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

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receiving instruction, students took short tests which consisted of items requiring classification of instances as either examples or nonexamples of the newly learned concepts. Cantu and Herron found that pseudoexamples enhanced the achievement of all students but that the instruction was more beneficial for concrete students. However, whether concrete or formal concepts were taught, formal-operational students achieved better. Their conclusion was :

> *Based on what we now know, we believe that no teaching strategy will eliminate the difference in achievement between concrete- and formal-operational students, that many important ideas of science require formal reasoning for total understanding and that, because of this, we should continue our efforts to develop procedures which can be used to enhance the intellectual development of students.* (Cantu and Herron, 1978, p. 142).

c. Total Modification of Instructional Format

Modification to the design and presentation of an instructional course as a whole according to Piagetian principles has been studied as a means of making formal concepts more amenable to students who are not operating at the formal level. Mele (1973), for example, reports that Kaplan's Problem-Solving Biological Curriculum was beneficial to the promotion of formal operational thought. More general approaches, such as Piagetian-based activities in a Personalised System of Instruction (PSI) format, as tested by Bunck (1978) and Hardin (1978), seem to have been effective only in fostering positive attitudes.

An instructional format modelled after the heuristic principles of Piaget is the learning cycle which is characterised by the sequential elements of exploration, invention and discovery (application) (Atkin and Karplus, 1962; Lawson and Renner, 1975a). More recently, Karplus (1977a, 1977b) has referred to these activities as exploration, concept introduction and concept application, which terms clarify the functions and properties of each element in the sequence.

The rationale of the learning cycle is that, through a series of successive equilibrations, some aspects of the formal modes of functioning can be induced. The potential benefits of such an instructional strategy are not limited to the concrete operational learner. The learning cycle signifies provision of the necessary practice experience for students already at the formal stage who may fail to apply their

existent schemes to novel subject matter. The cognitive conflict which initiates the self-regulation process can occur through direct observation of physical phenomena or through social interaction. Cognitive conflict and social interaction need not be confined to the exploration phase of the cycle but may be employed during the entire sequence.

Campbell (1978) utilised the learning cycle in a PSI format with physics students. All students improved significantly in the use of formal reasoning abilities as measured by written and experimental tasks. The learning cycle also aided in the development of social skills and more positive attitudes in the laboratory. However, no significant differences in physics achievement were observed.

Ward and Herron (1980) used the learning cycle as a basis for laboratory instruction in introductory chemical courses at university level. The practical sessions involved experiments on the three topics of chromatography, activity series and chemical interactions. Statistically significant benefits due to the introduction of the learning cycle were observed in only one of the three experiments.

The studies by Linn and Thier (1975) and Ward and Herron (1980) have independently suggested that long term use of the learning cycle is likely to increase its effectiveness.

Referring back to the research of Ward and Herron, all three experiments favoured formal subjects on formal measures, with significant performance differences in two of them. Other researchers have reported similar results (Bass and Maddux, 1982; Cantu and Herron, 1978; Lawson and Renner, 1975b; Nous and Raven, 1973; Sheehan, 1970). In all three experiments, the formal students outperformed the concrete students even on concrete measures, significantly so in two of them. This result is lent research support by, *inter alia*, Cantu and Herron (1978), Goodstein and Howe (1978) and Sheehan (1970). It therefore seems that concrete and formal students are capable of competing without disadvantage only on material which demands *nothing more than the memorization of facts and formulas.* (Ward and Herron, 1980).

2.4.6.3 Acceleration of Intellectual Development

a. Feasibility

Most of the teaching strategies outlined in the above paragraphs can be characterised as utilising a *matching model* construct. Instructional material is selected and organised in such a way that underlying cognitive demands are appropriate for the intellectual level of the learner. Although moderate success in the application of this model has been reported, there has been general agreement that learners who are operating at the concrete level of development, are still at a disadvantage when compared with their formal operational counterparts. The current situation seems to be aptly summed up by Cantu and Herron (1978) in their conclusion, mentioned previously, that intellectual acceleration is potentially a more fruitful approach to aiding the comprehension of concepts that have, after all, been born and developed within the logical structure of a mature discipline. Against this background, the feasibility of accelerating stages of intellectual development will now be discussed.

Vygotsky (1962) has shown that the relationship between intellectual development and education is always reciprocal. In Vygotsky's terms, didactic instruction, as distinct from incidental experience only, can, and normally does, play a role in facilitating transition from one stage of cognitive development to another. The concept of developmental stages is not invalidated by the demonstration that they are susceptible to environmental influence (Ausubel, 1968).

Contrary to common interpretation of the Piagetian stage construct, Piaget clearly admits the possibility of enhancing intellectual development by exposure to guided experiences with the stipulation that such experiences must be appropriately contrived :

> *... learning is possible [in the case of these logical-mathematical structures] if you base the more complex structure on simpler structures, that is, when there is a natural relationship and development of structures and not simply an external reinforcement.* (Piaget, 1964a, p. 184).

Ausubel supports the Piagetian restrictions on the type of instruction which may be of value in intellectual acceleration :

> *Developmental considerations inevitably impose a limit on the extent of acceleration that is possible, inasmuch as transition to the next higher stage is invariably an organic outgrowth of, and hence presupposes, the attainment of a certain level of consolidation of proficiency at the preceding stage.* (Ausubel, 1968, p. 214).

Piaget has criticised many researchers who claim to have taught logical operations to young children. Further, a Piagetian-based assessment of any instruction purporting to enhance intellectual development, would employ the criteria of retention and transfer to other problems involving the same logical operations :

> *Is the learning lasting? What remains two weeks or a month later? ... How much generalisation is possible? ... When you have brought about some learning, you can always ask whether this is an isolated piece in the midst of the child's mental life, or if it is really a dynamic structure which can lead to generalisations.* (Piaget, 1964a, p. 184).

Ausubel (1968) also states the importance of retention and transfer in discrimination between rote learning and genuine cognitive development. He stresses that the empirical rules acquired by simple drill are easily extinguished by perceptually deceptive appearances, unlike the stable and organised concepts representative of a particular stage of intellectual development.

b. Training Studies

Training, from the Piagetian standpoint, may be defined as the simulation of natural experience in a short-term laboratory setting, with a view to partially inducing cognitive reorganisation based on the progressive amalgamation of this experience and reflective activity. Training is thus distinct from teaching which must be construed within a much more general frame of reference. Before going on to discuss training studies in general, it is appropriate to mention here, in the context of teaching, that a major function of science education is to stimulate cognitive development (Renner and Lawson, 1973; Lawson and Renner, 1974). The Piagetian framework has been used explicitly in the innovation in science education represented by several science curriculum projects (Driver, 1981). These programmes include the Science Curriculum Improvement Study (SCIS) in America, Science 5/13 in England and the Australian Science Education Project (ASEP). All specify the

objective of the development of cognitive skills. The basic assumption underlying four other recent science development projects cited by Lawson (1982) is that improvements in formal reasoning will cause improvements in general achievement.

There is evidence in the literature of success or partial success in the promotion of scientific reasoning by training procedures. The present discussion will be limited to studies which have endeavoured to induce formal modes of functioning. Numerous attempts have been made to train younger children on the Piagetian conservation concepts. These studies have been reviewed by Beilin (1969), Ausubel (1968) and Brainerd and Allen (1971). In brief the reviews indicate that in most cases training of specific conservations has been successful.

Collectively, studies which have aimed at fostering formal reasoning, demonstrate that training does tend to spur, solidify or otherwise further formal-operational cognitive progress. Comparative evaluation of these studies soon leads to confirmation of the opinion expressed by Levin and Linn (1977) :

> *The great diversity of subjects, mode of instruction, method of measuring learning, and length of training make it difficult to draw precise conclusions about the effect of training.*

In general the training programmes may be divided into the four categories of individual instruction, programmed instruction, classroom instruction and experiential science. Within these categories, both cognitive conflict and the provision of strategies for the solution of problems have been used to describe procedures which enhance reasoning ability. In Piagetian terms, the rationale governing these techniques rests on the hypothesis that the consolidation of ideal cognitive competence may be retarded by lack of exposure to experiences necessary to develop efficient methods of organisation and the mental capacities for the fruitful assimilation of information. The selected technique is usually combined with some degree of practical experience.

Training programmes in general have been cognisant of Piagetian predictions on the restrictions to learning. For the most part, the scope of each investigation has been limited deliberately to one relatively narrow area of problem-solving. DeCarcer, Gabel and Staver (1978) have identified three classes of research in terms of training objectives. In the first category, students have been trained to give

correct responses on specific Piagetian tasks. Studies by Bass and Montague (1972) and Siegler, Liebert and Liebert (1973) belong to this class. The second category is composed of studies in which training on a specific mental operation is stressed. Subjects are therefore trained to generalise on mentally isomorphic tasks exemplified by the training task. This category includes studies related to the control of variables by Bredderman (1973), Case and Fry (1973), Lawson, Blake and Nordland (1975), Lawson and Wollman (1976) and Wollman and Chen (1982). Further studies belonging to this class are those by Enyeart (1981), Kurtz (1977), Lawson and Wollman (1975), Shyers and Cox (1978) and Siegler (1976), which have all been focused on proportional reasoning. Hammond and Raven (1973) and Nous and Raven (1973) have selected compensatory operations and correlative thinking as the targets of their respective training studies. Fischbein, Pampu and Mânzat (1970) and Barratt (1975) have examined the promotion of combinational problem-solving. The third class is composed of studies which have emphasised general changes from the concrete to the formal stage and are not concerned with any particular mental operation. Among such studies are those by McKinnon and Renner (1971), Pearce (1971) and Schwebel (1972).

In view of the methodological diversity and lack of agreement as to the criteria for successful training, only a general overview of the studies is given at this point in the thesis. Individual training studies which are relevant to the present work, will be discussed in later chapters. The absence of any norms for training studies has provoked a spate of comment and criticism which has established guidelines for future studies. These guidelines are vital to the present research design as it may already be apparent that this literature search is tending towards a theoretical motivation for a training study.

Levine and Linn (1977) and DeCarcer, Gabel and Staver (1978) have reviewed the literature on the implications of Piagetian research for high school science teaching. In contrast to an earlier review by Neimark (1975a), their considered opinions are that training studies give evidence that mental operations of the formal stage can possibly be enhanced. Research findings lend support to the view of Piaget (1964a) that efforts to accelerate development must focus on students whose ages are close to that taken as the most frequent age for attainment of formal thought.

Levin and Linn suggest that strategy learning not only enhances performance on the trained task but is effective in achieving specific transfer (Case and Fry, 1973; Grey (in Peel), 1971; Hyram, 1957; Lawson, Blake and Nordland, 1975; Olton and

Crutchfield, 1969; Raven, 1974). Experience with apparatus, especially when combined with the presentation of strategies, seems to facilitate nonspecific transfer (Linn, Chen and Thier, 1976; Linn, Chen and Thier, 1977; Linn and Thier, 1975; Siegler and Liebert, 1975). Cognitive conflict as a device to accelerate intellectual development has not been universally successful (Bredderman, 1973; Case and Fry, 1973; Peel, 1971). On the other hand, Ward and Herron (1980) have singled out three training studies (Campbell, 1977; Carlson, 1975; McKinnon, 1970) as having been particularly successful in their attempts to promote the transition from concrete to formal thought. The factors common to these studies were identified as physical interaction and social transmission. Peer interaction appeared to function by the production of cognitive conflict in subjects on the encounter of viewpoints different from their own. A training study by Johnson (1977) has in fact shown social interaction to be effective in producing internal conflict and, in turn, in accelerating attainment of the concept of conservation of area. Wollman and Chen (1982) also have recently used structured social interaction in a classroom training study with the control of variables as its central aim and report good results.

Barratt (1975) has criticised several published studies on the training of formal thought on the grounds that none of them has met all the methodological requirements for good training research. These include the use of transfer designs, immediate and delayed posttests and control groups (cf. Piaget, 1964a). In similar vein, DeCarcer, Gabel and Staver (1978) comment that strong inferences from most of the training studies in their review article are not allowed owing to the absence of retention data. A further weakness in the design of several studies was the lack of control of possible intervening variables. An acceptable research design demands, *inter alia*, adequate sample size, the use of a pretest as well as a delayed posttest and the presence of a control group. Their review is concluded by calling for more training studies which are properly conceived and which focus on retention achievement and transfer effects.

c. Evaluation of Experimentally Induced Change

Training studies have been examined in depth by Kuhn (1974) with respect to the logical basis of the method and surrounding theoretical and methodological issues. She points out the lack of agreement among researchers as to proper criteria for inferring change. A set of stringent criteria was formulated by the Genevan group studying experimental acceleration of intellectual development (Inhelder and Sinclair, 1969). A successfully trained subject must make responses that include appropriate

explanations, persist over time and generalise to nontrained material. In addition the subject should resist countersuggestion. Some researchers, such as Brainerd and Allen (1971) and Brainerd (1973), consider either explicitly or implicitly that these criteria are unnecessary or inappropriate. While Kuhn refutes this view, she claims that the evaluation of any training intervention remains ambiguous even where researchers have judiciously applied the Genevan criteria. Kuhn argues that appropriate explanations and durability of responses are both necessary but not sufficient criteria to permit judgement of genuine change. Moreover, the criterion of resistance to countersuggestion is not valid. The generalisation criterion is identified as the critical one but lends itself to idiosyncratic interpretation.

Kuhn elaborates her theme by stating that the effectiveness of a training strategy in promoting structural change depends on the extent to which the subject is compelled to reconstrue his conceptualisation of the problem with which he has been confronted.

> *In this light, the true enormity of the problem of devising an effective training technique quickly becomes evident. In a word, what [illegible] experimenter regards as a discrepant or anomalo[illegible]sentation, hence requiring some reconstruing, [illegible] not be at all disturbing to the child.* (Kuhn, 1974, p. 596).

Kuhn supports her contention by reference to the work of several researchers, including a conservation study by Murray (1972) and the review by Brainerd and Allen (1971). Finally, she regards as remote the possibility of inducing cognitive restructuring by means of the brief interventions characteristic of present training studies.

Kuhn suggests that the inconclusive results of existing training studies, which have arisen from the severe limitations to our present knowledge and methodological techniques, account for the current decline in interest in the performance of such studies. She proposes that future training studies should be undertaken as the second phase of a research programme that has as its foundation a detailed longitudinal assessment of the natural development of those behaviours thought to be relevant to the consolidation of the cognitive structure in question. A large body of normative data would provide investigators with unambiguous criteria by means of which the effectiveness of a training intervention may be assessed. A naturalistic longitudinal analysis would identify the environmental experiences which commonly

accompany development of the intellectual skill to be studied. Modelling proposed interventions on these experiences would increase the probability of genuine cognitive change. With the same ultimate objective, repeated interventions would be attempted at intervals over the period of natural development in order to hasten development yet preserve the natural patterns of intellectual attainment.

d. Rationale behind the Present Investigation

There has been a recent sharp decline in training studies and an increase in theoretical studies aimed at elucidating the finer details of the Piagetian construct. This shift of emphasis may have been occasioned by the severe limitations of the early training studies as suggested by Kuhn in her masterly exposition. Although relevant psychological research can make an important contribution to many pedagogic issues, the goal of educational studies should not be directed towards the discussion, exploration and elaboration of theories *per se*. The goal of such studies should be facilitation of the learning process and the problems indigenous to psychoeducational research can be inferred directly from the problems facing the classroom teacher. Bearing in mind that education intrinsically entails practical educator-educand encounters, a tendency among numerous studies for theorising divorced from practicality is perhaps unfortunate since the only valid resolution of a pedagogic issue is empirical test in the classroom.

> *Most science education research on the learner has contributed more knowledge to the paradigms of psychology than to science education.* (Lowery, 1980).
>
> *... Why can't we just phrase our research questions straightforwardly (as questions, not as theories to be tested) and get on with it?* (Westmeyer, 1982).

The ultimate value of present theoretical studies to education is not disputed. However, once the finer points of the theories under investigation have been established, it will then be necessary to embark on training studies to demonstrate whether these theoretical principles are useful in the classroom situation. Educational studies are necessarily cyclic in that theories are proposed and then tested by means of training and similar studies, after which the theories are refined or modified and then tested experimentally again and so on.

While many current studies are aimed at probing the minds of students, the present research, conducted by a concerned teacher, is intended to ascertain whether

classroom achievement can be directly improved. It would not be premature to utilise a training procedure provided such a procedure is designed around practical utility rather than more fundamental issues of cognitive functioning. The training study in this thesis addresses itself only to the critical extrapolation of aspects of pedagogy which have been derived from theoretical premises as a tool. If subjects can be made more intelligent by the training interventions in the sense of enhanced performance on problems with abstract connotations, then the training study will have served its purpose. It would be scientifically naive to expect that interventions on a short term basis can appreciably alter cognitive structure, hence caution is necessary in the explanation of possible positive results of the training study.

e. Language Demands

Having decided to implement a training study with these qualifications and reservations, further scrutiny of Kuhn's exposition serves to glean some prescriptions for sound design of the study. In particular, she has commented at length on the interpretation to be placed on the Genevan criterion of appropriate explanations as evidence of intellectual change in posttraining assessment. Brainerd (1973) has argued that the Piagetian assertion of the dependence of language on operativity means that some subset of subjects may in fact possess the cognitive structure(s) being assessed but fail a test which demands their linguistic expression. Kuhn contends that it is debatable whether stimulus refinements to dichotomous choice methods, as preferred by Brainerd, could ever prevent correct requisite two-choice discriminations made purely for idiosyncratic or extraneous reasons. She suggests that

> *Overall, the generalization seems warranted that the most trustworthy methods for assessing the attainment of a given cognitive structure are those that elicit a variety of responses, both verbal and nonverbal, and make an inference based on this constellation of responses.*
> (Kuhn, 1974, p. 592).

2.5 Selection of Methodology

2.5.1 Data Collection

The rationale underlying the methodology in this thesis is fully discussed in the appropriate chapters. However, from the outset, it is evident that, in a project

oriented towards intellectual acceleration, the empirical assessment of Piagetian levels of thought in subjects is of vital importance. The most frequently employed data-gathering techniques are the clinical interview and the use of paper-and-pencil test instruments. The research design should adopt the alternative which seems to offer the lesser compromise to the present objectives since, given current knowledge and methodology, both methods have limitations as well as advantages. The choice between the two methods is the subject of frequent debate in the literature.

2.5.1.1 The Clinical Interview

The *méthode clinique* which was developed by Piaget, is the classic procedure for the determination of level of cognitive development. The clinical interview is characterised by the presence of manipulative materials or other visual stimuli. Further essential features are flexibility and carefully planned experimenter questioning following responses from the subject, with a view to identifying, analysing and interpreting the reasons behind the responses. To this end, the interview also commonly incorporates observation of the reaction of the subject to counter-arguments.

The probing nature of the clinical interview is appropriate to detailed elucidation of cognitive activity and its assessment in terms of the Piagetian designated stages. Ward *et al* (1981), among others, have remarked that individually administered Piagetian tasks are the most widely accepted method for making determinations of cognitive levels.

Dexter (1970) has elaborated upon the universals of interviewing which, *inter alia*, demand that the interviewer

(i) be guided by a definite plan but refrain from being suggestive.

(ii) show no reaction which could show bias and expectation.

(iii) be continually alert.

(iv) be aware of the danger of misinterpretation of response.

(v) have a capacity for empathetic understanding of the subject.

Pines *et al* (1978) have also given attention to the administration of the interview and maintain that interviewing skills can only be developed by conscious effort over

an extended period of time. The clinical interview thus requires trained interviewers and interrater reliability checks to enhance investigator fidelity of the treatment.

Individual interviews are, moreover, very time-consuming and, more significantly, at the present time *our interview strategies are still unrefined and in a state of flux*. (Posner and Gertzog, 1982). Posner and Gertzog stress that continued research activity is needed in order to increase the applicability and validity of the clinical interview as a method for evaluating cognitive structure. Of particular concern is the lack of systemisation with which interview transcripts are presently analysed.

Donaldson (1979), after several years with the Geneva group, has shown that the interaction of the interviewer, student and testing materials have an effect on the resulting performance and interpretation. It is evident that,

> *As the interview grows in its innovative use in testing, possible effects of the method of administration are a valid concern urgently needing further systematic study*. (Wilson, 1981).

2.5.1.2 Respondent-Completed Written Instruments

There is a wide variety of data-gathering instruments in the alternative domain of respondent-completed paper-and-pencil forms from which scores on the desired cognitive characteristic may be extracted. Tisher (1971) and Tisher and Dale (1975) have advanced the generally accepted view that the only economical means of assessing large numbers of participants is to develop and evaluate objective test instruments which can be administered in the classroom situation. Many standardised instruments measuring cognitive maturation have been developed as a result of current increased interest in Piagetian theory as related to school and college science curricula. The rationale of these tests varies. Some rest on the assumption that Piaget's logical model has adequate explanatory power for the task-defined levels of intellectual development while others, regarding his meta-theory as unconvincing, offer reinterpretations of his concept of scientific reasoning in terms of cybernetic principles.

The tests also differ in construction. Some tests, while employing a paper-and-pencil format, adhere to the traditional interview principle that the subject should be influenced by his perception and therefore also involve the active handling of Piagetian-based or other apparatus. Active manipulation often demands spacious

laboratory facilities when the number of test participants is large. Some tests therefore substitute some form of demonstration or even a videotape of the demonstration. Other tests use a paper-and-pencil presentation only.

Controversy seems to surround the construct validation of group-administered tests of formal thought. Paper-and-pencil test instruments, with particular emphasis on their validity, reliability and usefulness to science educators, have been developed by, among others, Bart (1972), Burney (1974), Carlson and Streitberger (1983), DeAvila and Pulos (1979), DeLuca (1979), Karplus *et al* (1977), Lawson (1978), Longeot (1962, 1964), Milakofsky and Patterson (1979), Patterson and Milakofsky (1980), Raven (1973), Renner (1977), Renner *et al* (1978), Rowell and Hoffmann (1975), Shayer *et al* (1981), Shayer and Wharry (1974), Sheehan (1970), Sills (1977), Staver and Gabel (1979), Staver and Harty (1979), Tisher (1971), Tisher and Dale (1975) and Walker *et al* (1979).

Several of these researchers have argued that efforts to develop formal reasoning instruments by other workers have only partially met the criteria which are prerequisite for valid, efficient tests. On these grounds, Staver and Gabel (1979), for example, have attacked Burney (1974), Lawson (1978), Raven (1973), Shayer and Wharry (1974) and Tisher (1971). In turn, Staver and Gabel have been attacked by Pezaro (1982) who alleges that weaknesses in their factor analysis undermine any possible interpretation of their questionnaire and that further refining of their test is necessary.

2.5.1.3 Comparison of Methods

Roberts (1980) uses mathematical and statistical arguments to question the advisability of using paper-and-pencil tests such as the Longeot as a substitute for the clinical interview in ascertaining an unbiased estimate of formal operations ability. On a more general level, Renner (1979) hypothesises that removing the element of social transmission from the process of determining the intellectual level of a particular individual, reduces the validity of that process. Shayer *et al* (1981), on the other hand, contend that paper-and-pencil tests are in many circumstances more valid and reliable indicators than traditional Inhelder tasks. They have examined seven Piagetian tasks with samples of three hundred to five hundred subjects. Comparing performances on these tasks with those on their written equivalents, Pearsonian correlations ranged from 0,55 to 0,85. These findings are not supported by Tschopp and Kurdek (1981) who have assessed the relation between three traditional tasks, involving combinations, proportions and correlations, and their paper-and-pencil analogues which were devised

by Tomlinson-Keasey and Campbell (unpublished work cited by Tschopp and Kurdek). They report that the correlations between the two sets of tasks were low and nonsignificant with r's ranging from –0,20 to 0,35, (with the exception of the chemicals task and its written counterpart ($r = 0,35$, $p < 0,05$) provided that dissimilar quantitative scores were assigned).

Ward *et al* (1981) maintain that the Longeot (1962) test is a reliable instrument for assessing the cognitive levels of large numbers of students. Scores on the Longeot test exhibited a significant correlation ($r = 0,62$, $p < 0,01$) with the sum of scores on two Piagetian tasks (balance beam and flexible rods). Farmer *et al* (1982) report similar findings in their validity study of two paper-and-pencil tests, one being the Longeot, the other being coined the KLR test, referring to a test whose components were separately developed and used by Karplus and Lavatelli (1969), Lawson and Blake (1976) and Renner *et al* (1978). The scores obtained on each set of tests were compared with the composite scores on three traditional Inhelder tasks (chemicals, rods and shadows). The correlations between the Longeot and Inhelder scores ($r = 0,55$, $p < 0,05$) and between the KLR and Inhelder scores ($r = 0,61$, $p < 0,01$) were significant and moderately high. Farmer *et al* (1982) point out that the components of the KLR test, although each related to Piagetian logic, were developed separately and therefore should not be expected to demonstrate the same internal logical unity as the Longeot test which was developed as a Piagetian-based battery.

Blake (1980), on the other hand, has evaluated the predictive power of Sheehan's (1970) test and Tisher and Dale's test (1975), both based on the original tests of Longeot (1962, 1965), and arrives at the following conclusion :

> *Science teachers and researchers who wish to determine Piagetian levels of their students, should carefully examine the documentation establishing the concurrent or predictive validity of any pencil-and-paper test before they reject the conventional but time-consuming administration of individual Piagetian tasks in favor of such a test.* (Blake, 1980).

It is apparent that pencil-and-paper tests, in spite of criticisms, often justified, are invaluable, if not indispensable, to the teacher in the role of diagnostician where a reasonable match is required between the cognitive capabilities of the pupils and the logical demands of the learning material (the *matching model* of Shayer and Adey, 1981). In fact nearly all of the thirty-four Piagetian studies summarised by Sipe and Farmer (1982) utilised pencil-and-paper tests as data-gathering instruments. Sipe and Farmer suggest a *caveat :*

> *... the later Piagetians may have a measure of constructs relative to instructional need but they are probably not those Piaget and Inhelder defined operationally.*
> (Sipe and Farmer, 1982, p. 336).

Farmer *et al* (1982) have emphasised that the paper-and-pencil tasks in their study, described earlier in this section, provide a less rigorous definition of formal operation than do the Inhelder tasks.

2.5.1.4 Choice for the Present Research

Various written instruments may differ markedly in construction but the reported discrepancies do not settle the current debate among workers on choice of measure, the clinical interview or paper-and-pencil tests. Mayer and Richmond (1982) in their overview of assessment instruments in science, succinctly sum up the considered opinions of many researchers in the interview/paper-and-pencil test controversy :

> *Very few instruments have been put through an extensive period of development and refinement. Only if this is done, will we ever be able to attain enough confidence in the validity of the instruments we are using*

In the light of previous work and comments as reviewed above, on balance it seems that the interview method would be the better choice in the research situation, as distinct from the classroom situation. The probing of understanding inherent in the *méthode clinique*, which allows investigation and interpretation of the reasons behind responses, virtually eliminates the possibility that a subject might be incorrectly classified as operating at the formal stage on the task at hand. The detailed procedure characteristic of the interview method may elucidate certain research issues (see Chapter 4). It will also enable the use of a measurement scale which permits allocation of scores within each substage, a feature essential for statistical sensitivity, for which provision must be made in view of the fact that there is obviously no advance indication of the effectiveness of training. The statistical framework is a critical feature of any research and thus an entire section of Chapter 3 has been devoted to this topic.

Other considerations further supported the selection of the classic interview method. The group of subjects was entirely voluntary and it was vital to provide enjoyable activities to ensure attendance by all subjects until the end of the

investigation. From the researcher's teaching experience, the manipulation of apparatus, a characteristic feature of the interview method, accompanied by social interaction with the interviewer, would be viewed as an interesting activity, while paper-and-pencil tests would be unpleasantly suggestive of regular class tests. This idea was later proved correct (Appendix II). Further, the concrete goal-orientation of the Piagetian task at hand served to maintain motivation and interest of the subjects. This is clearly a factor which must be considered in the selection of a specific task or tasks as an estimate of formal operations and will be discussed in Chapter 4.

2.5.2 Data Interpretation

2.5.2.1 Limitations to Generalisation

Since a productive, disciplined study of testing in science education has to date not been achieved, it is clear that many of the developmental efforts have raised questions and new challenges for test research. An oft-levelled criticism which is applicable to both interview and written test instrument methods, is that innovative formats and/or variation in the mode of information presentation may affect subject performance or even shift the burden of perception from one group of abilities to another. This leads to the inevitable question of, once data on cognitive abilities have been collected, what the data actually signify. To this end, the dimensions of content and problem effects and their influence on performance must be carefully considered.

Any Piagetian study should operate from the perspective of caution in generalising the extent to which any assessment of a subject's stage of thinking reflects the actual operational capabilities of that subject. The Piagetian position postulates a certain internal coherence of cognitive stages but Piaget (1972) has emphasised that this tenet must not be misinterpreted as giving rise to the corollary that uniform performances should be expected from a subject across all types of task (Section 2.4.4.5).

In the discussion of the Piagetian stage construct earlier in this chapter, it was pointed out that growth in cognitive capacity always proceeds at two levels concomitantly : general and specific. For example, the dependence of the formal thinker on concrete-empirical props is only temporary and reflective of circumscribed immaturity in particular new subject-matter areas only. The interpretation of data purporting to measure Piagetian levels of thought must thus be circumscribed by the

intrinsic specificity of the assessment task. In particular, formal performance on one task may not be extrapolated to the conclusion that a subject is a formal thinker in all subject-matter areas. The sole permissible inference is that the subject exhibits formal reasoning on that particular task only. One may not even validly claim that the performance of the subject is generalisable to other situations which demand the same mental operations.

2.5.2.2 Documented Variations in Performance

The degree of homogeneity underlying the developmental stages and the degree of internal coherence of the specific operations involved in thought processes are important spheres of current interest. Both areas have clear implications for educational research and diagnostic classroom practice. Numerous empirical studies have been addressed to this question, the majority of which lend support to the theoretical exposition in Section 2.4.4.5.

Studies with a pragmatic approach have shown in general a lack of intraindividual consistency in performance across Piagetian formal operations tasks. Lovell (1961) reports significant association among two hundred 8–32 year olds on different sets of four tasks per respondent. Martorano (1977), on the other hand, obtains high degrees of intraindividual variability in the performances of eighty 11–18 year olds on a set of ten tasks which were representative of several formal schemata. Tschopp and Kurdek (1981) give evidence of nonsignificant correlations (r's ranging from [illegible] to 0,26) between three traditional tasks (chemicals, proportions and correlations). Pascual-Leone (1970) reports on the failure of a number of investigators to find, among subjects of a given Piagetian developmental level, high correlations for tasks involving a particular operation. Bady (1978) has indicated only moderate intertask reliabilities within the specific scheme, using five proportionality tests and five combinational analysis tests. Bady criticises most of the studies cited by Chiappetta (1976) in his review of Piagetian research, on the grounds that only one or two tasks were used for classification of subjects into Piagetian stages. One tenuous assumption underlying such an approach is high intertask reliability within the scheme involved. Further it is presumed that demonstration of the presence or absence of one scheme by a subject infers the presence or absence of formal operations in general.

2.5.2.3 Causes of Performance Variations

The above studies provoke the salient question of whether task differences reflect differential levels of cognitive development of the formal operations schemes tested or whether the task differences reflect the operation of a combination of performance factors. Driver (1981) has reviewed factor analytic studies by Lawson and Nordland (1976), Lawson and Renner (1974) and Shayer (1979) which suggest the underlying unity of the formal operations schemes. Pallrand (1979) has remarked on a differential pattern of development for combinatorial reasoning (earlier capacity) and proportional reasoning (later capacity). Lawson *et al* (1978) report a factor analytic study indicating the possibility of developmental links between proportions, probability and correlations tasks. Karplus *et al* (1980) suggest that tasks involving proportions, probability and correlations vary in difficulty. The observed differences in mastery of the various operations do not however deny the Piagetian tenet that the operations appropriate to each stage of reasoning basically emerge in unison (Section 2.4.4.5).

Flavell and Wohlwill (1969) have distinguished between a competence model and a performance model of cognitive development. Neimark (1975b) suggests that differential levels of performance by a subject across formal operations tasks may reflect degree of experience or familiarity with task materials. Further, Pallrand (1979), finding lack of consistency in performance on Piagetian tasks, suggests that factors inherent in various tasks tend to inhibit the use of certain cognitive structures. In the sciences, for example, such a factor would arise from the use of laboratory equipment which presents a multiplicity of perceptual cues to the respondent or learner. In similar vein, Martorano (1977) puts forward as factors affecting performance : the type and number of stimulus materials and dimensions of the tasks and the different physical manipulations required. DeLuca (1981) has applied cluster analysis to the study of Piagetian stages and reports that lack of synchronisation of substages across several tasks suggests that Piagetian tasks are situation-specific. Studies by Hughes (1980), Shayer *et al* (1976) and Wason and Johnson-Laird (1972) indicate that the contextual aspect of a task, rather than its logical structure, seems to be a determinant of performance. The importance of prior knowledge has always been emphasised by Ausubelian supporters and acknowledged, never denied, by Piagetian supporters. There is mounting evidence that individuals use implicit theories derived from prior experience on which to found their reasoning (Driver, 1981). As investigations by Karmiloff-Smith and Inhelder (1975) and Kuhn and Brannock (1977) show, these implicit theories or conceptual frameworks

> *... influence the way pupils tackle problems, the variables they consider significant and the factors they observe and to which they pay attention.*
> (Driver, 1981, p. 14).

Linn (1982) states that teaching, in order to be effective, needs to diagnose and remediate inaccurate rules used by students. Hewson and Hewson (1983) have shown that successful instructional intervention should involve the identification and use of prior knowledge possessed by the learners. Such intervention must include the explicit consideration and change of any conceptions of common phenomena which diverge from the accepted interpretations of these phenomena.

Linn (1977, 1978) and Linn *et al* (1981, 1983) have examined content and problem effects within a Piagetian framework and point out, *inter alia*, that current research methodology tends to confound the content of the task with the strategy being investigated. Wollman (1982), in his discussion of form versus content in Piagetian testing, identifies three dimensions of performance : working memory demands, task-specific information and form/content dissociation. It seems clear that any prediction which may be made about an individual's level of operativity, based on a single Piagetian task as a diagnostic measure, could only be a weak guide.

2.6 Directional Organisation of the Present Study

2.6.1 Theoretical Stance

Examination of the literature served to decide the theoretical stance together with the end and the means of the present research design. Useful research should be conducted against the background of a paradigm or model. Although the theories of Piaget and Ausubel cannot be said to constitute an amalgamation, the two theories do overlap. They also possess a common terminology which involves shades of meaning that have come to deviate from dictionary definitions and also differ in usage for each theory. In both theories, mental structures and prior knowledge are inextricably interwoven in the learning process. The complementarity of Piagetian and Ausubelian theories seems feasible as a guide for the organisation of this applied study which is aimed at maximal achievement of pupils of all levels.

2.6.2 Piagetian Nature of Study

Piagetian studies have shown that acceleration of intellectual development appears to be the most promising method of fostering achievement in physical science

at secondary level. The most suitable vehicle to achieve this growth seems to be a training study, even though such studies are not currently in vogue. Current research findings would seem to recommend the restriction of a particular investigation to one operational schema only as opposed to the investigation of logical operations as a whole. Since the combinatorial system is the foundation of formal thought processes, the selection of the combinatorial schema would seem appropriate in an acceleration programme.

The Piagetian standard of attainment for successful training is some degree of unwavering, lasting and generalised transition to the next higher stage. This requires that subjects be at an age near the spontaneous development of the schema to be investigated. Further, it cannot be expected that cognitive growth would readily be accelerated by, for example, a single short intervention. Of the Piagetian criteria, the most essential is the ability to transfer to new situations. Secondly, retention has been deemed necessary but not sufficient whereas resistance to counter-suggestion has been deemed unnecessary.

A diversity of methods exists for training. For any of these, the procedure must be organised with great care, both experimentally and statistically. A pretest-posttest control group design should be used. The most successful training studies have employed features of the learning cycle which involves a series of successive equilibrations arising from cognitive conflict. This implies active involvement of subjects in the training procedure. Social interaction is featured in the learning cycle and should be included if possible.

Allocation of Piagetian categories to subjects is demanded by research of this kind, but results are only applicable within the context and content of the task or tasks employed. No assumption of generalisability should be made, either within the schema being investigated or to other formal operations. If practicable, more than one task should be used for diagnosis of intellectual capacity.

The interview mode of data collection seems preferable to paper-and-pencil tests for the present purpose but its limitations must be considered. Furthermore, interviews must be conducted as far as possible within the norms of accepted practice suggested by specialists in interview techniques.

2.6.3 Ausubelian Nature of Study

There is no reason why the training should not serve simultaneously as Ausubelian advance organizer for novel academic material. To achieve such a dual role, the training must feature the Ausubelian principle of progressive differentiation in order to generate the subsumers of the subsequent learning material. There is lack of consensus as to the efficacy of advance organizers since, *inter alia*, Ausubel's definition of an advance organizer is not clear in the operative sense. In practice, a broader definition has recently been used to some effect. A particular example of this is a visual organizer. For the purpose of the present study, the visual organizer would seem to tie in with the Piagetian principle of concrete referents.

CHAPTER 3

THE RESEARCH DESIGN

3.1 Experimental Procedure

The planning stage of the research design involved examination of the characteristics of both Piagetian and Ausubelian approaches in order to optimise the experimental sequence for the synthesis of the two theories. The term, *synthesis*, as used here, is not intended in the dialectical sense but should be interpreted to mean that the two paradigms are viewed as complementary models of learning and are therefore used concurrently in the present investigation.

The general attributes and experimental sequence of a Piagetian training study designed to enhance the development of formal operational thought, are shown in Figure 3.1. It must be stressed that, for any meaningful outcome of the research, it is necessary that the subjects be divided into two groups, one of which is submitted to the training and the other serves as the control group, a requirement which is not always satisfied by the training studies reported in the literature. (This comment applies equally to Ausubelian procedures.) The investigation commences with a pretest, administered to all subjects, which usually examines the Piagetian scheme under consideration, although this may vary in cases where training is directed towards performance on a single task or towards accelerating the transition from concrete to formal thought in general. This is followed by the training of the experimental subjects. As was seen in Chapter 2, the technique used for inducing logical operations has not been standardised and is still a controversial issue. The control subjects are given an activity which is irrelevant to the study. The judgement of what constitutes an irrelevant activity is necessarily subjective, in the absence of any generally accepted criteria for such an activity. At the very least, this activity must not involve the same mental operations as the training task and should preferably promote confidence among the control subjects that *'treatment'* is being received. Further, this activity should avoid the same materials, mode of presentation and physical manipulations as the training task. Participation by the control subjects in the placebo activity should last for a period commensurate with the time used to train the experimental subjects. The posttest, which is usually the same as the pretest, is then administered to all the subjects. Finally, the more valid studies are extended to include examination of the important Piagetian criteria of retention and transfer of the learning.

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