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The acquisition of formal scientific reasoning by physical science pupils in standards eight and nine

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be based on the simpler, more elementary logical structures which the learner already possesses (Piaget, 1964a, p. 184).

The nature of Piagetian structures, however, may not be equated with knowledge. Piaget (1971) has acknowledged the influence of factual knowledge upon reasoning but maintains that it is not possible to formulate a general theory of the effects of knowledge since these effects are unpredictable. Piaget (1972) nevertheless contends that knowledge effects may cause inconsistencies in formal reasoning performance, suggesting that prior knowledge and enhanced performance are inextricably interwoven.

The richness of prior knowledge, therefore, is appreciated in several paradigms of learning. Returning to the role of prior knowledge from the Ausubelian perspective, the theory of meaningful learning propounded by Ausubel assumes that the learning task is potentially meaningful to the learner, namely, relatable to his cognitive structure on a nonarbitrary and substantive basis. However, Ausubel points out that the spontaneous availability or use of appropriate anchoring ideas in cognitive structure should not be relied upon (Ausubel, 1968, p. 131). He therefore advocates the strategy of deliberately manipulating the organisational strength of cognitive structure by the use of appropriately relevant and inclusive introductory materials *(organizers)* that are maximally clear and stable. These organizers must be introduced in advance of the learning material and, as opposed to overviews or summaries, are presented *at a higher level of abstraction, generality and inclusiveness.*

> *The principal function of the organizer 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, p. 148).

Ausubel advises application of this strategy to the presentation of the content of a particular subject-matter discipline by the use of a hierarchical series of organizers in descending order of inclusiveness. Programming subject-matter in this manner serves two functions. Firstly, each organizer makes available an appropriately pertinent and inclusive subsumer to furnish ideational anchorage for its corresponding unit of detailed, differentiated material. Secondly, the ideas within each unit as well as the subsequent units in relation to each other are also progressively differentiated (Ausubel, 1968, p. 154).

Ausubel distinguishes between two types of advance organizer. Where new material is completely unfamiliar to the learner, an *expository* organizer is involved. The expository organizer primarily affords ideational anchorage of the new piece of information to ideas which are already established in the cognitive structure of the learner. On the other hand, where new material is not completely unfamiliar, a *comparative* organizer is entailed. The dual function of the comparative organizer is to indicate explicitly to the learner the ways in which the new and the established ideas are similar and the ways in which they are different. The presentation of learning material, therefore, should offer explicit exploration of relationships between ideas. Where topics or concepts are essentially equivalent apart from contextual reference, the stable incorporation into cognitive structure or the acquisition of insights is dependent upon recognition of commonalities. However, the identification of differences between apparently similar concepts is also extremely important as such concepts often tend to be confused and interpreted by the learner as identical to one another. In such a situation, the newly-learned meanings cannot conform to the actual content of the learning material. Further, if new meanings are not easily distinguishable from existing knowledge, the latter may adequately represent new meanings for memorial purposes. The new ideas are thus reduced more rapidly than initially discriminable meanings. The retention of new concepts demands delayed reduction (Section 2.3.2). Ausubel maintains, therefore, that only discriminable variants of more inclusive established meanings have long-term retention potentialities (Ausubel and Fitzgerald, 1961). The use of comparative organizers that explicitly delineate similarities and differences between two sets of ideas characterises *integrative reconciliation* which is a basic principle of Ausubel's theory of instruction (Ausubel, 1968, p 155).

The presentation of learning tasks in which material is organised along parallel lines, that is, in which there is no inherent sequential dependence from one theme to the next, should therefore involve advance organizers that are expressly designed to further the principle of integrative reconciliation, thus mobilising all available concepts in the cognitive structure which can play an orienting and subsuming role in relation to the novel learning material. Ausubel and his collaborators have demonstrated the empirical success of comparative organizers by facilitating, for example, the learning and retention of an unfamiliar passage on Buddhism when the organizers bridged previously learned background knowledge pertaining to Christianity, suggesting the Buddhism passage to be a modified variant of its Christianity counterpart (Ausubel and Fitzgerald, 1961; Ausubel and Youssef, 1963).

2.3.5 Learning Set

Ausubel identifies meaningful *learning set* as a prerequisite for meaningful learning. Learning set refers to *current disposition [of the learner] to learn or perform in a particular way* (Ausubel, 1968, p. 313). Learning set possesses two components. The first component reflects general Ausubelian theory and is derived from prior learning experience. It consists of sophistication in the strategy of learning as reflected by relatively established cognitive acquisitions which guide both the sphere and content of ongoing learning activity. Ausubel describes this aspect of learning set as *learning to learn*. The second component consists of an appropriate attitude towards undertaking a given learning task. Associated with such an attitude are focusing of attention, mobilisation of effort and overcoming of initial inertia. This attitude, which exerts a facilitating influence on learning but is transient in nature, is described by Ausubel as the *warm-up* effect (Ausubel, 1963, pp. 202 203; Ausubel, 1968, p. 314). Ausubel holds that short-term improvements in learning, for example, those which last a single day, may be explained in terms of the function of advance organizers as warm-up elements. Since warm-up elements are rapidly dissipated, however, long-term improvements in learning are deemed to be caused solely by learning-to-learn effects of the advance organizers. Although warm-up elements are clearly facilitative of meaningful retention, for any valid assessment of the adequacy with which a learning task has been mastered, delayed posttests must therefore be utilised.

2.3.6 The Role of Practice in Learning

Learning and retention of academic material necessarily imply typically specific and intentional practice, namely, multiple presentations of the learning task. Practice, in Ausubel's view, is one of the principal factors which modify cognitive structure (Ausubel, 1968).

Repeated trials provide additional opportunities for the learner to interact cognitively with the learning material. These opportunities serve two ends. Firstly, newly-assimilated meanings which were established in cognitive structure on the initial encounter may be consolidated. Secondly, meanings which the learner partially or completely missed on the first encounter may be acquired. The influence of repetition in the establishment and consolidation of meanings has a facilitating effect on the learning of new related materials since repetition makes available in the cognitive structure stable new anchoring ideas for future learning tasks.

The changes in cognitive structure caused by the initial encounter with the learning material causes reciprocal changes in the learning task as perceived by the learner in subsequent presentations. Here, actual, as opposed to potential, meanings are conveyed to the learner since meanings have previously been derived from the learning material on the first trial. In addition, the establishment of meanings in general on the first encounter *sensitises* the learner to more subtle meanings on repeated trials (Ausubel, 1968, p. 283).

The forgetting of material between successive trials has an *immunizing* effect on the learner. Ausubel argues that the learner tends to become aware of his previously limited success in remembering the material and is therefore motivated to resolve existing confusion and ambiguity in the relearning trials (Ausubel, 1968, p. 282).

Meaningful learning, as opposed to rote learning, involves non random processes in cognitive structure. Ausubel suggests, therefore, that review sessio s may hold more value than sheer repetition or drill. Further, the principle of obliterative assimilation implies that, for optimum effectiveness, the timing of practice is important. Early review would therefore seem to be superior for consolidation since newly assimilated ideas are still reproducible as entities individually identifiable from the anchoring ideas to which they are linked. On the other hand, delayed review would seem to offer greater benefit in the relearning of forgotten material. Ausubel advocates use of a combination of early and delayed reviews which he sees as serving complementary functions (Ausubel, 1968, p. 283).

2.3.7 Cognitive Readiness

As has been pointed out by Novak (1979), an important characteristic of Ausubel's learning theory is its consistency with the key principle of Johnson's model for curriculum (1967) which emphasises the importance of careful planning of learning sequences. Further, regarding modern instructional theory, the Ausubelian view meshes with significant premises of Bloom's mastery learning strategy (1968, 1976) which are derived from Carroll's model for school learning (1963). The view of Carroll and Bloom that the majority of students are capable of mastering most school subject matter if they are given guidance and sufficient time to master relevant concepts necessary for later learning, can be explained through Ausubel's proposition of the nature and role of advance organizers, progressive differentiation of concepts and integrative reconciliation of concepts (Novak, 1979).

Contrary to common opinion in the literature, the reception learning theory explicated by Ausubel advances cognitive maturity as a criterion in the selection of material for presentation to the learner. The principle of cognitive maturity is, however, distinguishable from cognitive readiness. Cognitive readiness is defined as *the adequacy of existing cognitive processing equipment or capacity for coping with the demands of a specified cognitive learning task* (Ausubel, 1968, p. 176). Ausubel has further stated that the concept of readiness refers to level of cognitive functioning, not knowledge. This definition of readiness does not specify the manner in which this capacity is achieved. In contrast, maturation is given a more restricted meaning and is equated with a process of *internal ripening*. General cognitive maturity, therefore, *largely reflects age-level differences in intellectual capacity or stage of intellectual development* (Ausubel, 1968, p. 176). This statement is necessarily qualified by the manifestation of individual differences which reflect genetic influences and/or incidental experience. In fact, Ausubel has delineated three qualitatively distinct stages of intellectual development with the same stage names as Piaget and Inhelder (Inhelder and Piaget, 1958; Piaget, 1954, 1957) but with a somewhat different view of the distinctive features of each stage (Ausubel, 1968, pp. 198 ff.)

Ausubel stresses that the principles of readiness and maturation may not be equated. Maturation should be viewed as *one of the two principal factors (the other being learning) that contribute to or determine the organism's developmental readiness ...* (Ausubel, 1968, p. 177). In certain instances, readiness is a function of cumulative prior learning experience only but more typically depends on both maturation and learning.

The concept of readiness stipulates a reasonable economy in learning time and effort and warns against the risk and consequences of failure in instances of premature learning, in terms of the total educational career of the educand (Ausubel, 1968, p. 183). On these grounds, Ausubel criticises Bruner (1960) who believes that any subject can be taught intuitively to pupils at any stage of development. Further, Ausubel (1968, p. 214) quotes and endorses the view of Tyler (1964) :

> *Do common experience and observation not convince us of the impossibility of teaching such a class of responses as 'solving linear equations' to a neonate?*

2.3.8 Ausubelian Studies

While the number of Piagetian studies continues to increase,the number of Ausubelian studies reported annually has been fairly consistent since the mid-seventies and rather limited (Gabel *et al,* 1980). The findings of recent research will be returned to later and related to the earlier studies which will be examined first.

There are two review articles covering studies based on the learning theory of Ausubel up to the mid nineteen-seventies (Barnes and Clawson, 1975; Hartley and Davies, 1976). The studies have only general relevance to the present thesis and need not be considered individually. When the studies are taken as a whole, both articles argue that the efficacy of advance organizers has not been established. Hartley and Davies (1976) suggest that initial studies (Ausubel, 1960; Ausubel and Fitzgerald, 1961; Ausubel and Fitzgerald, 1962; Ausubel and Youseff, 1963; Fitzgerald and Ausubel, 1963) were persuasive but of limited generality. Later studies widened the area of inquiry but increasingly tended to be inconclusive (Hartley and Davies, 1976). Barnes and Clawson (1975) reached the same opinion from the thirty-two Ausubelian studies in their review, of which twelve favoured advance organizers while twenty reported no facilitative effects on learning. Both sets of authors emphasise, however, that statistical significance and practical significance are not synonymous. No clear patterns were discernible in separate analysis of design parameters such as the duration of study, type of organizer, academic standard of subjects, intellectual ability of subjects and level of the learning tasks in the cognitive domain. There seemed to be a tendency for subjects of average and below-average ability to derive less benefit from advance organizers. This possibility was borne in mind when drawing the sample for the present study.

Both articles indicate that methodological flaws or inadequacies were evident in many of the studies under review. Barnes and Clawson (1975) have put forward the following recommendations to future researchers to avoid weakness in research design and statistical procedures :

> *Carefully meet all of the required conditions for experimental research including random assignment of subjects to treatment groups, maintain independence of subjects, use the appropriate statistical tests, test for mastery of the organizer prior to presentation of the material to be learned, be certain that the test of the advance organizer and all tests of the material to be learned are different from one another, include a*

> *retention measure if possible, follow established procedures for test construction and maintain high reliability and validity*. (Barnes and Clawson, 1975, p. 657).

Research confusion stems from the fact that there is currently no clear consensus concerning the generation or recognition of advance organizers. Ausubel (1963) has provided logical distinctions between organizers and overviews but does not describe the operational definition of an advance organizer. Clawson and Barnes (1972, 1973) have attempted to arrive at such a definition. Other authors, however, have wished to avoid the restriction of a rigid definition and have adopted a wider view than Ausubel's broad definition of an advance organizer. The mathematical game organizer of Scandura and Wells (1967), the mechanical model organizer of Pella and Triezenberg (1969), the declarative statement organizer of Bayuk *et al* (1970) and the graphic organizers of Alexander (1977), Barron (1971) and Weisberg (1970) would appear to violate the high level of abstraction demanded by Ausubel's definition (West and Fensham, 1974) yet these pre-instructional strategies generally seem to offer advantages for the learner. West and Fensham (1974) have proposed that Ausubel's advance organizers may in fact be a specific type of a larger class of contrived materials whose role is to aid external conceptual organisation for learners whose cognitive structures lack or possess ineffectual knowledge organizers. This wider view was adopted by West and Fensham (1976). The sound basis of this view was later established by West and Kellett (1981) in their demonstration of the equivalence of the advance organizer and relevant prior knowledge, in outcome if not in process. These workers conducted a study which involved the existence in learners of an area of learning, prior to instruction, that was closely related to the concepts around which the learning programme was then directed. The course of instruction dealt with solubility and precipitation. The prior knowledge concerned the principles of chemical equilibrium which are particularly relevant to the subject matter of instruction since solubility product problems are specific equilibrium exemplars. West and Kellett showed that the prior knowledge was functional in the organisation of the novel material and removed any advantage which could have been offered by the use of an advance organizer. This finding is supported by studies along similar lines (Pines, 1978; Wesney, 1978) in which cognitive background was related to concept learning in science.

Barnes and Clawson (1975) call for research to establish the facilitative effects of nonwritten advance organizers. The promising results obtained by simulation-games, graphic and visual organizers have already been mentioned. Jerrolds (1967)

has employed a written format but shows that compact organizers stating the central idea seem to be as effective as the more cumbersome, conventional kinds of advance organizer. Earle (1971) has also departed from the continuous prose format used by Ausubel and reports success with advance organizers consisting of networks of important technical terms charting their relationship to one another.

Some studies have replaced the advance introduction of ideational anchorage as advocated by Ausubel by post-instructional strategies. Conflicting results have been obtained. Bauman, Glass and Harrington (1969) contend that post organizers have a greater facilitative effect than advance organizers, while other workers report the opposite (Bertou *et al.* 1972; Graber *et al.* 1972; Smith, 1976). While adhering to the conventional Ausubelian pre-instructional organizer, West and Kellett (1981) presented the organizer several times throughout their learning programme to indicate to the learner the bearing of a particular learning section upon the overall development of the terminal skill, a procedure also recommended by Goodman (1977). The desired frequency of presentation of the organizer has been investigated by Ewing (1977) who found that retention of the learning material was improved when subjects had only restricted access to the organizer, in the sense that access to the organizer was excluded during the study of longer learning passages.

Barnes and Clawson (1975) found that the length of treatment was not a critical variable in the studies covered in their review. They stress that this observation is inconsistent with the tenets of Ausubelian theory which discriminate between the learning-to-learn and warm-up aspects of learning set. Barnes and Clawson suggest that consistency with these tenets may be revealed when future studies focus on the effectiveness of advance organizers over intervals of at least ten days, which would be relatively extended periods when compared with several of the studies referred to in their review, which involved only one day.

Two later studies involving high school biology students have adopted this recommendation. Varano (1978) compared the influence of advance organizers with the use of behavioural objectives. Subject participation in the experiment lasted two weeks followed by posttests, both immediate and delayed by an eight-week period. Kahle (1978) conducted a similar experiment where a delayed posttest was administered three weeks after subject participation for a six-week period and an immediate posttest. Neither study showed any significant differences in immediate achievement between the experimental and control groups, but the experimental group was favoured on the retention test of Kahle.

Bouman (1976) reports similarly inconclusive results in terms of wide applicability in an investigation involving the use of cognitive organizers as a facilitator of comprehension of instructional material by undergraduate enrollees. Ewing (1977) demonstrates that advance organizers made a significant contribution to the learning of selected topics in the arts by eighth-graders but raises further research questions in the finding that the organizers were significantly more effective for learning and retention at some cognitive levels among female subjects but not for male subjects. This study supports the recommendation by Barnes and Clawson (1975) in their review for investigation into an area centred around the effects of advance organizers on learning at all levels of the cognitive domain.

In this assessment of advance organizers, the author's attitude should not be interpreted as ambivalent. The absence in the literature of conclusive proof either to support or to dismiss the use of advance organizers, does not imply that advance organizers are of no value. Without the existence of decisive negative evidence, it still seems worthwhile to carry out investigations involving advance organizers in Ausubelian or in modified form. The efficacy of advance organizers in teaching methods is not unique to Ausubel, if idiosyncratic terminology aside, one considers only the Ausubelian instructional sequence as opposed to the internal process in the learner. The inductive approach to instruction at primary and secondary level has been favoured by most prominent educators, dating as far back as Vives (1492–1540) and Comenius (1592–1670).

Against the background of the uncertainties and contradictions concerning the application of Ausubelian theory to concept learning, it would appear, therefore, that the pragmatic approach adopted by Moreira (1977, 1978) and Moreira and Santos (1981) might be the wisest initial course of action in the quest to refine or modify the use of cognitive organisers as a pedagogic strategy. Moreira organised the entire content of an introductory course in electricity and magnetism at the college level according to the Ausubelian principles of progressive differentiation and integrative reconciliation. In a sense, this sequence is diametrically opposed to the topic format customary at tertiary level, which begins with specific concepts and ends with the general equations describing electromagnetic phenomena. There were two experimental groups in different instructional modes, one self-paced and one attending conventional lectures, with two corresponding control groups following the classic approach. The results of the study show that it is possible to organise physics instruction in accordance with Ausubel's theory and attain at least the same level of achievement as a traditional approach on measures such as quizzes and

examinations, with the addition of possible advantages in terms of concept learning since the Ausubelian approach seemed to be more effective in fostering the ability of students to relate and differentiate physical concepts. This seems to have been particularly evident in the individualised instruction comparison programmes. Moreira and Santos (1981) have conducted a similarly designed experiment around an introductory physics course on thermodynamics. They report that an Ausubelian framework influenced the cognitive structure of students in such a way that there was more coherence of hierarchical organisation with the basic laws and the conceptual structure of the subject-matter than was evidenced with the traditional approach.

Another Ausubelian study designed to enhance scholastic achievement in the physics of electricity, this time at high school level, has been conducted by Roper (1981). Roper administered operationally defined expository advance organizers as well as comparative organizers during instruction to the classes comprising his experimental group. The classes constituting the control group were taught separately and received only a six hundred word passage on random numbers prior to instruction. He reports that the use of the organizers assisted the students of the experimental group to achieve better in both reproduction and comprehension of the subject-matter, as measured by a ten-item multiple choice test and by a two-item essay test respectively.

2.4 Developmental Learning

2.4.1 The Contribution of Piaget

Since the early nineteen-fifties it has been apparent that Jean Piaget has made the chief contribution to the study of intellectual development. Ginsburg and Opper (1969) advance the following reasons for this view :

(i) Piaget's theory of child development is more securely based upon the study of the child than those of other researchers whose tenets have been applied to the development of children (Freud, Lewin, Hull, Miller and Dollard, Skinner) since, for many decades, Piaget and his team collected empirical data on children of all ages

(ii) Piaget's theories have reoriented conceptions of the child's development, offering the first viable alternative to the stimulus-response behaviourist tradition.

(iii) Piaget has explored many new and interesting problems which were previously unnoticed, for example, the discovery of the principle of conservation.

(iv) Although insufficient *per se* to achieve renown, the sheer volume of the output of Piaget and his collaborators since 1920 is overwhelming.

2.4.2 Orienting Attitudes

The two major intellectual interests in Piaget's life were epistemology, namely, the branch of philosophy covering the domains of human knowledge, and biology. These disciplines shaped the theoretical framework or presuppositions of Piaget's approach to the psychology of intelligence. Piaget sought to integrate the philosophical approach which he considered too speculative and the scientific approach which he sometimes regarded as too factual (Piaget, 1965a). Piaget's research activities may be viewed as pursuit of a link between empiricism and logical positivism.*

Piaget's orienting attitudes concern, firstly, the nature of intelligence and, secondly, the structure and functions of intelligence. The link resulting from this inter-disciplinary co-operation is Piaget's interpretation of the psychology of human intelligence. This deals with the individual's attempt to comprehend reality i.e. epistemological issues, couched in terminology which has its origins in the field of biology Piaget's early research concentrated on the contents of the child's thought (e.g. Piaget, 1929; Piaget, 1932a, 1932b). After these initial investigations, Piaget's prime aim became the study of the fundamental processes underlying and controlling the content of thought, namely, the structure and functions of intelligence. The contribution of epistemology towards Piaget's set of orienting attitudes resulted, therefore, in the empirical investigation of the child's understanding of space, time, causality, etc., namely, the Kantian categories of thought. The contribution arising from his study of biology resulted in definitions of intelligence in general terms of growth, stages, adaptation, equilibrium and similar factors.

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*Logical positivism opens access to empirically accessible domains of reality as this branch of philosophy confines the names *knowledge* or *science* to the results of those operations which are observable in the evolution of natural science and mathematics, that is, free of metaphysical assumptions (Kolakowski, 1972).

2.4.3 Piagetian Interaction Theory

The distinctive feature of the specialised field of cognitive development is the need to understand how an organism of a particular kind, in its encounters with phenomena, constructs the world (Kessen, 1966). Study of the conception of reality by the organism involves consideration of the respective roles played by the organism or knower and the object known in the act of knowledge. Piaget subscribes to a constructivist position which is compatible with dialectical psychology, in his attempt to integrate the opposed views of rationalism and empiricism on this issue of epistemological origin. The rationalist view is that external reality has a minor function in the acquisition of knowledge since the human intellect possesses an intrinsic ability to apprehend the world. The knower therefore imposes on external reality his own structures of thought, designated by Kant as *a priori categories of understanding*. The empiricist belief, on the other hand, is that external reality is independent of the human intellect. The environment is experienced through the senses of the knower who is otherwise passive in the knowledge situation. Knowledge is thus acquired by the knower solely from his empirical experiences (Ginsburg and Opper, 1969).

The theory of *interaction* postulated by Piaget endeavours to reconcile the rationalist and empiricist interpretations of the knower-known relationship by proposing that each element makes a contribution of comparable significance. Piaget therefore admits the importance of the environment in the knowledge situation. However, the knower possesses a mental structure which influences his apprehension of reality. The term, *structure*, is a key concept shared by both Piagetian and Ausubelian theories. The customary meaning of the word, stated earlier in this chapter, has been modified for different contextual reference in each theory. The connotations of the term as used by the two theories are thus divergent. Piaget sees cognitive structure in terms of the adaptation or adjustment of an organism to its environment. This adaptation involves intellectual development which reflects evolution through qualitatively different stages of thought. In adaptation the organism organises separate patterns of intellectual behaviour or structures, acquired from past encounters with the environment, into higher-order systems or structures. The nature of reality is dependent on the kind of structure with which it is apprehended. With cognitive development, the child therefore acquires a progressively less superficial view of the phenomenon which represents reality to him. The development of cognitive structures, as hypothesised by Piaget, clearly involves active internalisation between the structure of the organism and the structure of the environment.

Piaget offers several definitions of intelligence in general terms, among which is intelligence expressed as a process of adaptation and organisation (Piaget, 1960). Adaptation may be interpreted as the tendency to establish equilibrium in the organism's interaction with the environment. This tendency involves the two processes of assimilation and accommodation. The term, *assimilation*, is another instance of an important notion which is common to both Piagetian and Ausubelian terminologies. The precise meaning of assimilation depends, therefore, on its contextual reference as determined by the particular theoretical stance involved. In the Piagetian sense, assimilation signifies incorporation of the environment into present patterns of intellectual behaviour. Accommodation describes the tendency of the individual to change these patterns in response to environmental pressures. Assimilation and accommodation are functionally invariant and complementary processes. The individual assimilates environmental events into existing cognitive structures and simultaneously accommodates *or* alters these structures, either by modification or transformation, in order to adjust to the demands of the external environment. This dynamic process of self-regulation is called equilibration (Ginsburg and Opper, 1969).

The instinctive equilibration of the organism with the environment means constant organisation of psychological structures by co-ordination and integration of coherent patterns which are effective in interaction with reality. These patterns which Piaget called schemes* are defined as essentially repeatable psychological strategies of intelligent action (Piaget, 1960). The non-random action of cognitive activities specifies the nature and direction of intellectual development. Equilibration implies a change towards increasing stability, consistency and completeness of the structures of intellectual behaviour (Smedslund, 1961). Cognitive development is perceived as a series of equilibration-disequilibration states.

2.4.4 The Piagetian Stage Construct

2.4.4.1 Meaning of Stages

General theories of intellectual development, such as those formulated by Piaget and his collaborators (Inhelder and Piaget, 1958; Piaget, 1954, 1960), include age-related advancements in at least four major areas of cognitive functioning, namely,

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*In Piagetian terminology, the French *scheme* is often translated into English as *schema* (plural, *schemata*).

perception, objectivity-subjectivity, the structure of ideas of knowledge and the nature of thinking or problem-solving (Ausubel and Sullivan, 1970). No attempt at a comprehensive presentation of Piaget's major theoretical tenets can be offered here and the present focus of concern will be restricted to an overview of the Piagetian stage construct as it pertains to the main issue requiring resolution in this thesis.

Cognitive sophistication is partially characterised by an age-related movement along a concrete-abstract dimension (Ausubel and Sullivan, 1970). This concrete-abstract dimension of intellectual development is viewed by Piaget as a progression from infancy to adulthood through four qualitatively distinct stages :

(i) the sensori-motor stage (birth to two years);

(ii) the pre-operational stage (two to seven years) which is subdivided into the pre-conceptual stage (two to four years) and the intuitive stage;

(iii) the stage of concrete logical operations (seven to eleven years);

(iv) the stage of formal logical operations (eleven years and above).

The central features of these stages will be presented in the next section but it must first be said that Piagetian stages may be regarded as particular sets of schemes which are in a comparative state of equilibration at some point in the child's development (Sullivan, 1967). Piaget professes an interactional position in postulating the four main factors which effect transition through his designated intellectual stages (Piaget, 1964a, 1965b). Equilibration is considered to be the principal factor which subsumes the other concomitant factors. The three subsidiary factors are :

(i) Maturation in the sense of Gesell (1954), whose embryological model of growth is accepted by Piaget as basically tenable when applied to phylogenetic traits;

(ii) the role of experience, including both incidental and provoked encounters with the physical environment;

(iii) social interactions between individuals, including both casual encounters and structured educational activities.

Variability in the two latter factors accounts for ontogenetic differences in the emergence of stages of intellectual development. In contrast to Gesell, Piaget views

environmental effects as at least as important as maturation in the determination of cognitive growth.

Primary references delineating the formal characteristics essential to the Piagetian stage theoretical construct may be found in Piaget (1956, 1960, 1967) and Inhelder (1962). Numerous secondary references are cited by Ausubel and Sullivan (1970). Among the parameters of these stage criteria is the premise that cognitive stages are hierarchical integrations, that is, earlier stages of functioning are subsumed or incorporated by means of a subordinate relationship, into later more complex stages of thought. A further fundamental assumption of Piaget is that successive changes in the structure of thought are invariant, although they may be sensitive, within certain limits, to endogeneous and environmental influences. Critics of stage theoretical formulations have been cited by, and their arguments refuted by, Ausubel and Sullivan (1970) and Herron (1978) who show that not only do Piaget's designated stages indeed reflect the influence of genetic and environmental determinants but that they also do not exclude continuous passage from one stage to another.

2.4.4.2 Stage of Concrete Operations

The previous sections have summarised the Piagetian interpretation of the process by which the organism progresses through intellectual stages. The stages themselves will now be described briefly with the restriction that the cognitive operations of interest in the school years are those identified as characteristic of concrete and formal thought. Further, the delineation of concrete and formal operations will here be concerned solely with the development of thought, to the exclusion of other cognitive processes. For a more complete account, the reader is referred to the lucid summaries of all four Piagetian stages, which have been presented by Flavell (1963), by Ginsburg and Opper (1969) and by Ausubel and Sullivan (1970), as well as the comprehensive primary exposition by Inhelder and Piaget (1958).

The major issue in Piaget's theory of cognition is, as was indicated in the previous section, the progressive interior organisation of knowledge by the individual, which results in progressively more elaborate and advanced cognitive structures. The presence of appropriate cognitive structures or schemes is a requisite for the inductive and deductive logic demonstrated by adult thought. The Piagetian cognitive structures are modelled after operations which have the properties of mathematical groupings

in general and the property of reversibility in particular. These logical models do not imply any explicit understanding of logic by individuals in their reasoning. The intentions behind the construction of Piaget's logical meta-theory are to provide clarity and adequate description in the representation of protocols of thought and to offer explanations and predictions of intellectual behaviour on a qualitative basis.

Piaget (1965b) holds that the emergence of concrete operations signifies the beginning of rational activity in the child. Prior to this point, the child exhibits transductive reasoning which assumes a relationship between two or more specific and concrete items when in fact there is none. According to Piaget, therefore, the reasoning of the young child moves from the particular to the particular without inference to or from the general. This type of thought may be considered to lie between deduction and induction. The young child's thought does not display reversibility, that is, the ability to bring a train of thought back to its starting-point. (While the important role of language and perception in reasoning is recognised, Piaget disallows these as constitutive of intellectual activity since neither displays complete reversibility.) Further, the young child fails to recognise the parts of a situation and tends to concentrate on only one dimension of the situation. This dimension generally involves the static states of the situation as the child is not attuned to changes in shape or form (transformations). The concrete operational child, on the other hand, is able to reverse the direction of his thought. He can also attend to several aspects of a situation simultaneously, showing a co-ordinative approach which Piaget terms decentration. Moreover, the child is responsive to transformations. Piaget conceives of these three facets of thought as irreversibility-reversibility, static-dynamic and centration-decentration (Ginsburg and Opper, 1969).

From the paragraph above, it is clear that kinetic and transformational images arise in the child for the first time during the concrete operational stage. The construction of images is an internalised, imitative activity on the part of the child. Both types of image may be reproductory or anticipatory. Reproductory images attempt to *copy* or represent events which took place in the past or objects which are no longer perceptually present. Anticipatory images involve expectation of future events or of changes in the form or the location of an object. Images of kinetic and transformational situations are essential auxiliaries to thought processes at this stage of development, although they are not causative of thought. Mental imagery is the subject of extensive investigation by Piaget but will not be discussed here as it has no direct relevance to the present research. The reader who may be interested in pursuing the topic is referred to Ginsburg and Opper (1969) and Furth (1977).

Piaget (1960) maintains that the operations characteristic of the concrete operational stage (seven to eleven years) develop in unison with respect to a particular task. The concreteness of this operational stage inheres in the fact that relationships can be grasped and meaningfully manipulated only with the assistance of concurrently available or recently prior concrete-empirical objects. Piaget has examined such issues as classes, relations and number and proposes logico-mathematical models called Groupings to explain the child's cognitive behaviour on tasks involving concrete objects. Grouping I, for example, is a comprehensive and integrated structure which reflects the processes underlying the child's classificatory abilities. The mental operations involved are therefore interrelated and may be specified as closure, associativity, identity, negation and tautology. On a nonformal and simplified basis, the classification model comprises hierarchical classes or elements, the binary operator of combining and these five properties which govern the application of the operator to the elements. The first property, closure or composition, properly describes the child's ability to understand a hierarchy. Closure states that the combination of any two elements of the system will result in another element of the system. The next property is associativity which means that elements may be combined in different orders to give final results which are equivalent. The third property is identity which states that there is a special element in the system referred to as the *nothing* element and which, if combined with any of the other elements, results in no change. Next is the property of negation or inverse which is actually a type of reversibility. Negation states that, for any element in the system, there exists another element known as the i[illegible]rse of the first, which when combined with the latter, produces the nothing element. Negation can therefore be considered as a form of reversibility as the thinker is thereby brought back to his starting-point. Finally, there is the fifth Grouping operation, tautology, which states that if an element is combined with itself (i.e. identity element), the result corresponds to the original element and therefore no change is produced (Ginsburg and Opper, 1969, pp. 129–131).

2.4.4.3 Stage of Formal Operations

In the previous section, it was seen that logical operations at the concrete stage are constrained by the particularity of the concrete experience of the child. These operations clearly do not entail transformations of all-inclusive hypothetical relationships between general abstract parameters, which are encountered in the formal operational stage only. The child entering the formal operational stage at approximately eleven years, becomes decreasingly dependent on non-abstract contact with empirical data until cognitive maturity, at approximately sixteen years, means

freedom from concrete-empirical reality as an essential to thought processes. When a child at the concrete stage is confronted with a problem, the child's attention is directed solely towards the observed attributes or results of the given situation or experiment. Foresight in tackling the problem is limited to extension of observed data according to the same methods as were originally used to obtain the data. On the other hand, the approach typical of the adolescent at the formal stage commences with a consideration of the theoretical combinations of eventualities which may pertain to the task. Only once hypotheses have been developed, are empirical data obtained in order to test the hypotheses. Finally, the adolescent arrives at new interpretations and hence the formulation of generalisations to which the observed results lead. Formal thought, therefore, is hypothetico-deductive. Piaget describes such thought as follows :

> *Instead of just coordinating facts about the actual world, hypothetico-deductive reasoning draws out the implications of possible statements and thus gives rise to a unique synthesis of the possible and the necessary.* (Piaget, 1957, p. 19).

Put another way, Piaget has characterized the change in level of abstraction which marks the shift from concrete to formal operations as reasoning from the possible to the actual :

> *Possibility no longer appears merely as an extension of an empirical situation or of actions actually performed. Instead it is reality that is now secondary to possibility.* (Inhelder and Piaget, 1958, p. 251).

Piaget postulates that the system of mental operations in the adolescent has reached equilibrium to a significant extent, that is, the cognitive structures are sufficiently stable for the effective assimilation of numerous novel situations. Furthermore, mature thought is flexible in view of the large range of cognitive operations available, which allows efficiency in problem-solving. The changed perspective of the nature of the universe has consequences for the entire mode of life of the adolescent, where *the possible and the ideal captivate both mind and feeling* (Ginsburg and Opper, 1969, p. 205). The adolescent at the formal stage possesses, for example, a tendency to become involved in abstract concerns such as political theories or metaphysical speculation. As a further example, in the affective sphere, he is now able to direct emotions at ideals such as love of freedom or dislike of exploitation.

2.4.4.4 Logical Models of the Formal Stage

Two logical models have been advanced by Piaget to describe intellectual achievement at the formal stage. The first model refers to the manner of derivation by the adolescent of relationships among the factors involved in a given situation. The set of the possible logical relations is expressed as a system of sixteen binary operations. Piaget next proceeds to describe how the adolescent manipulates the particular conclusion which has been derived from the experiment in order to reach a general statement of the principle involved. This introduces the second model, the so-called INRC Group. Both models, as has been mentioned earlier, are designed to represent the general structure of formal thought and do not suggest the explicit knowledge of any logic on the part of the adolescent.

The general approach to many experiments, in order to decide which of many possibilities is operative, involves holding all independent variables except one constant so that the effect of each independent variable (p) may be assessed in terms of a dependent variable (q). Piaget's system of binary operations applies to simple situations involving two factors (e.g. p and q), each of which may have two values (e.g. p or p; q or q). The system of binary operations in fact constitutes a special case of the more comprehensive combinatorial system. Although a binary model is clearly not always appropriate, one of the advantages of binary propositional logic is that it can deal with non-numerical statements (Ginsburg and Opper, 1969, p. 202). Only a restricted portion of Piaget's extensive theory will be mentioned here. In order to clarify the most common symbols used by Piaget in his binary system, the solution to a well known Piagetian task, the bending rods experiment, has been expressed in Table 2.1 in terms of one of the sixteen logical relations that make up the system. The rods experiment gives rise to a pattern of results known as implication. Other experiments or situations generate other patterns of results or functions. The set of results is called the sixteen binary operations. The set is shown in Table 2.2.

Table 2.1 Symbolisation of Rods Experiment

The Task:

Piaget presented subjects with a set of various metal rods which could be clamped at one end so as to lie parallel to and above the surface of water in a basin. The rods differed in composition, length, thickness and sh . : of cross-section. In addition, different mass-pieces could be attachec the end of the rod above the water. Subjects were asked to determine, by investigating these factors, which rods were sufficiently flexible to touch the surface of the water and then to explain their results (Ginsburg and Opper, 1969, p. 189).

Symbols:

Assume for simplicity that all the independent variables except length and weight are held ' ;nt.

Let p represent ngth.

Let $\bar{p}$ represent short length.

Let q represent heavy weight.

Let $\bar{q}$ represent light weight.

The dependent variable is the flexibility of the rods.

Let r correspond to great bending.

Let $\bar{r}$ correspond to little bending.

General Conclusion:

Bending may be caused by two completely unrelated factors, namely, length and weight.

Conclusion Expressed in Propositional Logic:

(i) The logical conclusion is called implication.

(ii) Implication may be written

length implies bending $p \supset r$
weight implies bending $q \supset r$

(iii) Stating this in specific terms, with a view to interpreting Table 2.2, if length alone is considered, then

$p \supset r$

The three possible outcomes of the experiment which may be observed (T) are

p with r
p with $\bar{r}$
$\bar{p}$ with $\bar{r}$

The outcome which may not be observed (F) is

p with $\bar{r}$

Table 2.1 Symbolisation of Rods Experiment

The Task:

Piaget presented subjects with a set of various metal rods which could be clamped at one end so as to lie parallel to and above the surface of water in a basin. The rods differed in composition, length, thickness and shape of cross-section. In addition, different mass-pieces could be attached to the end of the rod above the water. Subjects were asked to determine, by investigating these factors, which rods were sufficiently flexible to touch the surface of the water and then to explain their results (Ginsburg and Opper, 1969, p. 189).

Symbols:

Assume for simplicity that all the independent variables except length and weight are held constant.

Let p represent long length.

Let $\bar{p}$ represent short length.

Let q represent heavy weight.

Let $\bar{q}$ represent light weight.

The dependent variable is the flexibility of the rods.

Let r correspond to great bending.

Let $\bar{r}$ correspond to little bending.

General Conclusion:

Bending may be caused by two completely unrelated factors, namely, length and weight.

Conclusion Expressed in Propositional Logic:

(i) The logical conclusion is called implication.

(ii) Implication may be written

length implies bending $p \supset r$
weight implies bending $q \supset r$

(iii) Stating this in specific terms, with a view to interpreting Table 2.2, if length alone is considered, then

$p \supset r$

The three possible outcomes of the experiment which may be observed (T) are

p with r
$\bar{p}$ with r
$\bar{p}$ with $\bar{r}$

The outcome which may not be observed (F) is

p with $\bar{r}$

Table 2.2 The Sixteen Binary Operations

a. Key

T = the outcome is observed (Table 2.1)
F = the outcome is not observed
p = high value of first variable
$\bar{p}$ = low value of first variable
r = high value of second variable
$\bar{r}$ = low value of second variable

b. The Four Possible Outcomes of an Experiment

	Outcome			
	1	2	3	4
First Variable	p	p	$\bar{p}$	$\bar{p}$
Second Variable	r	$\bar{r}$	r	$\bar{r}$

c. All the Ways in which the Four Possible Outcomes Can be Observed or Not Observed*

Name of Operation	Outcome			
	1 p with r	2 p with $\bar{r}$	3 $\bar{p}$ with r	4 $\bar{p}$ with $\bar{r}$
1. Negation	F	F	F	F
2. Conjunction	T	F	F	F
3. Inverse of implication	F	T	F	F
4. Inverse of converse implication	F	F	T	F
5. Conjunctive negation	F	F	F	T
6. Independence of p to r	T	T	F	F
7. Independence of r to p	T	F	T	F
8. Reciprocal implication	T	F	F	T
9. Reciprocal exclusion	F	T	T	F
10. Inverse of independence of r to p	F	T	F	T
11. Inverse of independence of p to r	F	F	T	T
12. Disjunction	T	T	T	F
13. Converse implication	T	T	F	T
14. Implication	T	F	T	T
15. Incompatibility	F	T	T	T
16. Tautology	T	T	T	T

*Adapted from Ginsburg and Opper, 1969, p. 195.

The second model, aforementioned, describes the transformations conducted by the adolescent on those functions relevant to a given experiment from the binary operations in the formulation of general conclusions. This model, the INRC Group, has the rules of identity I, negation N, reciprocity R and correlativity C. The innovation here is C. Applied to a function, C changes conjunction which involves $\wedge$ (representing *and*), shown in Table 2.2 as operation 2, to disjunction which involves V (representing *or*), shown in Table 2.2 as operation 12, and vice versa. All other aspects of the function, however, remain unchanged.

The other three operations, as described for formal thought by the INRC Group, are now changed in their range of applicability. The concrete operational child has available identity, negation and reciprocity.* These operations can be observed, for example, in one of the most used Piagetian tasks, the conservation of continuous quantity (Ginsburg and Opper, 1969, p. 162). The task concerns the child's capacity to recognise that the quantity property of a set remains invariant in the presence of irrelevant alterations such as the physical rearrangement of the set. The concrete child therefore has these operations at his disposal but only in isolated forms which arise from immediate perception in contrast to the integrated system of the adolescent which includes operations on hypothetical propositions. For example, Piaget has shown that the adolescent is able to discover the principle of inertia even though this may not be observed in the real world. Piaget conducted a study where subjects were shown apparatus in which a spring device launched spheres of various masses and volumes singly across a horizontal track. The task was to predict the distance along the track at which the balls would halt. In addition, subjects were to explain the results (Ginsburg and Opper, 1969, p. 197). If p represents the ball's stopping, q the presence of friction and r the presence of air resistance, then

$$p \supset q \quad \text{and} \quad p \supset r$$

Combining these functions,

$$p \supset (q \vee r)$$

---

*Identity and negation were defined in Section 2.4.4.2. Reciprocity is a form of reversibility in that compensation observed in one object or situation is the reciprocal of the compensation observed within another object or situation. In other words, to produce a given result in an experiment, a low value of one variable combined with a high value of another variable is qualitatively equivalent to a high value of the former variable combined with a low value of the latter variable.

The above function can be expanded to the conclusion

$$p \supset (q \vee r \vee s \vee t \vee \ldots)$$

where s, t and ... indicate an indefinite number of other factors. The operation N on this conclusion implies a corresponding negation of statement p, i.e. slowing down, amounting to an assertion of continued motion. The result of this transformation is a new function, namely,

$$\bar{q} \wedge \bar{r} \wedge \bar{s} \wedge \bar{t} \wedge \ldots \supset \bar{p}$$

where $\bar{q}$ represents the absence of friction, $\bar{r}$ the absence of air resistance and $\bar{s} \wedge \bar{t} \wedge \ldots$ the absence of all other factors which may retard movement. The absence of stopping $\bar{p}$ is thus implied. This is a form of the principle of inertia which states in essence that if no factors impede the motion of the ball, then it will continue to maintain a uniform rectilinear motion. The operation N is Piaget's attempt to formulate the rules which the adolescent employs to derive this law which is not empirical fact.

2.4.4.5 Coherence of Mental Operations

These models describe the competence or optimum intellectual functioning of the individual, in contrast to his average or ordinary achievement which may on occasions be deficient because of factors such as fatigue or boredom. The stages are theoretical generalisations and so the observed form of behaviour of the individual may not be typical in all respects of the behaviours as categorised by Piaget. Further, Piaget's stages do not exclude the possibility of irregular development. Complete generality in intellectual development over content areas and levels of difficulty is not implied (Ausubel and Sullivan, 1970). Szeminska (1965), one of Piaget's collaborators, has pointed out that

> *the increasing reversibility of development and the schemas of the higher levels do not function identically in all situations ... the same child may be found at different stages depending on the problem.* (Szeminska, 1965, p. 52).

The child may be in different stages of development with regard to different areas of functioning. He may also display different stages of development with regard to problems involving similar mental operations. The latter gap or lag, referred to by Piaget as horizontal décalage, is considered to be caused by a lack of immediate transfer from one situation to another (Ginsburg and Opper, 1969, p. 162 and p.165).

Ausubel (1968) has discussed the contribution of dimensions of performance such as content and problem effects to the irregular course of Piagetian development. General intellectual development, in any given direction, occurs with increasing age and educational encounters and is independent of experience in particular subject-disciplines (Ausubel, 1968). However, the transition from concrete to abstract functioning takes place in each subject-matter field specifically and implies a certain prerequisite degree of sophistication in each field respectively (Ausubel, 1968). Once the over-all developmental status of an individual is reflective of cognitive maturity, the specific transition to abstract cognitive functioning in an unfamiliar discipline takes place much more readily as a result of the general cognitive changes that have occurred along the concrete-abstract dimension. It is therefore meaningful to designate an individual's overall developmental status as concrete or formal only on the basis of an estimate of his characteristic or predominant mode of cognitive functioning (Ausubel, 1968).

2.4.5 The Status of the Piagetian Construct in Education

Piaget was not an educator and only relatively recently examined the relevance of his work to education (Piaget, 1970a). In the recognition of links between the presuppositions of Piagetian developmental theory and education practice, there are currently three identifiable positions (Brown and Desforges, 1977; Driver, 1981). Protagonists of the Piagetian stage construct have been prepared to base entire curricula and teaching programmes upon it, as reviewed by Furth and Wachs (1974). On the other hand, as discussed by Engelman (1971), the most persuaded opponents of the theory assert that it has no implications whatsoever for education. In between these two contrasting positions lies an indeterminate area which reflects the third position. Supporters of this viewpoint do not differ in terms of the developmental sequences identified by Piaget but, to varying degrees, dispute his interpretation of these sequences. Piaget's logico-mathematical models have been assessed as inadequate by Parsons (1960) and by Bynum *et al* (1972). Alternative models to explain the development of operations have been constructed on cybernetic principles. Such theorists also postulate (Driver, 1981) that immediate memory span imposes age-related limits on cognitive advancement as the amount of information which can be processed simultaneously increases with age. The development of groups of executive strategies is thus dependent on the non-structural factor of working memory capacity (Case, 1974, 1978; Flavell and Wohlwill, 1969; McLaughlin, 1963; Pascual-Leone, 1969; Pascual-Leone *et al*, 1978; Stewart and Atkin, 1982). Dale (1978) advances the view that level of intellectual sophistication

and information-processing load are joint determinants of cognitive competence on a given task. He reports the emergence of formal thought patterns in some six-to-eight year olds and tentatively suggests that the relatively high information-processing demands of Piagetian tasks effectively masks the appearance of formal reasoning until a later age. Piaget and his collaborators maintain that memory cannot be dissociated from the functioning of intelligence as a totality (Piaget, 1968; Piaget, Inhelder and Sinclair, 1968; Inhelder, 1969).

The status of Piagetian theory is a decisive issue for those educators who derive pedagogical implications from it. The dichotomy between development and learning (Piaget, 1964b) is reflective of the classification of Piaget's position as predeterministic with certain reservations (Ausubel, 1968; Sullivan, 1968). The directional role of the environment in the induction of learning is sharply curtailed. Learning is subordinate to development of the structures of knowledge as a spontaneous process tied to embryogenesis and self-regulation. Thus limitations to learning stem from the intrinsic ability of the child at a particular stage of development.

> *... I think that development explains learning and this opinion is contrary to the widely held opinion that development is a sum of discrete learning experiences ... In reality development is the essential process and each element of learning occurs as a function of total development, rather than being an element which explains development.* (Piaget, 1964a, p. 176).

In the Piagetian framework, learning is a much more restricted process than development, provoked by external situations (e.g. didactic teaching) and limited to single problems of single structures.

> *... learning appears to depend on the mechanisms of development and to become stable only insofar as it utilises certain aspects of these mechanisms.* (Piaget, 1970b, p. 717).

The theoretical stance that the development of the learner is an active process of reciprocal interactions between endogenous and environmental factors, establishes the key educational issue as active, spontaneous, self-directed learning.

> *The principal goal of education is to create men who are capable of doing new things, not simply of repeating what other generations have done – men who are*

> *creative, inventive and discoverers. The second goal of education is to form minds which can be critical, can verify, and not accept everything they are offered. The great danger today is of slogans, collective opinions, ready-made trends of thoughts.* (Piaget, 1964b, p. 5).

The convergence of thought in Piaget, Rousseau, Froebel and Dewey is striking in their view of learning as an active engagement in enquiry. The significance of Piaget's contribution to progressive education lies, not in the statement of new principles, but in the provision of a vast body of data and theory, upon which practical educational programmes may be soundly based.

2.4.6 Piagetian Studies in Science Education

2.4.6.1 General Trends

In the past twenty-five years science educators have been examining the implications of Piagetian developmental theory for the teaching of science. Empirical evidence confirmed Piaget's formulations concerning stages of intellectual development. Ausubel and Sullivan (1970, p. 566) alone cite twenty-five references to research which substantiates the developmental sequences designated by Piaget.

Early studies stressed pre-operational and concrete operational aspects of the model. As late as 1977, the other major emphasis was on relating students' cognitive developmental level to other demographic data (Peterson and Carlson, 1979). Studies revealed that large numbers of students in secondary schools and universities had not reached the formal stage of thinking. Many of these studies have been summarised by Chiappetta (1976) and Levine and Linn (1977). Emphasis then moved to the formal operational stage. A number of training studies endeavoured to enhance students' intellectual development (DeCarcer *et al*, 1978). Current research in science education is still dominated by studies based on Piagetian developmental theory but the focus of the studies seems to have shifted (Gabel *et al*, 1980). There is increased emphasis on careful documentation of procedures to establish the reliability and validity of instruments. Research methodology is more refined than in the past with more sophisticated statistical methods being commonplace and more frequent use of nonparametric inferential statistics. There is growing recognition of the issues of the degree of internal coherence of the Piagetian stages and of the significance of the roles of task content and contextual reference in assessment of operational capabilities. Theoretical horizons are being enlarged by studies which focus in more

detail on specific schemata with a view to elucidating the finer structure of these aspects of Piagetian theory. Several recent investigations have a practical orientation and involve the development of teaching strategies based on Piagetian principles.

In view of the deluge of Piagetian studies and their diversity, this discussion is limited to the motivating factors behind the design of this thesis and the present survey of the literature will therefore be highly selective.

2.4.6.2 Studies Relating Theory to Teaching

Current research into teaching methodologies utilises the new perspectives of Piagetian theory which have emerged in the area of science education.

As research reported by Lawson and Renner (1976) and Renner *et al* (1976) has documented, the large proportion of secondary school pupils who are still reasoning at the concrete level, are able to learn very little, if any, material taught in an abstract verbal manner. Other investigators (Cantu and Herron, 1978; Howe and Durr, 1982a; Ingle and Shayer, 1971; Novick and Menis, 1976; Ward, 1972; Wheeler and Kass, 1974), have shown that full comprehension of most of the basic concepts of chemistry require formal operational thought. In an effort to eliminate the rote-meaningless memorisation of cognitively unassimilable material, many investigators have sought methods to make formal concepts more accessible to concrete thinkers. Analysis of the problem reveals two fundamental issues which are not necessarily separate from each other. The first part involves the instructional strategy and the corresponding demands made on the cognitive capacity of the learner. The second part involves the structural form in which concepts are framed.

a. Manipulation of Physical Models

The Piagetian principle of active learning requires that an instructional strategy should have some concrete referents. Piaget has emphasised that active manipulation of objects by the learner is a necessary (but not sufficient) part of teaching for cognitive development (Anthony, 1977; Ginsburg and Opper, 1969, p. 221; Piaget, 1974). Several studies have been undertaken to show that the manipulation of concrete molecular models will improve achievement (Drugge and Kass, 1978; Halsted, 1973; Talley, 1973). Halsted found that the performances of high school chemistry pupils improved with manipulative experience while Talley reported similar findings for college students. However, Drugge and Kass found no difference in achievement with ninth grade science students.

Researchers who examined the differential effects of manipulative experience on concrete and formal operational students are Gabel and Sherwood (1980), Baker (1978), Goodstein and Howe (1978), Kulm (1977) and Sheehan (1970). Sheehan, Baker and Gabel and Sherwood found that all students profited from the use of models whereas Goodstein and Howe and Kulm found that only formal students benefited from the manipulation. Although concrete methods of instruction have thus been successful in some cases, the comment made by Goodstein and Howe (1978) epitomises the limitations revealed by these studies :

> *However, concrete an activity, it is likely to fail in introducing essentially abstract ideas to students who think in concrete operational terms.*

More recently, Howe and Durr (1982b) have sought to improve comprehension of the concepts of the mole and the kinetic theory of gases, using both concrete materials and peer interaction. Essentially the same limitation as before was identified since only formal students were able to grasp subconcepts of the mole such as indirect determination of atomic mass, use of relative mass and calculation of molar mass. The study was nevertheless valuable in that critical attributes of the mole principle and the kinetic theory of gases were comprehended by both formal and nonformal operational students, accompanied by positive affective outcomes.

b. Use of Pseudoexamples

A variation on the strategy of manipulative experience is the expression of chemical concepts at the concrete operational level. Herron (1975), for example, suggests that students at the concrete level who are exposed to a formal topic, can be provided with concrete props which model the abstract concept. Concrete thinkers can thereby acquire a surrogate concept which they are able to manipulate, assisting transition to the actual concept later. Pseudoexamples (Cantu and Herron, 1978) consisted of illustrations, diagrams and models that could be used to focus attention on critical and variable attributes of concepts. Cantu and Herron investigated chemistry achievement by high school students using pseudoexamples to show perceptible *examples* and perceptible *attributes* of the concepts of mib*, ideal gas, isomer, metal, acid-base (operational) and acid-base (Bronsted-Lowry). After

Mib is the term coined by Cantu and Herron (1978) to represent a right-angled triangle with a segment perpendicular to the shortest side.

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