepts rules and problem solving in intellectual skills and cognitive strategies and executive strategies. Gagne gave special attention to the intellectual skills central to the purpose of schooling. He proposed that in learning these skills, the most important thing, was not reinforcement and practice but rather the systematic building of higher level skills upon lower level skills. This brings us to his third and most important attempt to overcome the limitations of behavioural technology.

Gagne for his work (1965) has drawn principles from both behavioural and cognitive literature. Gagne recognizes that his limitation to provide a means for specifying the learning conditions that are necessary for one to attain the highest and most complex varieties of human performance such as those displayed in invention or aesthetic creativity. The most that he offers in this regard is that "the production of genius is not based on 'tricks', but on the learning of a great variety of specific capabilities".

Gagne sets himself to the task of selecting those aspects of psychology which will help in designing better instruction. Learning must be linked to the design of instruction through consideration of different kinds of capabilities that are being learned. In other words, external events that are called instruction need to have different characteristics, depending on the particular class of performance change that is the focus of interest. Presence of the performance does not make it possible to conclude that learning has occured. It is necessary to show that there has been a change in the performance. The incapability for exhibiting performance before learning must be taken into account as well as the capacity that exists after learning. It is in fact the existence of prior capabilities that is slighted or even ignored by most of the traditional learning prototypes and it is these prior capabilities that are of crucial importance in determining the conditions required for subsequent learning. Learning takes place when a stimulus affects the learner in such a way that his performance changes from a time before being in that situation to a time after being in it. The change in performance is what leads to the conclusion that learning has occured. (Gagne 1965).

The strategy which Gagne adopted is to assume that there are several different types of learning some of which are subordinate to and components of other, more complex types. Gagne has drawn eclectically from many diverse and sometimes possibly incompatible theories in his search for a comprehensive taxonomy of learning types. He contends that he is not suggesting a new theory of learning. Though Gagne does not claim its theoretical importance, Hilgard and Bower (1966, p.569) suggest that he may be understating the significance of his taxonomy as "it may be the beginning of a unified theory of learning". Gagne's pivotal idea on learning is that learning of any new capability requires prior learning of the subordinate capabilities that are involved in the new capability. For example, any one, learning a higher order rule requires prior learning of simpler rules. Thus, any significant learning that one is to acquire may be analysed into a progression of subordinate learnings which will in turn help in the acquisition of various learned capabilities.

2.4.2 Learned Capabilities

Initially we must focus on what is learned, before discussing the conditions under which learning occurs. Learning conditions are not the same for different varieties of what is learned. Therefore, it is necessary to distinguish as clearly as possible the types of outcomes that learning has- the varieties of learned capabilities. These varieties must be observed as human performance. Gagne discusses five major categories of capabilities that human beings learn. These categories, which are intended to be comprehensive, are - (1) verbalizable information, (2) intellectual skills, (3) cognitive strategies, (4) motor skills and (5) attitudes.

(i) Verbalizable Information

Every student should be able to describe or state an event, a situation or an idea - the purpose of the learner's act is to tell information. Being able to state ideas is a learned capability called verbalizable information or simply verbal information. Verbal information is the knowledge about facts about common things. It is an important capability in the sense that it keeps the learner informed. The vast body of knowledge of information people possess is verbal knowledge or verbal information. It consists of facts or beliefs which are stored as propostions, e.g., there are seven days in a week; clinical thermometer is used for measuring human temperature; and so on. These verbalized knowledge are very important for a science or mathematics student. The learning of an increasing store of meaningful propositions is considered by Ausubel (Ausubel, Novak and Hanesian, 1978, p.238) to be of critical importance to intellectual development. Problem solving investigators of the information processing view often emphasize the role of general knowledge in successful problem solution. The representation of the problem space (Newell and Simon 1972) frequently can be shown to depend upon specific knowledge available to the individual.

Whereas verbal information consists of a student merely stating the desired information, intellectual skills involve the student knowing how to perform an act as contrasted with his knowing that certain conditions exist. (Gagne 1974b, p. 55). In school, the child learns to distinguish, combine, tabulate, classify, analyse, interpret etc. with respect to many concepts, rules or problems. The child interacts with the environment through all these actions. The general capability involved in all these can together be called intellectual skills. Every individual learn many kind of intellectual skills; simple and complex. The contents of school science and mathematics are virtually full of intellectual skills. Gagne emphasizes that intellectual skills are not units of verbalized knowledge. Thus, he states that in deriving them one must carefully record statements of 'what the individual can do' and just as carefully avoid statements about 'what the individual knows'. Gagne does not completely discard verbalized knowledge; but he does think that most important things learned in the school are intellectual skills and not verbalized knowledge (Gagne 1974b, p. 234).

(ii) Intellectual Skills

In school the child learns to distinguish, combine tabulate, classify, analyse etc. They learn many concepts and rules. Thus the child interacts with the environment using all these capabilities. These type of learned capabilities are called intellectual skills. School learning in particular consists in the acquisition of intellectual skill capabilities as a major objective. Intellectual skills are being dealt in detail in the next section as this is our focus of interest in the present study.

(iii) Cognitive Stategies

Cognitive strategies are a special kind of capabilities that govern individuals own learning, remembering and thinking behaviour. The phrase 'cognitive strategy' is usually attributed to Bruner (Bruner, Goodnow & Austin, 1956); Rothkopf (1968) has named them "mathemagenic behaviours";

Skinner (1968) called them "self management behaviour". Cognitive strategy is an internally organised skill which governs the learners' own behaviour they apply rather generally to various skills that are used by the learner to manage the powers of attending, learning, remembering and thinking. The internally organised nature of cognitive strategies means that conditions of instruction can have only an indirect effect upon their acquisition and improvement. Cognitive strategies are acquired, presumably over a period of years and refining such strategies, the student becomes an increasingly skillful independent learner and independent thinker. As goals of education, cognitive strategies are often accorded the highest priority by educational philosophers (Gagne, 1974b). O'Neil (1978) describes that cognitive strategy is composed of two parts: (a) a cognitive orienting task and (b) one or more representational, selectional, self directional capabilities. The term 'orienting task' refers to designate methods for inducing the student to perform particular kinds of operations. Thus these cognitive strategies regulate or modulate their internal process of (i) attending and selective perceiving, (ii) coding for long term storage, (iii) retrieval and (iv) problem solving.

(iv) Motor Skills

We learn a great many motor skills in early life, such as those involved in dressing, eating etc. which stay with us throughout our life, though, as the child advances the emphasis in school learning progressively shifts to tasks of a more intellectual cast. The acquisition of qualities of action precision and timing of muscular movements is the primary requirement in motor skill learning. The performances exhibited by a novice and an expert differ most apparently in the observable degrees of precision, smoothness and timing. This apparent change in the motor performances are progressively mastered. The course of learning for a motor skill depends, among other things, upon the task to be learned : the nature and the length of the procedure, the type and number of part skills that compose the total skill. 'If the component motor acts of a total skill have been previously learned, only a minimal amount of time have to be spent in putting them together in a procedural sequence' (Gagne 1977, p. 217). The obvious feature of motor skill is that they improve with practice. 'Practice makes perfect' is not a bad principle so far as motor skills are concerned; but the same requirements for practice do not apply to the learning of other capabilities such as intellectual skills, information and attitudes (Gagne 1977, p. 228).

(v) Attitudes

School learning also provides for the establishment of internal states that influence the individual's choices of action which are called attitudes. Attitudes do not determine particular actions; rather they make certain classes of individual action more or less probable. Gagne refers here to the definition of Allport's (1935, p. 810). "An attitude is a mental and neural state of readiness, organized through experience, exerting a directive or dynamic influence upon the individual's response to all objects and situations with which it is related" (Gagne 1977, p. 231). Attitudes are learned by most people incidently, rather than as a result of pre-planned instruction. In fact, planned objectives of attitude learning, whatever to be their specific nature, should form definite components of educational programmes for children and adults. Gagne refers to the human modelling studies of Bandura and his associates (Bandura, 1969) and suggest that human modelling forms one of the most dependable sets of events that has been found to produce changes in attitudes (Gagne 1977, p. 245). Although attitudes may be formed and changed in several ways, the principles of reinforcement contingencies can usually be readily recognised as playing an important part in attitude learning. The kind of personal action that lead to success are most likely to be those towards which individual displays a positive attitude. In many educational situations a desired positive attitude may most readily be assured by making it possible for the student to achieve success.

As Gagne has stated most important aspect of school learning is the acquisition of intellectual skills and the present study focusses exclusively on it. Therefore, a detailed review of Gagne's views on intellectual skills and the researches related to this aspect are presented in the following parts of the chapter.

2.4.3 Intellectual Skills

Stored in the long term memory are capabilities that make it possible for the individual to carry out various processes using symbols which include not only numerical operations but also the language used to represent the child's environment. Intellectual skill is a general name for such capabilities as identifying a class stimuli (concept capability), rules linking them (rule capability) and using them to solve problems (problem solving capability). Possing an intellectual skill means 'knowing how' as opposed to 'knowing what'. We learn many kinds of intellectual skills simple and complex. Most of the school science especially physics in full of concepts and rules and their applications to solve problems. This is true in the case of mathematics and even language learning (e.g., English Grammar). These intellectual skills seems to be the most important a student acquires during his/her schooling.

Involvement of intellectual skills in the performance of both concrete and formal operational tasks has been shown in many piagetian studies. A number of studies for example have demonstrated that prior learning of specific intellectual skills exhibit positive transfer to conservation tasks (Bucher and Schneider, 1973; Gelman, 1969; Wallah, Wall and Anderson, 1967) as well as to other problem solving tasks. (Bern 1967, 1970; Lowery and Allen, 1969). The typical finding in such studies is that prior learning of relevant concepts and rules bring about successful solution of conservation tasks in children regardless of their age.

Many of these studies mentioned have started out to discover conditions that may be employed to facilitate what is conceived (in Piaget's terms) as a transition from preoperational to concrete operational thought, or from concrete operational thought to formal operations. The usual findings has been that the desired post instructional performance depends upon the acquisition of intellectual skills (Gagne 1980). For instance, the successful reasoning about relative volumes of cylinders can be accomplished when the learners have acquired the rules relating cylindrical volume to base area and height. Thus, scientific reasoning also can be developed only through the acquisition of specific intellectual skills.

A typical intellectual skill which can easily be noted is a rule. For example, let us take Ohm's Law : V = IR where Voltage (V) is written as a relationship between current (I) and resistance (R). Before one can master this rule, a thorough understanding should be developed about the concepts voltage or potential difference, current and resistance. The mastery over these concept will also depend upon how one can discriminate between current and voltage. The knowledge about these concepts and rules can be used in solving problems related to parallel and series wiring etc. Thus we see that rule learning is typically a matter of combining simple component skills into a new pattern. A complex rule may usually be composed of many simpler rules, each of which may in turn may be further analysed into previously learned components.

For the learning of intellectual skills the most important internal condition is the recall of pre-requisite skills which are components of the new skill to be learned. Intellectual skills have several varieties increasing in complexity from discriminations to concepts, rules and higher order rules in problem solving process.

(i) Discrimination Learning

The capability to discriminate between objects or events based on their identifiable attributes is very important in school learning. A child learns to discriminate between a football and a tennis ball by its size or colour or weight; discriminates between a chalk and pencil by its size, shape, use etc. They look for discriminable attributes of these objects for identification and recognition. The child learns to respond differentially to these characteristics of objects that serve to distinguish them from one another - shape, sizes, colours, sound, symbols, etc. Learning difficulty may increase with similarity in attributes but the establishment of association leads to better discrimination. In fact, multiple discriminations are frequently required in school situations.

Pavlov trained dogs to respond to a given note by salivating on providing food following the sound of this note. The dogs then learned not to salivate when other notes were sounded. The latter was done by sounding another note and then not providing food - an extinction process. Pavlov studied the capacity of dogs to discriminate using various notes.

A discrimination is established through selective reinforcement of correct versus incorrect responses to the stimulus (object or event). When attitudes attributes become too many discrimination becomes complex and difficult discrimination learning depends to a greater extent upon the contrast practice when the correct features are amplified and incorrect ones suitably distinguished.

(ii) Concept Learning

The learning which makes it possible for the individual to respond to things or events as a class, results in the kind of learning outcome called a concept. Concept learning has been defined differently by various people. Before presenting Gagne's position in this, it should be worth mentioning the definitions given by a few others also.

Berlyne (1965), to whom Gagne also has referred to, believed that a concept is formed when overt behaviour comes to depend on certain properties of a stimulus pattern while disregarding other properties. It means forming, what logicians and mathematicians call, an equivalence class of stimulus situations, which share some characteristics but are distinct in other respects, and performing the same response to all members of the class (p. 45). Kendler (1964) defined concept learning as the acquisition of a common response to dissimilar stimuli. But he also went on to say that concepts are associations and that they function as cues or mediators of learned behaviour. This conception of a concept is basically similar to that of Osgood (1953) who emphasized the acquisition of a mediating process that can be detached or abstracted from the stimulus objects with which with it may initially have been associated. From a somewhat different point of view, Caroll (1964) defined a concept as an abstraction from a series of experiences which defines a class of object or events.

Although these definitions have been expressed with different language compositions they all have considerable agreement in many respects. Concepts, according to, Gagne (1966) has three general properties in common :

(i) A concept is an inferred mental process.

(ii) The learning of a concept requires discrimination of stimulus objects.

(iii) The performance which shows that a concept has been learned consists in the learner being able to place an object in a particular class to which it belongs.

Gagne (1970) indicates that learning concepts must proceed from discrimination of the sensible characteristics of objects and events to the formation of concepts. He argues that "Physical characteristics of objects need to be observed and discriminated with systematic thoroughness using all the externally oriented senses and that all the differential attributes of objects previously learned as discriminations need to be used for establishing concepts".(1970, p. 258). Discriminations are pre-requisite for the learning of concepts. Let us take the example of concept formation of a straight line. The child who has to master the concept of a straight line will have to differentiate it from curved lines. In the first stage the child learns to discriminate between lines which are straight and those which are not. In the next stage he is able to locate a straight line among the lines with various other variations. The contrast practice is to be continued till the learner shows convincingly that he discriminates 'straight' from 'not straight'. Thus, there is a generalization in the discrimination learning. In stage three, the child learns about the irrelevant dimensions of straight lines or non-straight lines like thick, thin, orientation etc. Once this is over, the learner has 'abstracted' the relevant object quality. He has acquired the concept of straight-ness.

A concept may also be learned through verbal instructions. A concept may be acquired by means of the contrast practice procedure employing a succession of instances varying in their irrelevant dimensions. But this procedure is not necessarily typical when the learner can be guided by the language. Suppose the learner wants to master the concept 'whales', the concept may not be adequately formed as the child may not have encountered with such a situation. A concept which is inadequate in this sense is not incorrect and may even be perfectly adequate for many purposes. Many a time the verbal label makes it relatively easy to structure the situation required for concept learning. Conditions in the learning situation of a concept, then, are the following :

1. The related objects are presented simultaneously, or nearly so, with the requirement that the learner places them all in the same class.
2. New objects or events are presented, to which the learner must respond as he does to those in the concept.
3. Identification of additional instances of the concept must be required.
4. Reinforcement of correct responding should be promptly provided.

Gagne (1966, p. 90) while discussing the concepts categorizes them into two : (i) concrete concepts - concept by observation and (ii) defined concepts - concepts by definition.

(i) Concrete Concepts

Concept by observation is the simple of the two whose learning condition require observation of the actual object and a contrasting presentation of the positive and negative instances. When we look at the common objects that we come across, every now and then, we are confronting with concepts by observation. Green, blue, chair, table, circle triangle etc. are all concrete concepts. A child in the early childhood learns to look at things, discriminate them and acquires the concept capability by observation.

(ii) Defined Concepts

For Gagne, a defined concept is a rule that classifies objects or events. For example; a jungle is an area of land overgrown with masses of vegetation; a cousin is the son or daughter of an aunt or uncle. These concepts require verbal definitions if they are to be learned in an adequate form. Certain concepts can be learned both as concrete concepts and defined concepts. For example, a young child may have learned about straight line as a concrete concept. It is enough and more to serve the purposes for the child. But at a later stage he may re-learn it in a defined form as the shortest distance between two points.

Some concepts can only be learned in a defined form. Uncle is one such example. One cannot identify instances of the class cousin on the basis of their appearance by picking them out or pointing to them. An individual who has acquired a defined concept, has learned this kind of a rule, and is able to apply it to any instance of the class. For example, let us look at the definition of a bottle - a rigid container made to hold liquid. Gagne's analysis (1977, pp. 130-131) of the object definition has four essential parts :

(i) A thing - concept which is the super ordinate class (as 'container' to 'bottle').

(ii) A set of characteristics or features of this super ordinate concept (rigid).

(iii) A relational concept which tells what the object does or is used for ("holding").

(iv) Another thing - concept which is the object of this verb. ("liquid").

Defined concepts are a set of rules for classifying. When the learners have acquired such a concept, they are able to follow the definition in actually classifying some object or some relations. Defined concepts are usually learned by means of their definitions. Mostly the verbal statement is communicated to the learner.

(iii) Rules Learning

A rule capability is an internal state which governs one's behaviour, and enables one to demonstrate a relationship. A rule is composed of several concepts. Rules are obviously of many types, in so far as their content is concerned. They may be defined concepts serving the purpose of distinguishing among different ideas; and they may be capabilities which enable the individual to respond to specific situations by applying classes of relations.

For Gagne rules are super concepts. It is formed by a chain of concept according to certain relations. Rules are among the most commonest learning matter a science-maths student comes across. To Gagne even defined concepts are simple rules. As the number of concepts involved increases the complexity of the rule also increases. Acquisition of this intellectual skill depends on the recognition of the relationship between concepts.

For a student to learn about Boyle's law, PV = Constant,- a rule, he should have already learned the concept of volume, area, defined concept of force, pressure etc. An individual who possesses the rule as a capability can be observed to identify these component concepts and also to demonstrate that they relate to one another in the particular manner of the rule. In accordance with the theoretical position taken by Gagne, the individual must have learned these component concepts as prerequisites to learning the rule. Assuming that these concepts have been acquired, learning a rule becomes a matter of learning their correct sequence. Stating Newtons law does not mean that the student possesses the rule capability. The capability is acquired when he possesses a mastery over all the concepts concerned with the law and fully understands the relations between them. The conditions in the learning situation of a rule are :

1. the learner must be told what kind of performance, in general will show that learning has been completed.
2. the concepts that will make up the principle must be involved via instructions.
3. verbal cues must be provided that will hint at the principle, although not really stating it.

4. a question must be provided that requires the learner to demonstrate the principle.
5. the learner must be required to state the principle (it has not been demonstrated that this is absolutely necessary for learning, though it may be useful for later instruction).

As previously emphasised, it is only when prerequisite concepts have been mastered, a rule can be learned with full adequacy. Otherwise there is a danger that a rule or a part of it may be learned as items of verbal information. It is challenge for instruction to guide the learner to master the rule adequately, for there is a possibility,unfortunately, that inadequate rules may be learned (Gagne 1977, p. 140).

(iv) Problem Solving

Problem solving capability is the most important and the top of Gagne's learning hierarchy. It is the natural extension of rule learning with the learner taking an active part. Most of the processes in the problem solving activity take place within the learner. It is not simply a matter of applying previously learned rules but also a process that yields new learning. It is not the kind of drill dealing with routine situations but the process involved in finding solutions to novel problems. In the course, learner uses the previously learned rules as well as the cognitive strategies. What emerges from problem solving is a higher order rule a part of individual's capability.

One result of problem solving for the learner is the acquiring of a new and more complex rule (higher order rule) which combines some simpler rules. This happens with minimal verbal instructions as guidance. Problem solving as a method of learning requires that the learners discover the higher order rule without specific help. Presumably they thus construct the rule in their own manners joining many of the rules which they learned earlier.

Problem solving in novel situations consists of the use of discovery method. In problem solving the learner discovers combination of previously learned rules that he can apply to achieve a solution for a novel problem situation. He learns to combine the rules t he has already learned into a great variety of novel higher order rules. He may do this by stimulating himself and also by responding to various forms of stimulation from his environment. By means of the process of combining old rules into new ones, he solves the problems that are new to him and this acquires a still greater store of new capabilities (Gagne 1970, p. 59).

Great discoveries: Newton's laws of motion, Einstein's theory of relativity, Kepler's laws of planetary movement, Otto Han's discovery of nuclear fission etc. are all the result of intense problem solving activity. The solution of a problem is not through a sudden flash of insight, if insight is taken in its face value, because these insight are not developed in the case of a layman. These discoveries are the outcome of thinking of and about the problem for a long time and applying all the known rules. Conditions within the learning situation of problem solving are :

1. the principles that must be put together to reach a solution and the stimulus situation that poses the problem must be continuous - the learner must hold them in mind all at the same time.
2. there must be a recall of relevant principles.
3. verbal instructions should be provided to channel the learner's thinking, such as statements of the goal and the general form of solution.

The research studies have shown that successful problem solving requires the problem solver to have three kinds of capabilities (Gagne, 1980b). He or she must have concepts and rules (intellectual skills) relevant to the problem. As a second component, organised verbal knowledge is considered to be a vehicle for thought of a productive sort. And then there are cognitive strategies; research studies show this to be very specific in character, so they might best be called task strategies. By inference, there appears to be a kind of strategy called 'executive strategy' which is some what more general and enables the problem solver to choose wisely among task strategies. Out of these, which are the factors learnable? We have known much about intellectual skills which can be learned through a highly systematic progression from simpler to more complex skills. Organised knowledge is also highly learnable. Organised knowledge, here, means not only facts but also the intricacies involved in them. Problem solving strategies, though evidence is lacking at the present time, may directly be taught. They are strategies specific to the task. Thus we see that several important factors in problem solving are learnable and also instructable.

2.4.4 Task Analysis

A discussion on task analysis brings to focus contributions from three traditions. They are :

(a) associationist/behaviourist tradition (Thorndike, Gagne);

(b) work of Gestalt School (especially Max Wertheimer) and

(c) the Piagetian task analysis.

Thorndike, in his 'Psychology of Arithmetic' published in 1922, proposed the analysis of arithmetic task, in terms of specific connections, or bonds, between sets of stimuli and responses, and the organisation of instruction, to maximise learning of both the individual bonds and the relations among them. What is important about Thorndike's work is that he developed a concern not only with the laws of learning in general, but also with the laws of learning as applied to a particular discipline, arithmetic; thus starting a tradition of experimental work in instruction by psychologists.

Wertheimer's (1959) book, 'Productive Thinking' originally published in 1945, discusses several mathematical problems. Analysis of these tasks for Wertheimer consisted of displaying the problem structure on which algorithms are based, rather than analyzing actual performance. Wertheimer suggested that exercises could be introduced which focus students attention on certain aspects of the problem structure which should increase the likelihood of achieving insight. It is clear, though he did not suggest any schemes for instruction, that his notions imply the necessity of analysing tasks into components (Resnick, 1976).

Piaget's most important contribution to task analysis is probably his pointing out that there are important differences between children and adults in the way they approach certain tasks, the knowledge they bring to them and the processes for which they are capable of. Piaget is particularly attuned to changes in the internal structures available to people at different stages in their intellectual development. Explanation of a task performance for Piaget consists of descriptions of logical structures that underly it, and of the structures ontologically preceded and therefore in a sense gave birth to current ones (Resnick, 1976). Piaget's work makes it impossible to ignore differences between performance strategies of novices and experts. The neo-Piagetian work seems to investigate single tasks and look for competence versus incompetence rather than for stages of transformations of competence.

But when we take into consideration instructional relevance and instructability, Gagne's approach to task analysis comes to the forefront. His aim in task analysis is to facilitate instruction for which the subordinate capabilities identified are to be quite clearly described as instructable components. His tasks are drawn from school curricula and where formal validation studies of their analysis occur. They are to a large extent based on the effectiveness of actual instruction in the units identified (e.g., Gagne, Mayor, Garstens and Paradise, 1962).

Gagne's task analysis is based on his strong belief that success of instruction depends mainly on splitting a complex task to simpler tasks digestible by the learner. His hierarchical analysis is based on the idea that any particular higher order skill consists of several lower order skills. The resulting sequence is not a linear sequence but a branching net work of subordinate skills. It is better to start from the higher order skills going down to the simplest lower order skill as from problem solving ⟶ Rules ⟶ Concepts. Task analysis is done in that order, but the instruction in the reverse order. It consists of an analytical approach in preparing the instructional material while adopting a synthesizing method for instruction. Thus, Gagne's particular contribution within the behavioural perspective is a practical method for generating sequences of instructional tasks. In his general notion of transfer, inclusion of simple tasks in more complex ones, Gagne offers a strong suggestion for how to organize instruction for purposes of acquring higher order knowledge and skills. Thus, at a certain level the success depends on organizing the instruction. Thus Gagne's task analysis gives a highly practical approach to instruction compared to all others discussed previously.

2.4.5 Learning Hierarchies

Gagne's original model of hierarchical learning (Gagne, 1962) was that the ability to perform a complex task could be analysed into a net work of prerequisite capabilities or elements of knowledge. Gagne called these net works learning hierarchies. The important implications of learning hierarchies for classroom learning have been recognized and a number of validation studies published (Gagne, 1973; White, 1973). Gagne's theory which can rightly be included as 'training psychology' concentrates on conceptualizing performance goals or tasks breaking those tasks down into smaller subcomponent tasks, developing training components to ensure the achievement of each of the subcomponents and arranging the entire learning situation into sequences that ensure adequate transfer from one component to another and that prerequisite learning will be achieved before more advanced ones.

What is learned by a child in a school is an organized set of intellectual skills. The individual rules and concepts comprising such a set may have demonstrable relations to one another in a logic sense. They are also related each other in the psychological sense, that the learning of some are pre-requisite to the learning of others, just as concept capabilities are pre-requisite to learning of rule capabilities. These pre-requisites given by Gagne (1977, p. 34) are as shown in Fig. 2.1 .

Higher Order Rules in Problem Solving
(Require as Pre-requisites)
↑
R U L E S
(Which require as Pre-requisites)
↑
C O N C E P T S
(Which require as Pre-requisites)
↑
D I S C R I M I N A T I O N S
(Which require as Pre-requisites)
↑
Basic Forms of Learning
Associations & Chains

Fig. 2.1: Learning Hierarchy

The psychological organization of intellectual skills may be represented as a learning hierarchy, often composed largely of rules and concepts. Two or more concepts may be shown as pre-requisites to a single rule, two or more rules may be shown as pre-requisite to the learning of a super-ordinate rule. The entire set of rules and concepts thus organized in relation to one another forms a learning hierarchy that describes an on the average-efficient route to the attainment of an organized set of intellectual skills which represents "understanding of a topic".

Gagne (1968) claimed that the elements of learning hierarchies consists only of intellectual skills, and not units of verbal information. A validation study in graphical skills carried out by White (1974b) supported this claim.

Gagne's hierarchy of learning makes it possible to relate learning to the content of instruction in an orderly manner as shown in the Fig. 2.2 .

Stage by stage construction of conditions of learning based on previously acquired capabilities and looking ahead for what is to be needed by a following stage of learning places a great deal of emphasis upon pre-requisites. Learning hierarchies have been seen as valuable aids to

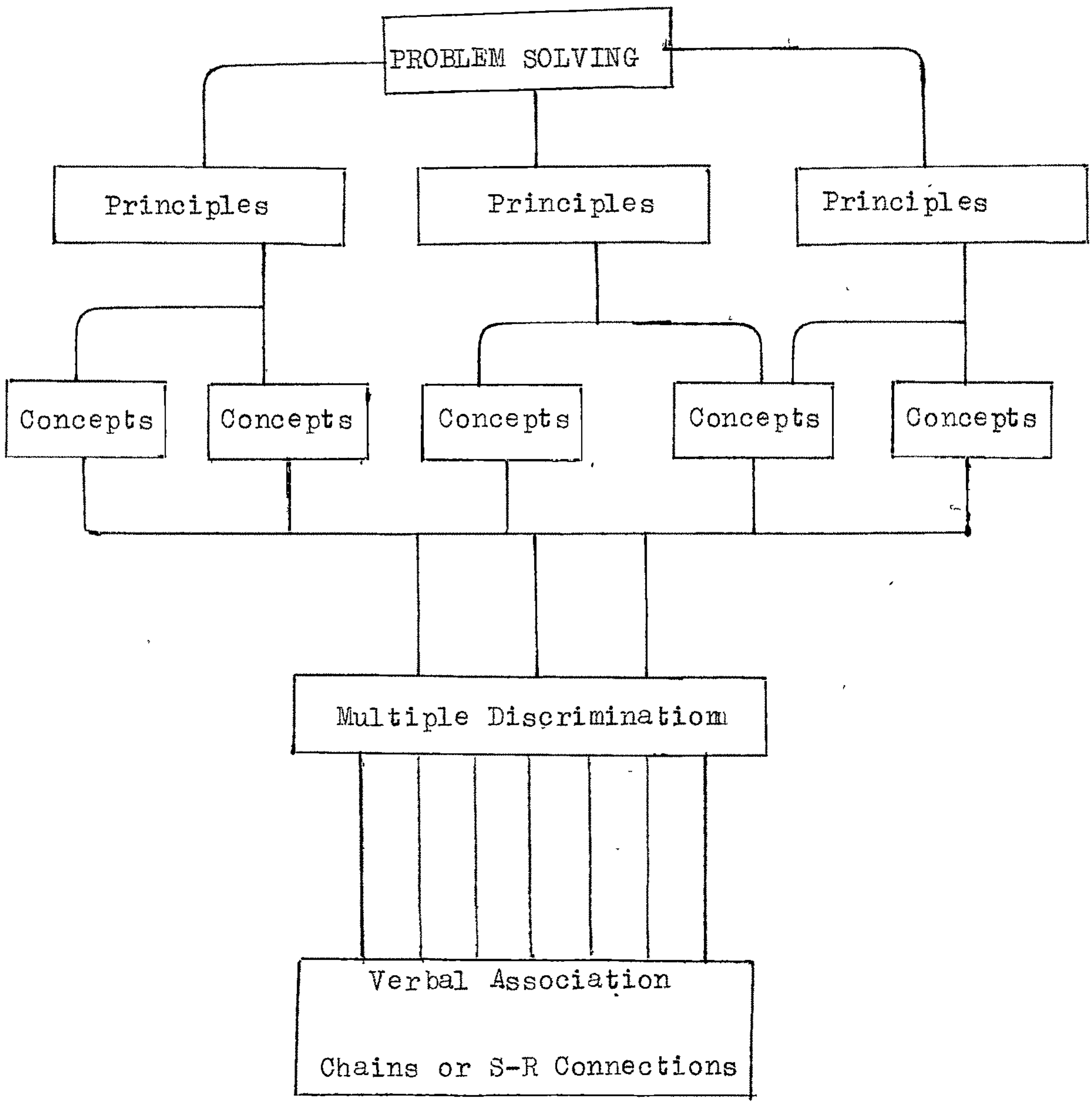

Fig. 2.2: Steps in Learning Hierarchy

the design of instruction and their employment in the development of instructional material is of immense value.

2.4.6 Gagne and Science Processes

Many educators have written voluminous things about science processes; but the view established by Gagne has been most influential (Finley, 1983). Scientific processes, scientific method, scientific inquiry are some of the terms which have been used by most of the science educators. For Gagne, scientific inquiry is the terminal objective of science education. He describes enquiry as 'a set of activities' characterised by a problem solving approach in which each newly encountered phenomenon becomes a challenge for thinking. Such thinking begins with a careful set of systematic observations, proceeds to design the measurements required, clearly distinguishes between what is observed and what is inferred, invents interpretations which are under ideal circumstances brilliant leaps, but always testable and draws reasonable conclusions (Gagne 1963, p. 145). In order to engage in this scientific method of enquiry, Gagne argues that students must be able to make inductive inferences and to judge when inferences are valid. These capabilities depend upon the students having learned a great deal of conceptual knowledge including broad generalizable principles and the component concepts of those principles; for Gagne knowing a rule (such as law of conservation of momentum) implies being capable of using it in a wide variety of situations in which it can be tested. Capability in rules depends on the mastery of concepts. Having learned a concept means to be able to respond in consistent ways to classes of objects or situations such as those where the concept might be involved (Gagne,1970).

For Gagne the pre-requisite knowledge of concepts and principles can be obtained only if the students have certain underlying capabilities - the science processes which are needed to practice and understand science. The processes must be stated from simple to complex. They are hierarchically organized with the ability to use each upper level process dependent on the ability to use the simpler underlying processes. Observation is considered to be the fundamental skill, by virtue of its position at the foundation of the hierarchy of skills, needed to discover the broad knowledge required to conduct enquiry. It is described as the process of observing likenesses and differences in single objects that vary in their physical characteristics as detectable by any of the senses (Gagne 1965, p. 3). Gagne views the science processes as the foundation for scientific enquiry.

They are the generalizable intellectual skills needed to learn the concepts and broad principles used in making valid inferences.

2.4.7 Philosophical Basis of Gagne's Views of Science Processes

The philosophical premise upon which Gagne's views of science processes are based is that knowledge develops inductively from sensory experience. There are two parts to this premise: one related to empiricism and the other to induction.

Gagne's views on science is consistent with the early empiricist view that knowledge is inferred from experience. This is evident in his description of observation as the fundamental skill of detecting the characteristics of objects via the use of sense. The fact that he places observation at the foundation of the learning of science concepts from which broad principles are formed is a further indication of the empiricist nature of his position (Finley, 1983).

Gagne (1970) indicates that learning science concepts must proceed from discrimination of the sensible characteristics of objects and events to the formation of concepts. He argues that "The physical characteristics of objects need to be observed and discriminated with systematic thoroughness using all the externally oriented senses". For example, the child must learn to discriminate green objects from yellow objects rough from smooth ones, and heavy from light objects. Discrimination of objects on the basis of sensory impression are the basis of forming concepts such as green, yellow, rough, heavy etc. that can be used independently of the actual objects. Moreover, concepts have to be learned before learning principles of which they are fundamental components. This view of concept formation and role of concepts in the statement of principles is nearly identifical with the views expressed by Hume (1974) who believed that the impressions and ideas to be components of experience.

The present view of science processes also include a commitment to induction. This component is evident in Gagne's (1973) description of scientific enquiry as a matter of solving problems by 'unrestrianed induction thinking' (p.153) and his description of how concepts are formed. The classical view of induction as the method of science was proposed by Francis Bacon in 1602, Robert Boyle in 1672, and Sir Isac Newton in 1687 (Burtt, 1949). The basic tenets of induction are that science enquiry consists of four stages :

(1) Observation and collection of facts,

(2) Analysis and classification of those facts,

(3) Inductive derivation of generalizations from the facts and

(4) Further testing of generalizations.

We see that there is a clear inductive inference from multiple sensory impressions to generalized idea involved in Gagne's view of concept formation.

Gagne's view of science as inductive is consistent with these classical positions. Enquiry begins with observation and proceeds through systematic organization of data, inductive formation of inferences and testing of those inferences such enquiry is based upon concepts inductively inferred from discrete sensory impressions that are similar and contiguous (Gagne, 1970).

2.5 An Instructional Design

The theoretical discussions presented in the previous sections and in particular Gagne's conditions of learning form the backdrop in which the present study attempts to design an instructional strategy to teach physics at the secondary level. What specific components should be included in an operational framework have been derived from the discussions given in the previous sections. In this section, a comprehensive design of instruction is being discussed explicitly along with brief explanations about its theoretical and practical implications. The explanations are mainly in line with Gagne's views; in relevant places these views have been compared and contrasted with the views of certain others essentially to bring in greater clarity.

A teacher, according to Gagne, is a designer and manager of instruction and an evaluator of student learning. Gagne thinks that the efficiency of learning can greatly be increased by providing systematic learning situations. These systematic approaches should be designed according to the principles established through research. The internal processes in learning can be influenced by external events in the form of environmental stimulation. Thus, instruction consists of the teacher planning and controlling these events. As the manager of instruction it is the teacher's job to plan, design, select, and supervise arrangements of these external events, with the aim of activating the necessary learning process (Gagne and Briggs, 1974, p. 44). Instructing, then, means arranging the proper conditions of learning that are external to the learner. These proper external conditions include the teacher communicating verbally with the student to inform him of what he (she) is to achieve, reminding him of what he already knows, directing his attention and actions, and guiding his thinking along certain lines.

When instruction is viewed, as a deliberate manipulation of the environment in order to get a person engaged into purposeful learning and to achieve the desired learning outcomes, then, proper planning of instruction becomes absolutely necessary. The instructional design should take into account the principles of learning, specifically the conditions under which maximum learning occurs. The theories of learning conditions for learning and some of these are controllable by the procedures of instruction. The instructional theories have tried to elaborate and explain these variables which can be controlled through various steps in instruction.

The instruction should consists of the following steps in instruction :

1. Framing learning objectives
2. Task analysis
3. Instructional sequences
4. Deriving learning hierarchies

5. Development of instructional material
6. Instructional management
7. Performance assessment and evaluation.

(i) Framing Learning Objectives

The identification and definition of proper learning objectives is an important step in the design of instruction. Objectives serve as guidelines for developing the instruction and for designing measures of student performance to determine whether the course objectives have been reached. Initially the aims of instruction are frequently formulated as a set of purposes for a course. These purposes are further defined and converted into operational terms by the process of defining performance objectives. These describe the planned outcomes of instruction; they are the bases for evaluating the success of instruction in terms of its intended or expected outcomes. Instructional objectives describe the class or performances that may be used to determine whether the implied human capability has been learned. Though the statement of objectives imply mastery (Bloom 1971), it does not specify any level of mastery. The objectives must be framed for each topic and each lesson. Robert Gagne gave a novel and practical direction to the instructional designers' endeavour when he pointed out that most behaviour can be categorized on the basis of the conditions necessary for its acquisition.

(ii) Task Analysis

Gagne (1970) amd Gagne & Briggs (1974) insist that a proper task analysis must be performed in order to sequence the events in a lesson. Gagne's division of intellectual skills can form the basis of a task analysis. Task analysis involves the breaking up of a complex task to still simpler tasks. The acquisition of a complex capability, then, is a matter of accumulation of capabilities through successive levels of complexity. Task analysis have come into rather widespread use among instructional designers, particularly in the field of mathematics and science education (White 1973). A typical model of task analysis developed by the investigator for the topic of the laws of friction is given in the Fig. 2.3 . The main steps involved are concepts, rules and problem solving as suggested by Gagne.

(iii) Instructional Sequences

It is very clear that learning cannot take place all at once; but in succession or one after the other. Thus, for effective instruction there is a great need to sequence the content so as to optimize learning. Previous researches have identified a number of ways in which varying the sequence of instruction can significantly affect the student response to

Task analysis

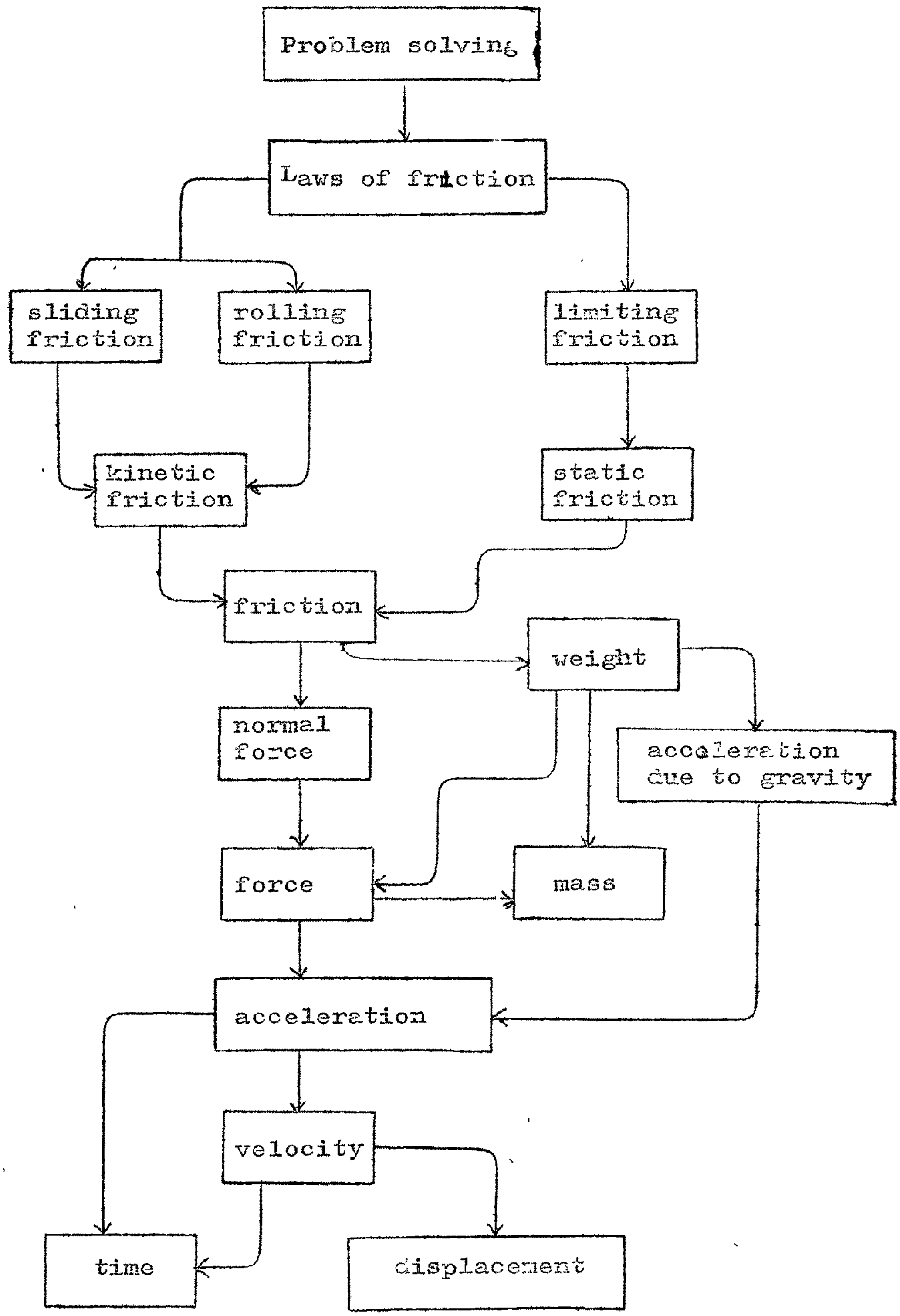

Fig. 2.3 Task analysis map - Friction

instruction (Boreham et al 1985). These include: presenting examples before or after presenting a solution rule (Hermann 1969), presenting general concepts before or after detailed information (McDade, 1978) and presenting a concrete model before or after concrete abstract text (Mayer 1977). Also the sequence can be from theory to application or from application to theory; gneral to detailed or detailed to general and simple to complex or complex to simple. Planning the sequence may be conceived for the whole course, for a topic or unit or for individual lessons. Piagetian studies clearly indicate that selection and arrangement of subject matter should be based on the child's perspective rather than on that of the discipline specialist.

Ausubel's subsumptive sequence is one kind of general to detailed sequence. Types of sequencing include Norman's (1972, 1973) notion of "web learning", Bruners (1960) notion of a spiral curriculum and the Reigethlth-Merril notion of an elaboration sequence (Reigeluth et al, 1980; Reigeluth and Stein, 1983). There are differences among these sequences also for example Ausubel insists that advance organizers summarise the content that is to be learned rather than 'epitomizing' it. The elaboration theory calls for presenting (i) a simplified version of the synthesizer for a lesson, before the lesson and a completed version of the synthesizer after the lesson.

Gagne's simple to complex design in the learning hierarchy seems to hold much promise for instructional design especially in science. While the task analysis consists in top to bottom (breaking up of the complex ones to simpler forms) the instructional sequence he advocates is from bottom to top i.e. from simple tasks to the complex tasks in problem solving. The sequence adopted in the present study is also simple to complex as this seems to be the one of the most logical sequence which may be adopted for science instruction.

(iv) Deriving Learning Hierarchies

Learning hierarchies are only the logical follow up to the task analysis and sequence in instruction. Learning hierarchies are entensively discussed in the earlier section and as such no attempt is made to discuss them again. In fact, learning hierarchies consist in very smaller elements compared to the one we have seen in task analysis. A typical learning hierarchy from Weigand (1970) referred to by Gagne and Briggs (1974) is given here in Fig. 2.4 .

(v) Development of Instructional Material

Once the learning objectives and sequences are decided, the next important aspect is the preparation of instructional

VARIABLES IN AN INCLINED PLANE

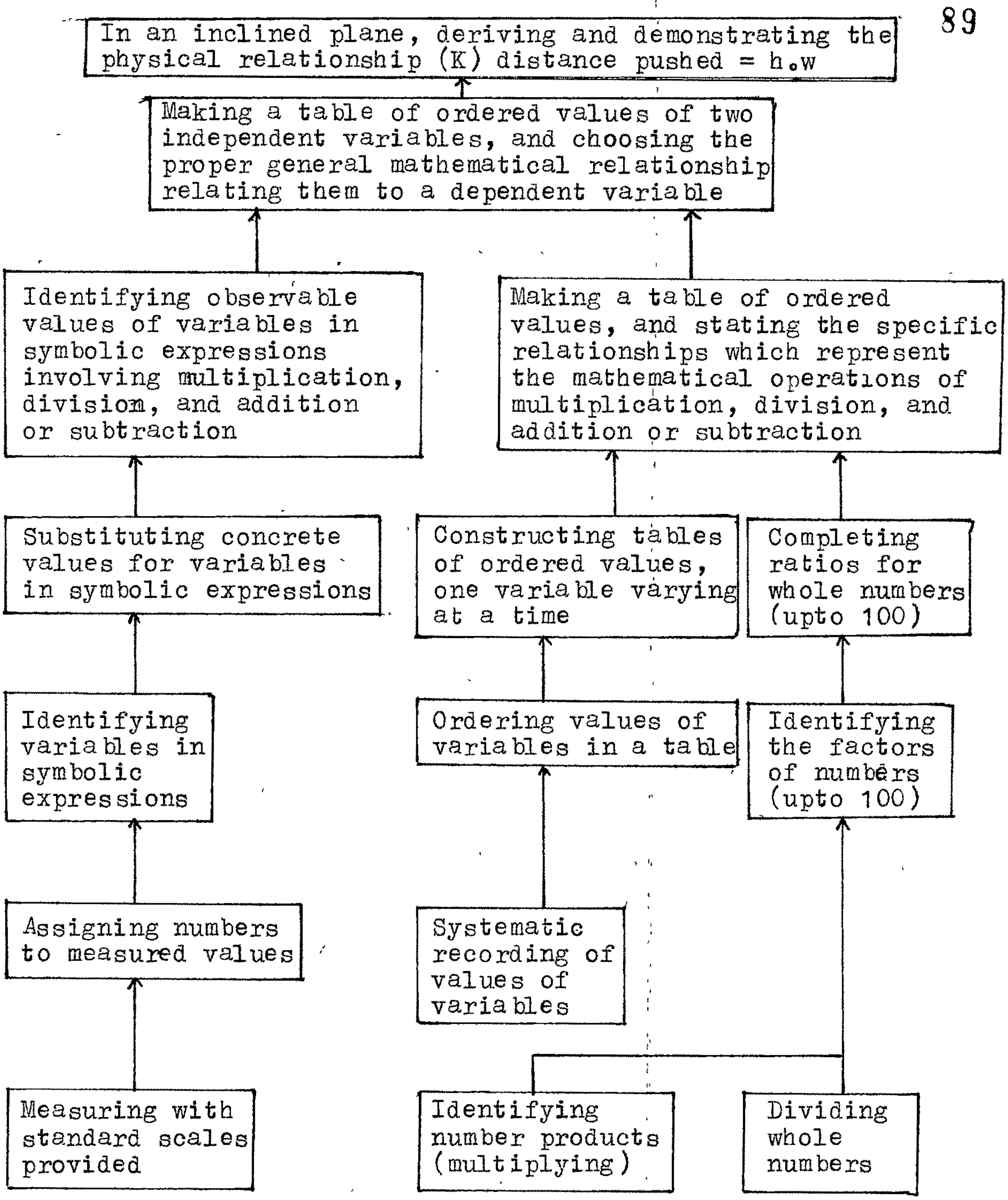

Fig. 2.4: A Learning Hierarchy for a Science Problem (From Wiegand, V.K., 1970)

material. It is something like collecting the materials required for construction after preparing the necessary architectural drawings. These instructional material should be prepared in accordance with the performance objectives as well as the task analysis and sequences suggested. The language used needs special attention. It should easily be understandable to the children of that age and stage of development. The clarity and unambiguity in the statements and description are very important. More about development of material is given in Chapter IV.

(vi) Instructional Management

Instructional management is the most important step where the teacher takes decisions about how to instruct the students. It is the teacher and the student actual setting and process in which both the teacher and the student participate making use of the instructional material. The actual classroom events-instructional events- may take a variety of forms. Some events may demand teacher's participation to a greater degree and others to a lesser degree. The events of instruction are designed to make it possible for the learner to proceed from 'where he is' at the beginning of a lesson to the achievement of the capabilities identified as lessons objectives.

The exact form of communications to the learner is not something that can or should be specified in general for all lessons, but rather it must be decided for each lesson. The particular communications chosen should fit the circumstances and be designed to have the desired effect upon the learner. Gagne (1968) lists the following instructional events :

1. gaining attention
2. informing the learner of the objective
3. stimulating recall of pre-requisite learnings
4. presenting the stimulus material
5. providing learning guidance
6. eliciting the performance
7. providing feedback about performance correctness
8. assessing the performance
9. enhancing retention and transfer

It is to be noted that all the events of instruction do not invariably occur in the exact order mentioned above, although this is their most probable order. Also all the events mentioned above need not occur always. Various kinds of events can be employed to gain the learners' attention. The content can be taken even from the history of the subject. A short talk on the life of Curie family should raise the children's curiosity to know more about radioactivity. The famous story of Archimedes should be enough and more for introducing Archimedes principle in physics. Even an interesting demonstration, a film or any visual will do the trick. It is always better that performance objectives are made known to the learner, though in some cases the no special communication may be required. For science instruction in secondary schools if the objectives are to be communicated effectively, they must be put into words that the students can readily understand. Recall of pre-requisite learned capabilities are essential for the progress in learning situation. This may be done by a communication which asks a question through discussion.

Presenting the stimulus material forms a very important event in the instructional process. Different intellectual skills need different types of presentation. Proper communication demonstration, dramatising the event etc. are just few ways to approach this. Providing guidance to learning helps the learner immensely. For example, while solving a problem the hints given at the appropriate time will eliminate incorrect direction and lead to problem solution quickly. Hints as a strategy seem to be good in that they direct the behaviour of the subjects and also may be beneficial to transfer the strategy to other problems. The amount of hinting or evidence needed will also vary with the learner. Some learners require less of learning guidance than do others in most situations. They simply 'catch on' more quickly.

Eliciting performance starts with the communication for example, "You have seen how we solve the problem; now show me how you solve these problems." Here, it is mostly a student activity where student will engage in purposeful learning. Repetition, practice etc. are the points to be considered here. Feedback deals with the communication of correct or wrong or the degree of correctness of answer. In case of wrong answer, further guidance could be provided to correct the same. The performance will indicate whether desired capability is being achieved or effectiveness of the instruction. Obviously the single, double, or tripple observations of performance that are made immediately after learning may be conducted in quite an informal manner. Few questions, after the learning activity is over, will give us an idea about the capabilities achieved. Provision for enhancing, retention and transfer should be included in any instruction. As for transfer of learning this can be best done by setting some variety of new tasks for the learner; tasks which require the application of what has been learned in situations that differ substantially from those used for the learning itself. Transfer will take place when the learner starts solving problems on his own.

(vii) Performance Assessment and Evaluation

The outcome of the planmed instruction instruction consists of student performances which show that various kinds of capabilities have been acquired. An objective referenced assessment material should be prepared and administered to the student at the end of the topic. Such tests will show whether the intended capabilities have indeed been achieved or not. The performance objectives should form the key factor while framing the tests. The rate of learning may vary among the students. Mastery learning may be taken essentially as that if proper conditions can be provided, perhaps 90 to 95 percent of students can actually master most objectives to the degree normally reached only by good students. When the mastery is defined for a test assessing performance on an objective this also defines the criterion of success for that objective. That is, the teacher must decide as to how well the learner must perform on the test to indicate the achievement of that objective. The administration of the test applicable to course objectives and the definition of mastery level for each objective provide the means for evaluating both the course itself and the performance of individual students. For the purpose of assessing student performance on the planned objectives of a course, objective referenced tests employing a criterion referenced interpretation constitute the most suitable procedure (Gagne and Briggs, 1974). They serve several important purposes :

1. They show whether each student has mastered the objective, and hence may go on to study another objective.
2. They permit early detection and diagnosis of failure to learn, thus helping to identify the remedial study needed.
3. They provide data for making improvements in the instruction itself.
4. It also gives the student a re-assurance about the objectives and what he was supposed to learn.

Apart from the topic tests evaluation may also done to assess the acquisition of each capability i.e. at the end of every concept or rule. This may be done by asking questions based on the particular task. Teacher communicating to the student about his degree of accuracy of the answer provides immediate feedback to the student. In the most typical instance of reinforcement the learner makes a response that reflects his newly acquired capability and then is told whether his response is right or wrong. As Gagne (1974, p. 43) puts it, "Presumably, the process of reinforcement operates in the human being not because a reward is actually provided but because an anticipation of reward is confirmed".

2.6 Conclusion

As human beings are highly adaptable in their learning, it may not be surprising that one kind of plan of instruction may seem to be about as good as another. The differences between the effects of such plans, if any, cannot be realised unless it is put to vigorous test in a real classroom situation. The test for any learning theory and the design of instruction therefrom depends initially on its capacity to adapt to the prevailing classroom conditions. So for any discussion on an instructional strategy should be supported by a classroom experiment and one such attempt made is reported in Chapter IV. But before going to the experimental aspect it may be fruitful to have an idea about science instruction research in India, which is one of our main concern. Therefore, an attempt is also made to review some of the researches conducted in the area of science education in our country, in the next Chapter.