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CANADIAN THESES ON MICROFICHE | ***THÈSES CANADIENNES SUR MICROFICHE***

NAME OF AUTHOR/*NOM DE L'AUTEUR* Margaret D. CUSACK

TITLE OF THESIS/*TITRE DE LA THÈSE* TEACHING PRACTICES IN JUNIOR SECONDARY SCIENCE CLASSES

UNIVERSITY/*UNIVERSITÉ* Simon Fraser University

DEGREE FOR WHICH THESIS WAS PRESENTED/*GRADE POUR LEQUEL CETTE THÈSE FUT PRÉSENTÉE* Master of Science (Education)

YEAR THIS DEGREE CONFERRED/*ANNÉE D'OBTENTION DE CE DEGRÉ* 1980

NAME OF SUPERVISOR/*NOM DU DIRECTEUR DE THÈSE* Dr. Marvin Wideen

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TEACHING PRACTICES
IN JUNIOR SECONDARY SCIENCE CLASSES

by

Margaret D. Cusack

B.Sc., University of Adelaide, 1959

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF

THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE (EDUCATION)

in the Faculty

of

Education

SIMON FRASER UNIVERSITY

December 1979

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Author: _____

(signature)

Margaret D. CUSACK

(name)

4-12-79

(date)

APPROVAL

Name: Margaret D. Cusack

Degree: Master of Science (Education)

Title of Thesis: Teaching Practices in Junior Secondary Science Classes

Examining Committee

Chairman: M. Manley-Casimir

M. Wideen
Senior Supervisor

A. Whitney
Second Member

A. Sherwood
Third Member

J. W. George Ivany
Professor and Dean of Education
Simon Fraser University
External Examiner

Date approved December 4, 1979.

ABSTRACT

Recent research in science education has been greatly influenced by Piaget's theory of intellectual development, particularly that aspect of the theory which relates to the development of formal-operational structures. This study focused on teaching strategies likely to promote formal-operational reasoning patterns in adolescents. From the research literature in secondary science teaching, ten teaching practices were identified which were considered likely to promote the development of formal thought. Six of the practices related to student activities and four to teacher activities in the classroom. An instrument was then constructed, based on these strategies, which employed a modified sign system to determine the frequency of occurrence of each of the activities. Science teaching was then observed and audio-taped in 18 randomly selected junior secondary science classrooms for a total of 52 lessons in two school districts in British Columbia. Subsequent coding of these lessons enabled the identification of present teaching practices being used by the teachers in the sample. In addition, it allowed the determination of the extent to which current teaching practices in those classrooms were similar to those practices considered likely to develop formal-operational reasoning patterns. It was found that junior secondary science teaching in this sample

did not resemble the ideal pattern which would be expected if the development of formal reasoning was a major objective of teaching. It was concluded that the junior secondary science teachers observed in this study were either unaware of, or not interested in, promoting the development of students' reasoning patterns towards formal-operational structures.

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CHAPTER I

INTRODUCTION TO THE STUDY

Context of the Problem

In recent years secondary and college science educators in many countries have been significantly influenced in their thinking by Jean Piaget's theory of intellectual development. Herron (1975 and 1978), Karplus (1977), Lawson (1979), Lowell (1979), McKinnon and Renner (1971), Shayer (1970) and Wollman and Karplus (1976) are among those who have examined that aspect of the theory which deals with the development of formal-operational reasoning patterns from concrete-operational structures as it pertains to science teaching. In addition, research carried out by Cantu and Herron (1978), Case and Fry (1973), Goodstein and Howe (1978) and Sheehan (1970) shows that students capable of operating only at the level of concrete operations cannot successfully learn abstract science concepts. They all consider that these more complex reasoning patterns typical of the formal-operational stage are essential for understanding and successful achievement of topics taught in upper secondary science courses.

However, an examination of international studies in which the intellectual development of adolescents has been

assessed reveals that a high percentage of adolescents and young adults operate at the concrete-operational level. Chiappetta's (1976) review of ten such studies carried out in the United States; Shayer, Kuchemann and Wylam's (1976) testing of over ten thousand students in the United Kingdom; Karplus, Karplus, Formisano and Paulsen's (1977) testing of students in seven countries; Han's (1977) work in Korea; Lowell's (1979) and Wheeler and Kass's (1977) work in Canada all consistently show that the majority of students in grades seven through twelve function at the concrete-operational level.

Earlier writings by Piaget (Inhelder and Piaget, 1958) have implied that many students attained the stage of formal-operations by 14-15 years. In view of studies done since then, outside Geneva, Piaget (1972) has shifted his position and now considers, in line with their findings, that normal subjects may not attain the stage of formal operations until between 15 and 20 years.

This means then that few students in junior secondary schools are at the formal-operational stage, but that many are at the age at which they would be capable of developing toward that stage. This suggests a need for instruction at the junior secondary level which attempts to promote development of students' reasoning toward the more sophisticated formal-operational structures. Students who then progress to biology, chemistry and physics courses at senior high school level at around 15-16 years of age would possess

the necessary structures to enable them to interact with, and understand, the fundamental abstract concepts contained in those courses.

Thus it is argued that the known level of development of students entering senior secondary science courses falls short of that considered necessary for them to fully understand the concepts presented at that level. It is for this reason that science educators such as Arons (1976); Blake and Nordland (1978); De Carcer, Gabel and Staver (1978); Lawson and Wollman (1976); Renner (1978); consider that the development of formal-operational reasoning patterns should be one of the primary goals of science teaching in secondary schools. Their position, however, assumes first that what occurs in school does enhance the intellectual development of the student and second that there are teaching practices which can promote the desired development from concrete-operational to formal-operational functioning. Friot's (1976) study indicates that there are some school experiences which do assist the development of concrete operations to formal operations.

Piaget himself (1964) is quite specific about the factors which bring about the development of the structures of one stage to a higher stage. Until recently, however, attempts to implement his ideas have been restricted to the pre-primary and primary years. This trend Brainerd (1978, p.287) attributes to the difficulty and expense of experimenting at the junior and senior high school levels and to their

curricula traditionally being less flexible than in the early school years. Nevertheless the factors which Piaget considers bring about intellectual development are the same for all stages.

This being the case, it was decided that it would be useful to examine the studies and development in Piagetian oriented research in science teaching, to enumerate a list of teaching strategies which would be profitable in developing formal-operational structures in adolescents in junior secondary science classes. A further step could be to consider current practices in the light of such teaching strategies.

Statement of the Purpose

One purpose of the study then was to identify from the literature those teaching practices which are considered likely to lead to the development, in junior secondary students, of formal-operational structures from concrete-operational reasoning patterns. These practices were to be used to form the basis of an observation schedule. A further purpose was to use this instrument to identify current teaching practices used by junior secondary science teachers in two school districts of British Columbia and to determine the extent to which their teaching practices were similar to the Piaget-derived practices.

Specific Questions to be Considered

What are the teaching practices considered by the literature to aid the development of formal-operational reasoning patterns in adolescents?

What are the teaching practices currently being used by junior secondary science teachers?

To what extent are current teaching practices in junior secondary science classes similar to those considered in the literature to aid the development of formal-operational reasoning patterns?

As has already been pointed out earlier in this chapter, many science educators and teachers, including the author, consider the development of the underlying structures of formal thought to be an important goal of teaching science in secondary schools. If there are some teaching practices which are considered likely to assist the students' development toward that desired stage of development, then it is important to know how similar such practices are to current teaching practices in junior secondary science classes.

It might be argued that the type of teaching which occurs in secondary science classrooms is already known or, if not, that it can easily be determined by asking teachers to describe what teaching strategies they use. There is,

however, very little recent documented evidence available about science classroom teaching practices. Furthermore, teachers usually report greater variability of activities in their classrooms than do students in the same classrooms (Science Assessment Contract Team, 1978, p.39). Studies such as those carried out by Gallagher (1970), and Medley and Mitzel (1963), which employed systematic observations of classroom behaviour were done some time ago. A more recent study reported by Galton and Eggleston (1979) did address the identification of cognitive behaviours in secondary science classrooms but that study was carried out in the United Kingdom. It was therefore considered that to determine accurately what teaching practices currently occur in junior secondary science classrooms it was essential to directly observe teaching in those classrooms.

Limitations of the Study

Since the number of science teachers observed in this study was small, and since the sample was drawn from two school districts in British Columbia, it is not possible to generalize the findings of the study to a wider population.

There was only limited time in which to develop the instrument used for coding the teacher and student activities observed in this study and the instrument served the dual purpose of determining present teaching practices and

comparing them with ideal teaching practices. Both of these factors may have limited the description of current teaching practices and therefore limit the internal validity of the study. In addition, an inherent limitation in any observational study of this kind is the effect of the presence of observers on routine classroom activities and student-teacher interactions.

CHAPTER II

REVIEW OF RELATED LITERATURE

Organization of the Literature Review

Since this study depends on an understanding of Piaget's theory of intellectual development, particularly those aspects of the theory which are pertinent to concrete and formal operations, then the parts of the theory which deal with these stages will be reviewed and discussed in sufficient detail to show how they are related to the teaching of secondary science courses.

The concrete-operational and formal-operational stages are considered to be distinctly different levels of development. The mental operations of each of these stages will be discussed to show the limitations and capabilities of each in relation to science subject material being presented to secondary science students.

The cognitive levels of students at the junior secondary level, already mentioned, will be discussed in more detail. Then students' achievements in science courses will be viewed in relation to the cognitive level at which they function. Course contents and their cognitive demands will be related to the expected levels of students taking the courses. Then

studies in which different teaching strategies have been employed in an attempt to overcome differences in intellectual levels of students will be reviewed. Since these attempts show that there are no strategies yet studied which eliminate the poorer achievements of concrete-operational students then ways of promoting development to the formal-operational stage will be examined. The final section of the review will identify teaching strategies recommended to encourage this desired development. But first, the theory itself.

Piaget's Theory of Intellectual Development

Piaget (Inhelder & Piaget, 1958) considers that there are four major stages of cognitive development through which all individuals progress, in the same invariant sequence: the sensori-motor stage which occurs from birth to about two years of age; the pre-operational stage between about two and seven years; the concrete-operational stage between approximately seven and eleven years or older, and the formal-operational stage which develops from around eleven years of age. As mentioned before, Piaget now considers that this last stage is attained in normal subjects "...if not between 11-12 to 14-15 years, in any case between 15 and 20 years" (Piaget, 1972, p. 10).

Brainerd (1978) explains that Piaget believes that there are abstract organizational patterns, called structures,

which underlie cognition and control it. These structures, or reasoning patterns as they are often called by Karplus et al (1977b) grow and change during the course of an individual's development. Each stage is governed by its own unique set of structures. The key differences between successive stages are due to qualitative reorganizations of structures. Renner and Lawson (1973) give an excellent description of them:

> Mental structures represent a more or less tightly organized mental system to guide behavior. During development of the human infant to adulthood these structures must be built within the brain. A complete development sequence of structures is not genetically given to the child, they must be learned. According to Piaget the building of these mental structures is what underlies the process of intellectual development. (p.165)

Teaching, then, should be aimed at developing new mental structures if it is to promote development from one stage to another.

Flavell (1963) points out that an essential characteristic of a stage is that the structures defining earlier stages become integrated into those of the following stages. The stage of formal operations then incorporates cognitive activities which are performed on the preceding concrete-operational stage. He further explains that

> a stage has an initial period of preparation and a final period of achievement. The preparatory phase with its flux and instability

> gradually gives way to a later period in which the structures in question form a tightly knit, organized and stable whole. (p.21)

Structures control how and what we think and guide behavior. They actually represent our knowledge. An educator interested in developing the structures of a more advanced stage should be aware of the gradual development of new structures and be prepared to allow sufficient time for repetition of new thinking patterns. He should also be alert to the fact that new structures are initially unstable and therefore cannot always be used reliably by a student. Sometimes newly developed reasoning patterns will be put into operation successfully; at other times they will appear to be absent and teachers should learn to expect this inconsistent behavior during a student's development.

Two principal, fundamental, and complementary characteristics of intellectual functioning which Piaget considers to be invariant over the whole of a person's developmental span are organization and adaptation. The organizational characteristic can be inferred from the fact that intelligent behavior does not seem to be a random trial and error process. The very young infant, for example, has available the separate behavioral structures of either looking at objects or grasping them. After a period of development he combines the two into a higher order structure which enables him to grasp something while looking at it. The coordination of the

physical processes of the body into an efficient system is also considered to be a result of this organization tendency.

The second general principle of functioning is adaptation. All organisms are born with a tendency to adapt to the environment and man is no exception. According to Sigel (1969, p.466) Piaget conceives of intelligence "...as an adaptation to the social and physical environment." Intellectual adaptation is an interaction between a person and the environment. Further, adaptation is considered in terms of two complementary processes: assimilation and accommodation. These two processes will be discussed in some detail because it is through them that new structures develop. Knowledge of such development is of prime importance to this study.

Assimilation and Accommodation

On the one hand, a person incorporates or assimilates incoming information into his present structures, while on the other hand he modifies or changes, that is, accommodates existing structures to enable him to make sense out of the new information. It is clear, then, that the two processes are complementary. A person assimilates an environmental event into a structure while at the same time he accommodates the structure to understand or make sense out of that event. Thus accommodation is involved in developing new and more complex structures and these structures determine and limit

behavior.

When incoming information is within the scope of an individual's existing structures it is assimilated with very little change or accommodation. If, however, new information is too far above the individual's present level of development any attempted assimilation requires too much change in the existing structures and it cannot be accommodated. Piaget says this causes disequilibrium in the existing structures. New information well within the range of existing structures is easily assimilated but since it does not demand any accommodation, it does not promote any development.

For the teacher wishing to promote the development of more complex structures there are implications about the selection of material to be taught. New experiences should be chosen which are just sufficiently novel as to produce the right amount of assimilation and accommodation to enable more complex structures to develop.

These complementary processes obviously play a key role in Piaget's explanation of intellectual development but they are not the only factors involved. Before considering them in relation to science teaching practices, the other factors will be discussed.

Factors Underlying Intellectual Development

Piaget (1964) lists four main factors which explain the development of one set of structures from another:

> First of all maturation...since this development is a continuation of embryo-genesis; second the role of experience of the effects of the physical environment on the structures of intelligence; third, social transmission in the broad sense; and fourth, a factor which is too often neglected but one which seems to me fundamental and even the principal factor. I shall call this factor, equilibration, or if you prefer it, of self-regulation. (p.173)

Since the concern of this study is the development of adolescents' reasoning patterns towards formal-operational structures which will enable them to understand abstract science concepts, then each of the four factors mentioned by Piaget will be considered in more detail in reference to science teaching.

Maturation

The intellectual capacities of a young child are obviously very different from those of an adult. As the brain and central nervous system mature they make it possible for the child to use thought and language. Ginsburg and Opper (1979) consider "the question is not <u>whether</u> maturation has an effect, but how <u>important</u> the role of maturation is and <u>how</u> it operates" (p.207). If maturation were the only factor involved, then teachers would only have to wait for it to produce the required development. Obviously other factors have an effect but they are necessarily limited by a student's level of maturation. There

is very little a science teacher can do about the role of maturation except to note that it may set some limitations on intellectual development.

Physical Experiences

A second influence on development is contact with the environment. By means of physical actions such as handling objects and manipulating them, a child extracts from the objects themselves knowledge of their physical properties. For example, weight is experienced by lifting different objects and shape, such as the roundness of a ball, is understood by handling a ball. These are physical experiences which involve the assimilation of new ideas into existing structures. In addition, new knowledge can be gained by reflecting on these interactions with materials. A child playing with pebbles learns about the size and weight and texture of them but by continuing to manipulate them, rearrange them and count them he eventually learns that their number is the same no matter how they are arranged, or in what order they are counted. This new knowledge, gained by reflective abstraction of the child's actions, requires a logico-mathematical experience. Piaget distinguishes this from purely physical experiences.

Social Transmission

In addition to maturation and physical experiences there is a third factor: social or linguistic transmission. This refers to such things as a parent telling a story to a child or perhaps a teacher giving instructions to a class or students discussing a question with their peers. The child can learn a multitude of ideas if they are passed on in this way. As Ginsburg and Opper put it, "Because of social transmission, the child need not re-invent everything for himself" (p.211). But it must be remembered that just listening to a conversation will not enable the child to understand the topic being discussed. He must possess the cognitive structures which enable him to assimilate it before he can appreciate knowledge passed on by other individuals. Social transmission itself is not sufficient to produce cognitive development but it does aid in cognitive development. For this reason, schools and other places where verbal interactions and discussions are likely to occur or are encouraged, such as churches and clubs, contribute to intellectual growth but do not entirely determine it.

There is a fourth factor which integrates the effects of the three just discussed: equilibration.

Equilibration

According to Piaget this is a self-regulatory process and may be considered to involve the following steps. First, an individual has some given level of intelligence such as the structures which make up the concrete-operational level of intelligence. The range of situations demanding intelligent behaviors which these structures can handle is limited. If new information is encountered which calls for intelligent behavior beyond their scope then such encounters produce a state of disequilibrium in the structures. The structures must change and become more intricately organized to allow this information, which is currently beyond their scope, to be assimilated. A new level of structures results which is more complex, and which is considered more stable, because there will be fewer situations which will subsequently throw them into disequilibrium because their scope has broadened.

This whole process is called equilibration or self-regulation and is considered by Piaget to be constantly occurring between birth and late adolescence, after which very little broadening of structures is believed to occur. The equilibration process is the mechanism by which the child moves from one state of equilibrium to the next, that is, from one stage to the next.

The science teacher interested in encouraging intellectual development should provide situations which

induce equilibration in students. New experiences should be planned which are just beyond the student's present level of reasoning. Students should then be encouraged to interact with the new ideas and discuss them with their teachers or peers until they eventually accommodate them by applying effective new reasoning patterns.

When new problems are first encountered, such as one involved in working out the number of moles of acid required to dissolve certain weights of a metal, they require the student to inter-relate existing reasoning patterns (here the ideas of the mole concept, concentration of solutions and stoichiometry). The carrying out of various laboratory activities using different volumes and concentrations of acid with the same weight of the metal would provide physical experience of the problem. Discussion with the teacher or other students in the class would provide social transmission of ideas relating to the problem. The student who cannot immediately solve the problem should be allowed time to reflect on his observations and if necessary restructure the task in an attempt to solve it. In this way, he then comes to realize the shortcomings of his present reasoning patterns. Eventually, if he cannot reach the correct answer by himself, his teacher or his peers may have to provide it for him.

Having correctly worked through the problem once, the student should repeat similar activities to make sure the interplay of thought and action induces enough self-

regulation to firmly establish the newly developed reasoning patterns. Karplus et al (1977b) emphasize that this repetition is necessary to enable the new structures to become fully integrated with the old to produce a new equilibrium. They also insist that an essential part of the process is to provide situations in which the student initially has time to try to work out new problems by himself. If he cannot, then he is aware of the inadequacy of his reasoning, and ready to alter his existing structures. This approach assumes that the student has had previous experience with the basic ideas needed to solve the new problems, otherwise the whole exercise is far too difficult and the new reasoning patterns too far above existing ones to allow interaction with it.

The idea of inducing equilibration will be referred to again when specific teaching strategies to promote formal thought are being considered. Before that is done, however, there are some other aspects of the theory and related literature to be discussed. They include, first of all, a more detailed look at the mental operations of the concrete-operational and formal-operational stages in terms of secondary science subject matter.

Mental Operations of the Stages

Concrete-operational Reasoning Patterns

Concrete operations are based on the logic of classes and the logic of relations. Classification involves the ability to set up classes and hierarchies of classes. This in turn involves the ability to use the operations of addition, subtraction, and multiplication in dealing with classes. For example, children at this stage would recognize that the class of all children is made up of the sum of boys and girls. In the same way, the number of boys could be found by subtracting the number of girls from the total number of children. Pre-operational children do not recognize these relationships because they do not possess reversibility which is essential for this type of reasoning. They can only deal with the parts, or the whole class, but cannot make generalizations about both.

The operation of seriation also develops during the period of concrete operations. For example, at this stage a child can put sticks of different lengths in order of increasing length, without necessarily starting with the shortest or the longest. The child not only recognizes some sticks are longer, he also recognizes some are shorter than others and he can progress from any stick with which he starts. Again the process involves reversibility.

Another concrete operation that has been widely investigated is that of conservation. Children at this stage

recognize that two corresponding rows of ten equally spaced objects have the same number of objects. If one row is then spread out, the child who can "conserve" will recognize that they still both have the same number of objects. Prior to the concrete period children will claim that the longer row has more objects.

In addition, children at this stage can conserve mass. They recognize that no matter what shape a piece of plasticine is made to assume, it will always have the same amount of substance in it if nothing is added or taken away. Brainerd (1978) and Neimark (1975) consider that the host of replication studies done in the area of conservation show that children acquire conservation of mass, then weight and then, some two years later (in the formal-operational stage), they conserve volume.

Children at the stage of concrete operations possess reversibility, and conserve mass and weight. The concrete operations they possess are based on the logic of classes and the logic of relations. Using these operations they are able to deal with reality, that is, concrete objects.

Sigel and Cocking (1977) summarize the abilities at this stage by saying:

> In the concrete operational period the child thinks in operations but is tied to the observable and needs props to work with. The child is able to think in terms of classes, relations and number. To be able to do this he has to be able to understand reversibility and conservation. (p.65)

Since the student at this stage can only employ the operations in the presence of concrete objects or directly observable properties, his reasoning and problem solving still have many limitations. He cannot yet deal with potential actions, abstract ideas or theories. As Cantu and Herron (1978), Hartford and Good (1976), and Goodstein and Howe (1978) point out, this means that such science topics as the kinetic theory, the law of constant composition and atomic theory are currently beyond his scope.

Formal-operational Reasoning Patterns

Once the student develops the structures of the formal-operational stage, however, his thinking processes are entirely abstract. Verbal statements may be substituted for objects and a new type of thinking, propositional logic, operates. The student's thinking is no longer tied to reality; he can deal with hypothetical propositions.

An adolescent who possesses the reasoning patterns of formal thought approaches problems and observations in a systematic way. In the course of experimental manipulations in the laboratory, any observed outcomes are considered as being only a part of a whole range of possible occurrences. That some outcomes do not occur enables the formal student to isolate the factors which might prevent them from occurring and yet allow others. The formal adolescent, then, is able to think in terms of all possible combinations, "whether

these combinations arise in relation to experimental problems or purely verbal questions" (Inhelder & Piaget, 1958, p.253).

This combinatorial system which is developed enables him to see reality as only one of many possibilities. Concrete structures do not allow this type of reasoning.

While the ability to think in terms of all possible combinations is considered by Piaget to be the fundamental difference between the formal stage and the concrete stage, there are other mental operations which he considers are developed concurrently with this structure. One is the ability to hold all factors constant in an experiment but the one under investigation. Piaget views this as another outcome of the adolescent's ability to handle all the sixteen binary operations of propositional logic.

The other operations which the formal adolescent possesses are referred to as formal-operational schemes and are closely related to the formulation of scientific laws and the extraction of functional relationships by which they are mathematically interpreted. They are the operations of proportionality, probability, and correlational thinking. Both propositional-operations and formal-operational schemes are considered by Piaget to develop in synchrony during adolescence.

Accordingly, a formal student can be recognized by the way he approaches new problems. Flavell (1977) describes

it in the following way:

> The formal-operational thinker inspects the problem data, hypothesizes that such and such a theory or explanation might be the correct one, deduces from it that so and so empirical phenomena ought logically to occur or not occur in reality and then tests his theory by seeing if these predicted phenomena do in fact occur. (p.103)

That is, the teacher can expect the student to be able to use hypothetico-deductive reasoning.

In more general terms, the adolescent who is a formal thinker can be expected to engage in a variety of forms of thought which would be impossible without the combinational system (the sixteen binary logical operations) or some logical equivalent of it. Ginsburg and Opper (1979) describe the formal operational student as one who makes reality secondary to possibility, who can imagine that many things might occur and that many interpretations of data might be feasible. The adolescent's thought is hypothetico-deductive, he can consider all possible combinations and he can deal with propositions as well as objects. His thought is flexible and versatile and he is capable of dealing with problems in many ways from a variety of perspectives.

> The formal stage appears to differ appreciably and significantly from the earlier Piagetian stages. Full development appears to be very much the rule at earlier stages but appears to be the exception at this stage. (Dulit, 1972, p.297)

Between the concrete-operational stage and the fully developed formal stage Piaget considers that there is a lengthy phase of preparation during which the adolescent may sometimes give evidence of using formal structures but at others revert to using only concrete structures. It is a stage in which the individual's structures are in disequilibrium and is referred to as the transitional or formal stage III A. Teachers can expect students at this level to occasionally but not reliably apply formal reasoning to their problem solving but even the occasional use should be taken as evidence that they are developing towards the desired final stage.

Of direct concern to this study is how the stages of development relate to the contents of a science course. What scientific concepts do concrete-operational and formal-operational reasoning patterns enable a student to assimilate?

Karplus and his co-workers at Berkeley, California have published a summary of the reasoning patterns they expect students at each stage to be capable of using. The summary, reproduced in Table 1, is useful because it relates each mental operation to a particular science topic or gives a science course content which a student using that operation could understand.

Another summary is provided in Table 2, which was prepared by Lovell (1979) working in the United Kingdom. It

Table 1

Concrete and Formal Reasoning Patterns

Examples of Concrete Reasoning Patterns

C1 Class Inclusion - classifying and generalizing based on observable properties (e.g., distinguishing consistently between acids and bases according to the color of litmus paper; recognizing that all dogs are animals but that not all animals are dogs).

C2 Conservation - realizing that a quantity remains the same if nothing is added or taken away, though it may appear different (e.g., when all the water in a beaker is poured into an empty graduated cylinder, the amount originally in the beaker is equal to the amount finally in the cylinder).

C3 Serial Ordering - arranging a set of objects according to an observable property and possibly establishing a one-to-one correspondence between two observable sets (e.g., small animals have a fast heart beat while large animals have a slow heart beat).

C4 Reversibility - mentally inverting a sequence of steps to return from the final condition of a certain procedure to its initial condition (after being shown the way to walk from home to school, finding the way home without assistance).

Examples of Formal Reasoning Patterns

F1 Theoretical Reasoning - applying multiple classification, conservation logic, serial ordering, and other reasoning patterns to relationships and properties that are not directly observable (e.g., distinguishing between oxidation and reduction reactions, using the energy conservation principle, arranging lower and higher plants in an evolutionary sequence, making inferences from the theory according to which the earth's crust consists of rigid plates, accepting a hypothesis for the sake of argument).

F2 Combinatorial Reasoning - considering all conceivable combinations of tangible or abstract items (e.g., systematically enumerating the genotypes and phenotypes with respect to characteristics governed by two or more genes).

F3 Functionality and Proportional Reasoning - stating and interpreting functional relationships in mathematical form (e.g., the rate of diffusion of a molecule is inversely proportional to the square root of its molecular weight).

F4 Control of Variables - recognizing the necessity of an experimental design that controls all variables but the one being investigated (e.g., in the Mealworm Puzzle, recognizing the inadequacy of the setup using Box 1).

F5 Probabilistic and Correlational Reasoning - interpreting observations that show unpredictable variability and recognizing relationships among variables in spite of random fluctuations that mask them (e.g., in the Mealworm Puzzle, recognizing that a small number of specimen showing exceptional behavior need not invalidate the principal conclusion).

Note: From Karplus, R., Lawson, A.E., Wollman, W., Appel, M., Bernoff, R., Howe, A., Rusch, J.J., and Sullivan, F. Science teaching and the development of reasoning. Lawrence Hall of Science, 1977.

Table 2

Early and Late Concrete and Formal Operations

Early concrete operations

The pupil will investigate what happens in a haphazard way

- will argue that "this goes with that" (association only)
- will order a series (e.g. lengths or weights) but is unable to do so as part of a perception of a relationship in an investigation
- is unable to use any model as theory.

Late concrete operations

- will find out what happens, including the use of seriation and classification as tools of perception
- can use ordering relations to partially quantify associative reasoning, e.g. "as this goes up that goes down," "if you double this you must double that"
- can use seriation and the multiplication of two seriations as perceptual strategies
- understands the rules of a simple model but not in relation to the experiment at hand.

Early formal operations

The pupil will show more interest in looking for why.

- see the point of making it simplified to one variable, but cannot perform the simplification systematically himself
- be able to establish causative necessity
- use or perceive metric proportion in a concrete situation
- make simple deductions from a model if the use of the latter is explained.

Late formal operations

- have an interest in checking a "why" solution
- know that in a system of several variables he must "hold all other things equal" while investigating one variable at a time
- formulate general or abstract relations
- use direct and inverse proportionality for perceiving and formulating relationships
- actively search for an explanatory model or extend one that is given.

Note: From Lovell, K. Intellectual growth and the school curriculum. In F.B. Murray, The impact of Piagetian theory. University Park Press, 1979.

is included because, unlike the Karplus one, it lists the operations which a student is considered to possess during the early or preparational phase of each stage as well as during the fully developed phase. The operations listed on this table are written in more general terms than those in Table 1 and are therefore perhaps less useful for working out the relationship of the stages to the contents of a secondary science course.

The table does, however, provide guidelines for teachers who are interested in trying to determine from the thinking behavior of their students the intellectual stage to which they have developed. For example, if a teacher recognizes that a student sees the necessity, when investigating a system of several variables, "to hold all other things equal" while investigating one variable at a time, then the student is at the late formal stage. That student should also be able to formulate general or abstract relations and be able to use direct and inverse proportionality.

The thinking patterns used by students in science lessons can give teachers an insight into the developmental stage of the students. A general idea of the cognitive stage to be expected can also be gained from the ages and grade level of the students. This follows from the results of studies done by science educators in which Piagetian stage has been determined. Some of these studies will now be discussed.

Cognitive Levels of Secondary Science Students

Several studies have been done in all parts of the world to determine the ages at which adolescents attain formal thought or alternatively to determine the stages to which students in high schools have developed. Initially Inhelder and Piaget (1958) led investigators to believe that the onset of formal operations occurred as early as eleven years and was fully developed by around fifteen years of age. Correspondence with Inhelder by Dulit in 1972 makes it clear that only those subjects in the 11 to 15-year-old group who did display formal thought were reported in that reference, and they came from the better schools of Geneva. More recent studies make it clear that development to the formal-operational stage, once expected to have occurred in the early secondary years, should not be expected until much later.

Since formal operations are complex and consist of several different reasoning patterns, then only those studies which have employed three or more Piagetian-type tasks to determine stage level will be discussed here. As Bady (1978) points out, "It is meaningless to claim that a specific percentage of the population is formal or concrete based on the results of a task or two. The structure of formal operations is more complex than that..." (p.238)

As discussed in the introduction to this study, Chiappetta (1976) reviewed seven studies carried out in the

United States in which the cognitive level of high school students was determined. The results of these studies together with several others are summarized in Table 3. They show that between 77 and 83 per cent of junior high school students were found to be at the concrete-operational level. Between 41 and 86 per cent of senior high school students were also found to be concrete. It should be noted, however, that the latter very high percentage was reported by Nordland, Lawson and Kahle (1974) who carried out their testing in a disadvantaged urban high school.

Blasi and Hoeffel (1974) presented a table of the percentage incidence of formal-operational thought across different ages, as found by various researchers, and concluded that a large percentage of individuals of normal intelligence and average social background did not seem to function at the formal-operational level in adulthood nor in adolescence.

If one focuses on only those studies which are concerned with junior secondary students, as presented in Table 3, then the percentage who are fully formal-operational is quite small.

For example, Friot (1976) working in the United States found 6 per cent of a sample of 210 grade eight and nine science students to be fully formal. Han (1977), working in Korea with grade nine students, found 0 per cent to be fully formal while 22 per cent were early formal-operational.

Table 3

Percentages of Students at Different Piagetian Stages

Study	N	Grade Level		Piagetian Stage Con. %	Tr. %	Form. %
Friot (1976)	210	8,9	Pre	82	-	6
			Post	44	-	40
Han (1977)	127	9		78	22	0
Lawson (1974)	101	11,12				
	51	Biol		64.8	-	35.2
	50	Chem		22	-	78
Lowell (1979)	50	7,8		88.5	11.5	0
	62	9-11		70	16.7	13.3
Nordland, Lawson & Kahle (1974)	96	7		83.4	-	15.6
	506	11,12		85.6	-	13.2
Renner & Stafford (1972)	298	7-9		77	13	6
	290	10-12		66	17	14
Sayre & Ball (1975)	214	7-9		89.2	-	10.8
	205	10-12		42.4	-	57.6
Tisher (1971)	232	7-9		71.6	-	28.4
Wheeler & Kass (1977)	168	10		78.5	-	21.5

Lowell (1979), working in Canada, tested 112 randomly selected grade seven through eleven subjects and found 88 per cent of the grade seven and eight group to be concrete-operational. In Australia, Tisher (1971) found 71.5 per cent of a sample of 232 junior secondary students to be concrete-operational. Sayre and Ball (1975) found 13.5 per cent of their sample of 214 grade seven, eight and nine students in the United States to be formal. Working with a slightly older group, Wheeler and Kass (1977) found 21.5 per cent of their sample of grade ten chemistry students in Canada to be fully formal-operational. While this is the highest percentage reported, it means that only one-fifth of the students at that level are capable of consistently operating with formal reasoning patterns.

Further, studies carried out on a much larger population such as those conducted by Shayer et al (1976) in the United Kingdom and Karplus et al (1977a) in Austria, Denmark, Germany, Great Britain, Italy, Sweden and the United States gave a similar picture of intellectual development. For example, the Shayer study, which tested over 10,000 students between the ages of nine and fourteen years, showed that most students in early adolescence showed rapid development in concrete thinking but that only one-fifth of them showed further development toward formal-operational thought. In fact, only 5 per cent of the students tested had reached that stage by age 14-16 years.

The Karplus study which tested 1800 girls and an almost equal number of boys in the 13 to 15-year-old age range was more limited in that it was only concerned with two areas of formal reasoning. It showed that a large fraction of the students used concrete reasoning patterns exclusively when doing problems involving proportional reasoning and control of variables.

It should also be noted here that the authors of the Karplus study found small but significant country-to-country differences which they attributed to the influence of teaching on the development of the reasoning patterns investigated. They considered that "applying proportional or control-of-variables reasoning is not the result of a process exclusively internal to the young people" (Karplus et al, 1977a, p.416).

Meanwhile, it must be concluded from the studies of the intellectual level of development of students in junior secondary schools that only 15 to 20 per cent of the students are capable of operating at the fully formal-operational level. While there would be some, about 15 per cent, at the transitional level most, around 70 per cent, would be concrete-operational.

The next topic of discussion, then, is the effect that the learners' level of development has on their achievement in science classes.

Level of Cognitive Development and Achievement in Science Classes

If, as just concluded, the majority of adolescents in high schools function at the concrete-operational level and thus do not possess formal-operational reasoning patterns, then this would be expected to affect their achievement in science. In fact, several investigators have examined the relationship between the cognitive level of development of students and their grades in science subjects, or their level of achievement in science tests. De Carcer, Gabel, and Staver's (1978) review of some of these investigations showed that high school students' grades and SAT scores were significantly correlated with the students' levels of cognitive development.

For example, Sheehan (1970), who worked with 104 randomly selected high school students, found that subjects classified as formal-operational on a pre-test consistently scored higher on a post-test of science questions about topics taught during the intervening period than those classified as non-formal. Similarly, Sayre and Ball (1975), who randomly selected 214 students in high schools in grades seven to nine and 205 students in grades ten to twelve, subsequently classified them as formal or non-formal on five Piagetian tasks. They then compared the student's intellectual level as determined by these tasks with the grades obtained in all of the student's subjects. Subsequent

analysis showed that both junior and senior high school students who were classified as formal received significantly higher grades than did those classified as non-formal.

Lawson and Renner (1974) administered four Piagetian tasks to 134 students in grades ten, eleven and twelve in a high school in an above average suburban population in Oklahoma. Then they tested the same students' understanding of science subject matter, taught during that current school year, with 15 concrete and 15 formal multiple choice questions. The results supported Sayre and Ball's premise that concrete-operational students would be unable to develop understanding of formal concepts although they would understand concrete concepts. In a critical analysis of this study by Wilson (1977), he commented "that higher level questions (Bloom's Taxonomy) are more difficult for students to answer...It is not surprising that students on a concrete level find simpler questions easier to answer" (p.14).

Put more simply, the research confirms what one would expect: students with higher levels of cognitive development are capable of higher achievement in science, when the subject matter is more difficult and more abstract, than students with a lower level of development. For this reason, a substantial portion of secondary science subject matter, particularly that which deals with theories and concepts or which involves proportional reasoning and the formulation of mathematical relationships between variables,

is not suitably matched to the intellectual level of the learner.

While discussing achievement and its relationship to intellectual development, it is appropriate to examine briefly both of these in relation to the more general measure of intelligence: IQ.

IQ and Piaget's Stages of Development

The distribution of Piagetian stages of thinking in British middle and secondary school children as reported by Shayer et al (1976), referred to earlier in this review, suggested that students with high ability level as measured by intelligence tests developed more rapidly toward the formal stage than those with average ability. Of a school population which had students in the top twenty per cent of ability, 23 per cent had reached the fully formal stage by age 14-16 years, compared with 5 per cent at that level in an average school population.

This is in agreement with studies reported by Blasi and Hoeffel (1974). Their tabulation of the percentages of formal-operational thinkers in various populations by age and by IQ range showed that when the IQ range was above average the percentage of subjects who operated at the formal-operational level was always higher for a given age range than when the IQ range was average. For example, Lunzer (1965) found that 48 to 54 per cent of above average

IQ eleven to fourteen-year-olds were fully formal. Dulit (1972), who tested boys between sixteen and seventeen years of age with an IQ range of 130-140, found 75 per cent of them to be fully formal.

De Vries (1974) investigated the relationship between IQ, achievement and Piagetian assessments and found that Piagetian tasks appeared to measure different things from either achievement or intelligence tests. She reported that her results agreed with the low to moderate relationships reported between Piagetian task measurements and IQ cited in other literature.

While IQ and Piagetian stage refer to different measures, it appears that students who are found to score well on IQ tests are likely to develop to the stage of fully formal thinking at a younger age than students who have low IQ scores.

Students in the same science class will have varying abilities and will be at different Piagetian levels of development. Recognizing this, some teachers have attempted to devise teaching strategies which would overcome the differences, particularly when trying to teach science topics which require the understanding of abstract concepts. Studies which investigated the effects of these different teaching strategies on students' understanding of the science concepts taught will now be discussed.

Teaching Strategies Employed in an Attempt to Overcome Differences in Cognitive Levels of Students in Science Classes

Most of the experimental studies which have investigated the effects of differences in instructional mode on achievement in science subjects have used two different methods of teaching. One, referred to as an active or concrete method, involved an emphasis on the handling of models and the manipulation of, and interaction with, concrete objects. The other, referred to as verbal or formal, used a didactic approach in which students were simply told about the science topics or were involved in verbal reasoning about new topics being presented.

Talley (1973) in a one-semester introductory college chemistry course provided an experimental group of students with molecular models for all the reactions studied and encouraged the students in that group to use the models to represent all the reactions introduced and studied in the semester-long course. The control group were taught by the didactic method. For questions in the post-test, which involved higher cognitive level thinking, the experimental group showed significantly higher achievement, suggesting that the interactions with the models had enabled the students to come to a better understanding of the chemistry studied.

Sheehan (1970) worked with students in a younger age group: those between 12 - 6 and 13 - 5 years in a junior

secondary high school. Having administered the Longeot test to classify a large group of students according to Piagetian stage, he randomly selected 30 students from the concrete-operational and 30 from the formal-operational stages. Half of each of these groups were then assigned to two different modes of instruction; concrete and formal, in three science concepts.

The results of the post-test on understanding of the science taught during the three days' instruction showed that the highest achievers were the students classified as formal who had received concrete instruction. The achievement of the formal students taught by the formal method was higher, but only slightly, than the concrete students taught by concrete method.

Sheehan concluded from these results that formal-operational students achieve better in science than concrete-operational students regardless of the method of instruction. Secondly, concrete instruction was more effective than formal instruction with both formal-operational students and concrete-operational students. It appeared that when students manipulated materials and interacted with them, more assimilation and accommodation of new information into their existing structures occurred, which produced a consequent increase in their knowledge.

In another study, conducted by Cantu and Herron (1978), high school students were classified as concrete-operational

and formal-operational by administration of the Longeot test. Twenty students from each category were subsequently assigned to two chemistry classes. They were taught six chemistry concepts, one per week for six weeks in a daily twenty-minute activity period, by two different instructional methods.

The experimental group were provided with diagrams, examples, models and illustrations to focus the students' attention on the perceptible attributes of the abstract concepts being taught in an attempt to reduce the need for hypothetico-deductive reasoning unavailable to the students who were concrete-operational. The other group was taught by verbal methods without any of the aids mentioned above.

On the post-test, which was designed to test the students' understanding of the six concepts taught during the study, the concrete-operational students who had been taught with the aid of examples, were found to have achieved significantly higher than those taught without the aids. Unlike the Sheehan study, there was no significant difference in achievement between the formal students taught by each method. Cantu and Herron considered the following conclusion justified: "No matter whether concrete or formal concepts are being taught one should expect the achievement of formal-operational students to be greater than the achievement of concrete-operational students." Further, "no teaching strategy will eliminate the difference in

achievement observed between concrete-and-formal-operational students" (p.142).

Goodstein and Howe (1978) reached the same conclusions after their study, which involved four classes of a regular high school chemistry course in six weeks' instruction in stoichiometry. They chose this particular topic because it required knowledge of the particulate nature of matter, understanding of the mole concept and the ability to do proportional reasoning, all of which required formal-operational reasoning patterns. Also, this topic depended only minimally on previous learning in the course which meant that any achievement as measured by the post-test would depend very largely on instruction in the topic during the experiment.

They first determined the Piagetian stage of each student by using a test designed and validated by Gray. Then instruction was given to all four classes over a period of six weeks. Two of the classes were taught by methods which made frequent use of models of atoms, ions and molecules whenever possible, and also included activities which involved the idea of weight ratios of atoms of different elements. The other two classes were taught by the lecture-response mode but this was combined with the normal laboratory work for this topic.

The results of the post-test showed that the concrete-operational students did not profit from the use of

concrete-examplars but that those students who were at the fully formal-operational stage did. Again it appeared that the students who benefitted most from active instructional methods were those who already possessed the underlying structures of the formal stage with which to interact with the materials and ideas presented.

Goodstein and Howe considered that their study indicated that if the intended learners were incapable of formal thought when the science topic required that level of thinking, then "the topic should either be postponed...or reduced in complexity and abstractness so that it can be comprehended at a concrete-operational level" (p.365).

From the four studies looked at in detail in this section of the review it appears that no matter what teaching strategies are employed in science classes, the student who benefits most is always the one who has already developed the underlying structures of the formal-operational thinking patterns. This is particularly evident when the science topic being taught involves the use of those reasoning patterns, such as proportionality and the formulation of abstract relationships (as in the Goodstein and Howe study above) which are considered by Piaget not to develop until the formal stage. It is concluded that no teaching strategy overcomes the differences in cognitive levels of the students.

Formal students are at a distinct advantage when it comes to understanding most science concepts. Recognition of this advantage has led some science educators to investigate the possibility of training concrete students to develop some of the thinking patterns known to be possessed by formal students.

Training Studies Which Attempt to Develop Formal-Operational Reasoning Patterns

De Carcer et al (1978) cited 15 such training studies which have been reported in the literature since 1971 and discussed them according to the category on which the training focused. Those in which students were trained to give correct answers on specific Piagetian tasks were looked at first.

Training on Specific Piagetian Tasks

Studies in this group measured the effects of different instructional strategies on students' achievement of delimited Piagetian problems. Within this group were studies such as those carried out by Bass and Montague (1972), who trained ninth grade students by means of self-instructional sequences to give correct responses on two Piagetian problems. The students used each sequence for three one-hour sessions over a period of three days. The percentage of students who could correctly recognize the

quantitative relation between the four factors involved in the inclined-plane problem did not appreciably differ between pre-test and post-test. On the balance task, the percentage operating at upper formal stage, III B, increased from 45 to 75. While no level of significance was reported, the authors considered that the learning hierarchy they had devised for the balance task was more successful than the one for the inclined-plane task. They concluded that the self-instructional format used in this study was a serious limitation on the study and concluded that the type of modifications in the students' thinking that they were hoping to achieve was probably best accomplished through active interventions by an experienced teacher.

It appeared from this and other studies that appropriate instructional procedures could be developed to teach students specific Piagetian tasks. Since no data was collected on the retention of these abilities, De Carcer et al considered that the usefulness of such studies to science teachers was very limited. The science teacher interested in promoting the development of formal thought has no idea whether the ability to master the tasks is permanent or transitory. Nor does he know whether it can be transferred to other tasks.

Training to Isolate and Control Variables

The ability to control variables has been the focus of a large number of training studies even though it is only one component of the structures of formal thought. It is, however, a component which is crucial to using scientific reasoning in science classes.

The study carried out by Lawson and Wollman (1976) using students in grades five and seven is probably the most important one. In it they pretested students to classify them according to their Piagetian stage, then randomly assigned them to two groups. One group received training in the concept of controlling variables by participating in four 30-minute sessions of individual training on several tasks. The other group received no training.

Following the training sessions, all students in both groups were post-tested using three carefully selected Piagetian tasks. One of these tasks determined whether the training was effective in facilitating the ability to control variables with materials identical to those used during training. The second task determined whether the training was generalizable to another problem involving the control of variables (specific transfer), while the third task was used to determine the extent to which training encouraged formal thinking (non-specific transfer) which Piaget says develops at the same time as the ability to control variables.

The results showed that instruction did affect the transition from concrete to formal functioning with respect to the ability to control variables. It also showed that the training was generalizable to specific transfer even for students whose pre-test classification was concrete. The training did not generalize to non-specific transfer.

Case and Fry (1973) developed a program to train non-formal, low SES secondary students to design controlled experiments. Their training, which took one 40-minute period every week for twelve weeks, involved the students in designing experiments in which only one factor was varied at a time, while all others were held equal. The post-test showed that those students who had participated in the training program could detect flaws in experiments which did not control all variables but the one being investigated, significantly more often than the control group.

Again, neither the Lawson and Wollman, nor the Case and Fry study tested the durability of the newly-acquired skill. Bredderman (1973), however, who did test retention of the newly-acquired ability to control variables showed that the effect of training was only transitory.

It appeared, then, that even when training studies were apparently successful and the science teacher had the details of the successful instructional strategies there was more that he needed to know, such as retention span, before he could attempt to use those strategies with confidence to

promote intellectual development. De Carcer et al considered that more studies needed to be done with adolescents in the high school situation with larger numbers of students before generalizations could be made about improving the cognitive levels of students in secondary science classes.

A further point to notice is that in nearly all the training studies the duration of training was quite short; one or two sessions per week for two to four weeks. The constraints of the school situation in which the studies were carried out may have demanded that the times the student spent on these activities had to be short. It is worthwhile noting, however, that the unexpectedly successful result of the Case and Fry experiment was obtained in a study which extended over a period of twelve weeks and was done during normal lesson time.

The shorter term studies appeared to be less successful except those which involved the control of variables reasoning pattern. Training studies then are perhaps promising but their methods need to be tested further on larger groups of students before they could be contemplated for classroom use. Lawson and Wollman (1976) considered that even if they were found to be useful they should not be used to accelerate development but "to avoid what might be called 'stage retardation'...Ample evidence exists that this phenomenon of stage-retardation is indeed widespread" (p.248).

The fact that such a large percentage of the secondary school population has only concrete-operational reasoning patterns with which to operate places real constraints on what can be taught in science classes and what can be understood and achieved by students in those classes. Short-term bursts of a teaching strategy to promote the development of a single transient formal-operational structure will not be of much use in overcoming this existing situation.

It is not surprising that conscientious students, who attempt to achieve well in science classes where the cognitive functioning required by the course content is above their level of intellectual development, resort to rote memory or learn algorithms to enable them to cope with problems in the subject. According to Herron (1978b) students cannot help but "develop poor study habits, poor attitudes towards school, and low self-image" (p.602).

What are needed are long-term teaching procedures and school experiences which enable students to develop the logical structures of formal thought from those of the concrete stage. Few studies have investigated directly whether any teaching methods or science classroom experiences can achieve this, but one study by Friot (1976) is of interest here.

Friot recognized that Piaget considered that a student who possessed the prerequisite physiological maturity would change his logical thought processes significantly if he

were permitted to interact with objects, events and situations in his environment. She therefore specifically set out to identify junior high school science courses that emphasized student investigations. She found three which were taught at grade eight and nine level and all were of the "inquiry kind".

Each of 210 students in seven classes were interviewed with six Piagetian tasks to determine their level of development. They were then interviewed again seven months later. In the intervening period those in five of the classes were taught by teachers trained in the inquiry curriculum they used while those in two control classes were taught by the traditional-demonstration method.

As expected, over such an extended time all groups showed gains in formal thought between pretest and posttest (see Table 3) but these gains were not randomly distributed. Students in two of the classes (grade eight TSM and grade nine IPS) showed significantly greater gains in developing the reasoning patterns of the formal-operational stage than any of the others. Since ages were similar and other subjects studied were the same, Friot concluded that "learners can be moved from concrete operations to formal operations by virtue of their school experiences" (p.89).

While Friot contends that some curricula are better than others in promoting the development to formal-

operational thought, it is not the curricula which are of interest in this study but rather the methods or strategies used in teaching them. If there are some instructional strategies which can be used in science classrooms which are considered likely to promote the intellectual development of students towards formal thought, they should be encouraged.

The literature discussed in this review leaves no doubt that the students who possess the logical structures of formal-operational reasoning are much better achievers in science classes than those who are not at that level. This is because many of the important ideas in science courses require formal reasoning for total understanding. It is known, however, that only about 20 per cent of students possess that ability. Teaching strategies which attempt to overcome the lack of development of that ability favour the student who is formal rather than the student who is concrete. Short-term training studies appear to promote the development of only one aspect of formal reasoning and that development is only transitory.

The teaching of some abstract concepts, such as bonding theory, can be delayed but there comes a time, particularly at senior high school, when certain concepts must be taught in biology, chemistry and physics and these concepts, such as genes, stoichiometry and the laws of motion, all demand formal-operational thinking patterns. Since there is no quick and easy way to develop the under-

lying structures when the need arises, and no teaching strategy which overcomes the lack of them, then it is desirable that science courses in grades eight, nine and ten aim to develop them. Students in junior secondary science classes would have the necessary maturational level for the development. What are needed, then, are guidelines about teaching procedures which could be used in junior secondary science classes which could promote the development of formal-operational reasoning patterns. Students who proceeded to higher level biology, chemistry and physics classes would then be better equipped to understand the contents of those courses. This is not the present situation but it is one at which science teachers could aim.

It is intended, then, to extract from the literature teaching strategies and procedures which are considered by educators interested in Piaget's theory most likely to promote the development of the operations of formal thought from concrete-operational reasoning patterns. While Herron (1978b) considers research on strategies to enhance intellectual development is still in its infancy and that "it is premature to suggest the exact strategy that might be successful" (p.601), there are many guidelines which keep on being emphasized in the literature which appear useful as long-term teaching procedures to enhance intellectual development.

Long-Term Teaching Strategies to Promote Intellectual Development

Having now thoroughly investigated Piaget's theory of intellectual development as it relates to the teaching of science and the development of formal reasoning in adolescents, it is possible to enumerate several important guidelines for putting theory into practice. There are certain strategies which are frequently mentioned as being necessary for the development of the underlying structures of formal thought from those of the concrete stage.

Piaget's own research has not been concerned with education but, rather, with the study of the growth of knowledge and the development of the underlying cognitive processes or mental operations which control that growth. Some of his comments, however, leave no doubt that he considers his theory pertinent to education. His statements in Schwebel and Raph (1973) are an example; when he criticizes:

> the mistakes of classical educational theory, which reduces the learner's role to looking and listening instead of acting himself, or which (and this is almost the same thing) replaces objects with audio-visual representations without concern for the fundamental role of spontaneous manipulations. (Piaget, 1973, p.x)

Educators, too, consider that there are many implications for teaching methods to be gained from studying his theory of intellectual development. Sigel (1969) considered

that "The theory...provides a conceptual framework within which to...devise teaching strategies" (p.466). Duckworth (1964) was of the same opinion:

> Everybody in education realizes Piaget is saying something that is relevant to the teaching of children....Contrary to the view most often attributed to him he maintains that good pedogogy can have an effect...Piaget is not saying that intellectual development proceeds at its own pace no matter what you try to do. He is saying that what schools try to do is usually ineffectual. You cannot further understanding in a child simply by talking to him.

Particular strategies will now be enumerated. Accompanying each one will be a discussion of its derivation from Piaget's theory or the related literature and an explanation of its intended purpose.

The single most important proposition to be derived from Piaget's work is that the role of the child in learning should be an active one. "The child must discover the method for himself through his own activity" (Piaget, 1970, p.30). This point is continually emphasized by Piaget. In another instance he wrote more fully:

> It is absolutely necessary that learners have at their disposal concrete material experiences (and not merely pictures), and that they form their own hypotheses and verify them (or not verify them) themselves through their own active

> manipulations. The observed activities of others, including those of the teacher, are not formative of new organizations in the child. (Piaget, 1973, p.x)

Students in science classrooms should be provided with situations in which they themselves experiment, try things out, manipulate materials, and in which they are given time to pose their own questions and seek their own answers. Duckworth (1964) further emphasized the point by saying that "the goal in education should not be to increase the amount of knowledge but to create an environment in which the child can invent and discover" (p.4). These experiences are essential for intellectual development.

Teachers in secondary science classrooms should, then, organize their teaching so that students can manipulate materials themselves. The teachers would rarely demonstrate scientific principles by manipulating apparatus themselves. Occasionally this might be necessary to teach a new technique, but it should not be used as a means of teaching new concepts and ideas. Piaget's objection to demonstrations as a method of teaching students was illustrated by his reply to Hall (1970), who asked about the effect of a teacher demonstrating to students the correct solution to the chemicals problem: "It would be completely useless. The child must discover the method for himself through his own activity" (p.30).

Physical experiences and concrete manipulations are not the only factors influencing development. According to Piaget (1964), development is promoted by four factors (already discussed in detail at the beginning of this review), another of which is social interaction.

Translated to the classroom situation, this means that peer interactions should occur; class and group discussions should be encouraged and organized so that students can converse, share experiences, argue, compare notes and different approaches to problems, and discuss conflicting results obtained from the same experiment. Brainerd (1978), in pointing out the need for peer interactions, contended that discussions among peers without the inclusion of the teacher were more conducive to causing disequilibrium in existing structures because the discussions would be less restricted. Disequilibrium, according to Piaget, is one of the prerequisites for the development of the more sophisticated structures of a higher stage from simpler ones of a lower stage.

Other educators have also discussed the need for student discussions in classrooms when considering implications of Piaget's theory to education. Renner (Renner et al, 1976) considered that throughout history classrooms have had to be reasonably quiet places where student interactions have been actively discouraged. While he would not endorse all forms of verbal student-to-student interaction,

he was emphatic about the value of social interaction and considered that a "classroom should show interaction with the objects of the discipline and between students pursuing the discipline" (p.174). This is an approach that is realistic for science classrooms both at the secondary and college level for which Renner et al were advocating its implementation. Sigel (1969, p.466) emphasized the same point: "Social interaction and stimulation which Piaget stresses is so important for the development of intelligence can easily be provided in the school classroom situation."

In a science classroom which encouraged peer interactions students would discuss their observations and conclusions with their classmates. Students would work in small groups to facilitate discussions, although there would be times when students would need to write down results or do written calculations quietly on their own after they had benefitted from discussion work.

Inhelder, Sinclair and Bovet (1974) discussed two more factors which were necessary to cause disequilibrium in existing structures thereby promoting the development of new structures capable of assimilating more abstract concepts. First, there must be an application of existing schemes to an increasing variety of situations so that,

> Sooner or later, this generalization encounters resistance, mainly from the simultaneous application of another

> scheme; this results in two different answers to one problem and stimulates the subject seeking a certain coherence to adjust both schemes or to limit each to a particular application...The situations most likely to elicit progress are those where the subject is encouraged to compare modes of reasoning which vary considerably both in nature and complexity, but which all, individually, are already familiar to him. (p.265)

What are needed to develop new structures are the dynamics of the conflict between already existing structures or schemes. The source of the progress is the disequilibrium which incites the student to go beyond his present understanding.

The second factor which Inhelder et al considered necessary to induce the necessary disequilibrium was the experiencing of a discrepancy between the students' own ideas and predictions and the actual outcome of experiments or ideas with which they interacted.

The implication of these two ideas for the science teacher attempting to promote intellectual development to formal-operational structures from concrete-operational ones is clear. The teacher should introduce new work in terms of simple,easily understood examples which bear some relation to existing knowledge and then proceed to more complex, less easily explained examples. On the basis of the new ideas just assimilated students would then be asked to predict the outcomes of proposed new experiments or

activities. Having made the predictions, they should then plan the procedures for the activity to test out their hypotheses and compare the observed results with their expected result and with the results of other students.

> Experience, particularly experience of discrepancies between one's predictions and ideas and the actual outcome of their realization, is therefore an important factor in the acquisition of knowledge. (Inhelder et al, 1974, p.267)

Karplus et al (1977b) applied the same ideas in their workshop based on Piaget's theory of self-regulation (or equilibration) which discussed science teaching strategies which promoted the development of reasoning.

A science classroom in which these ideas were put into practice would have students working out their own procedures for handling apparatus and determining relationships between variables. In this way they would be more likely to think about their predictions and when necessary realize the limits of their present reasoning.

The students would be encouraged to make conclusions and propose hypotheses on the basis of their observations. In engaging in activities which they themselves planned, students would be forced to think about their observations and attempt to integrate them into their existing structures, which would thereby become more complicated and

therefore capable of assimilating more complex ideas.

Karplus et al (1977b) developed an approach for teaching science which they considered promoted the development of formal-operational reasoning patterns. By deliberately setting out to induce disequilibrium they argued that self-regulation would occur. Their approach involved a learning cycle which consisted of three phases: exploration, concept introduction and concept application.

The first phase: exploration, aimed at inducing disequilibrium. They proposed that during exploration of a new topic, teachers would aim at getting students to reflect on present knowledge and thereby recognize its limitations.

> During EXPLORATION, the students learn through their own actions and reactions in a new situation. In this phase they explore new materials and new ideas with minimal guidance or expectation of specific accomplishments. The new experience should raise questions that they cannot answer with their accustomed patterns of reasoning. Having made an effort that was not completely successful, the students will be ready for self-regulation. (Karplus et al, 1977b, pp.5-8)

The particular strategy used here would be one in which the teacher asked questions aimed at determining the students' current level of thinking about the topic.

The second phase, concept introduction, started with the introduction of a new concept or principle and always

followed, and related directly to, the exploration activities. If the initial activity involved dissolving different solutes in water and maybe comparing the amounts of different solids which dissolved in the same volume of water at different temperatures, then the concept introduced might be a quantitative idea of solubility or it might involve the idea of concentration of a solution.

During concept application, the last phase, students applied the newly-acquired concept to a wide variety of situations. For example, having worked out a suitable way of measuring the solubility of solids and having realized that solubility changed with temperature, then various measurements of solubilities at different temperatures could be done.

During these activities the new reasoning patterns, evoked during concept introduction, were given time to stabilize. Some students need more time and more applications than others for the required conceptual reorganizations to occur. The learning by repetition and practice suggested in the last phase would be needed in varying degrees by different members of the class. Each student would be able to benefit from each phase according to his needs; all members of the class would not be expected to complete the same phases of the cycle in the same time. The order in which they were presented and experienced, however, would always be the same.

Several teaching strategies are necessary if the learning cycle approach is used. Students would be given ample opportunity to repeat activities and experiments. Students would be able to progress through activities at various rates. The science classroom would often contain students engrossed in different activities to do with the same topic and teachers would be involved in discussions with students to determine the students' state of understanding of the topic.

Some other ideas implicit in the learning cycle approach will be mentioned now. Concrete concepts would always be introduced prior to formal ones. Simple experiments would precede more difficult ones. Experiences, and examples in laboratory work, discussions, and text books should precede concept introduction.

Since the rationale behind the teaching cycle approach was the induction of disequilibrium in the adolescents' existing mental structures in order to cause repeated accommodations and eventual assimilation of new knowledge then students' questions would rarely be given direct yes or no answers to their questions. Instead, teachers would encourage students' questions but they would respond to them with further questions aimed at encouraging the students' own thinking along the correct path of investigation about the problem. There would be times, however, when direct answers would be essential, such as when a new

term or definition was forgotten. The answers to that type of question should be answered immediately or the student directed to a source such as a text book which would quickly provide it. The concern would be with encouraging a student to think and verbalize his thinking patterns rather than with labelling his answers right or wrong.

In order to encourage students to develop the desired approach to their work, teachers should model the behavior they hoped to promote. They should be prepared to reason out loud when problem solving and when developing hypotheses from their observations.

According to Schwebel and Raph (1973), the teacher who attempts to follow Piagetian theory "does not present ready-made knowledge...but, rather, provides opportunities for the child to construct his own knowledge...through his own reasoning" (p.213).

Since the first objective of this study is to enumerate the teaching practices which Piaget's theory of intellectual development and Piaget-oriented science educators consider will promote the development of formal-operational reasoning patterns, the practices just discussed in detail will now be summarized.

The intention is to use the summary of student and teacher activities which follows to form the basis of an instrument which will be developed and used in this study. The instrument provides a means of identifying current teach-

ing practices in junior secondary science classes and of determining whether current teaching practices are similar to those which are considered likely to develop the underlying structures of formal thought.

Summary of Teaching Practices Considered Likely to Promote Intellectual Development

Student Activities

Students would be organized into groups so that peer interactions and discussions of conflicting results or opposing ideas could induce disequilibrium in the students' existing mental structures.

Students would be able to carry out their own experiments and manipulate materials since Piaget considers it absolutely essential that students have concrete material experiences through which they can investigate solutions to problems.

Students would be encouraged to plan their own procedures for investigating scientific relationships. In attempting this, students would be applying existing knowledge and comparing the actual results of their experiments with those they predicted. This would ensure that their thinking would be more actively involved with the underlying relationships between variables than if they always followed prepared instructions.

Students would be encouraged to make conclusions or propose hypotheses after carrying out investigations or making observations. This would force students to form more tightly organized mental structures which incorporate newly learned ideas with previously learned facts and ideas.

Students would be given the opportunity to repeat activities and observations or to carry out similar activities. Not all students can assimilate new ideas immediately. Depending on their previous knowledge and existing reasoning patterns, different students need varying amounts of experience with new ideas and scientific principles before they can establish and stabilize newly acquired reasoning patterns. For the same reasons students would be able to progress at their own individual rates through any particular topic.

Teacher Activities

At the same time as the above activities for students occur, teachers would be including the following activities in their teaching practice.

Teachers would ask questions aimed at determining the students' existing levels of understanding of a topic. During the introduction of new areas of investigation and at intervals during its development the teacher would ask questions to gauge the students' level of understanding and progress and if necessary redirect students' activities and thinking.

Teachers would also ask thought-provoking questions or questions which could not be answered immediately by students with their present knowledge and reasoning patterns. These questions would be designed to demonstrate to students the inadequacies of their existing thinking patterns so that they would realize the need to gain further knowledge and to extend the capabilities of their present mental structures.

Teachers would encourage students to explain and account for their observations. By attempting to make sense out of their measurements and observations students develop more complex reasoning patterns and more tightly organized underlying mental structures which can then assimilate more difficult information in the future.

CHAPTER III

METHOD AND PROCEDURES

This chapter includes a discussion of the sample, a description of the method of data collection, and the development of the instrument and its subsequent use.

The Sample

From a list of junior secondary schools in two school districts in the lower mainland of British Columbia with similar SES, the names of ten junior secondary schools were randomly selected, five from each district.

Before contacting individual schools, the school boards in each district were approached for permission to carry out research projects in the district. A letter was sent to each school board office with an outline of the purpose of the study and the procedures which would be followed in the course of its completion.

When permission was granted to approach the junior secondary schools in each district (see Appendix A), the principals and the science department head in the school were approached and a meeting arranged between the researchers and the science staff of the school. It should be pointed

out at this stage that, although the purpose of this particular study was to identify teaching strategies most commonly used by junior secondary science teachers, there were other researchers involved in the project who were following other lines of investigation. Teachers were therefore being asked to co-operate in a multi-purpose undertaking.

At each meeting a request was made to observe and audio-tape three normal classroom science lessons given by each of the teachers of science in the school. In this way it was hoped to record the activities of a sample of at least 30 teachers giving lessons in junior secondary science classrooms. When requested, an outline of the purposes of the project (see Appendix B) was made available to the teachers so that they had some idea of the areas of interest of the researchers.

When teachers in schools which were initially randomly selected were unable to co-operate, more schools were randomly selected from each school district. The same approaches to science staff were made through the principals and science department heads until eventually most junior secondary schools in both districts had been approached. By then it was near the end of the 1978-79 school year when school schedules were being disrupted, so further approaches were delayed until the beginning of the next school year. At that time, another school district was approached in an attempt to increase the number of teachers in the sample from 18 to 30.

Collection of the Data

In each of the co-operating schools, times convenient for the participating teachers were arranged, in which observers went into classrooms to audio-tape and observe three regular teaching lessons per teacher. It was requested that the lessons being recorded involve as near to normal procedures as the presence of observers would allow. Lessons which were wholly occupied by tests were not observed and within each school a range of grade eight, nine and ten lessons were selected whenever possible.

In addition to audio-taping each lesson, the observers were requested to keep a written record of the activities and movements which occurred in the classroom. It was anticipated that any silences or ambiguities on the audio-tapes would then be understood by reference to the record sheets when they were coded at some later date. Details of blackboard work, text book references and laboratory activities, which would not be recorded on the tape, were also noted.

The Development of the Instrument

Herbert and Attridge (1975) in their guide for the developers of observation systems warned that "with so many systems extant which are under-developed and underused, one

needs good reasons for the creation of new ones particularly where they resemble instruments already in existence" (p.5).

Consequently, a thorough search was made for a coding schedule which focused on the teaching practices of interest in this study. They included activities of both the teacher and the student, some organizational aspects of the lessons and some cognitive aspects of the science teaching. Since activities in science classrooms are often quite different from activities in other classrooms it was considered that only a schedule specially designed for coding occurrences in science classrooms would be appropriate.

A search through Simon and Boyer (1970), which listed 79 systems developed in the United States for observing classroom behaviour, revealed only four which were relevant to science classrooms. None of them were readily adaptable to coding teaching practices which were related to the development of formal reasoning. The Science Observation System developed by Altman came closest to the needs of this study since it covered procedures and routines used in science classes but, as it contained both cognitive and affective behaviours, it was not usable here.

A further search of the literature revealed only a few schedules specifically designed for classroom observation. One produced by Fischler and Zimmer (1968) was developed to enable its authors to classify teaching techniques observed in science classrooms. By teaching technique they meant

any activity which the teacher carried out specifically to promote learning in the classroom. Even though its aim was to classify teaching on a verbal or doing level or according to whether the students actively participated in science activities, it could not be adapted to the needs of this study.

Galton and Eggleston (1975), working in the United Kingdom, developed a science teaching observation system to measure how teachers differed in their behaviour in science classrooms. Their schedule, however, was directed only at the intellectual transactions which took place during science lessons (Galton & Eggleston, 1979, p.76).

Finally, since no suitable existing observation schedule was found, one was developed specifically to meet the needs of this study. Since an objective of the study was to compare current teaching practices with Piaget-derived teaching practices the schedule was based on those practices, summarized at the end of the previous chapter, considered likely to aid in the development of formal reasoning. The main features of the items used in the final form of the instrument are listed in Table 4. The items were organized into student activities and teacher activities. Each of these were further divided according to whether the activity was considered likely or unlikely to promote the development of formal-operational reasoning patterns. Those items listed under student activities and numbered S1 to S6 represented activities considered likely to aid in the de-

Table 4

Science Teaching Observation Instrument Items

STUDENT ACTIVITIES

Students:

S1. Work in groups so that they can discuss their activities, results, ideas.

S2. Plan their own procedures for carrying out laboratory activities.

S3. Discuss their observations, or applications of a new concept, with their peers before attempting to answer text book questions.

S4. Make conclusions or propose hypotheses about observations made during laboratory activities.

S5. Manipulate apparatus themselves. They set up their materials, do their own laboratory work, use microscopes, etc.

S6. Repeat or extend their observations after discussing their conclusions with their peers or the teacher. May be a repetition of an activity to increase familiarity with a new concept.

S7. In a class all do the same activities in a lesson. The whole class progresses through a topic at the same rate.

S8. Follow text book instructions for laboratory activities. (or follow a procedure written out by the teacher on the blackboard, hand-out sheet, etc.)

S9. Write answers to questions from the text book on their own without any discussion with peers or teacher OR do lab write-ups on their own.

S10. Use algorithms to find answers to problems, e.g. are taught how to manipulate a formula such as D = M/V to find an unknown quantity.

S11. Use memorised material, e.g. definitions, valence and apply them without necessarily understanding them.

Table 4 (Cont'd)

TEACHER ACTIVITIES

Teacher:

T1. Asks questions to determine the pupil's level of understanding of a topic - whole class, individually or in groups.

T2. Asks questions which are thought provoking and designed to arouse the curiosity of students or designed to make students aware that there are still things they cannot explain with their present knowledge of a topic.

T3. Encourages students to verbally explain, or account for, or make sense of their observations made during a lab activity.

T4. Interacts with individuals or small groups to ask questions, check students' progress, become aware of the reasoning patterns they are using.

T5. Talks to, lectures, or claims attention of whole class at once. Lesson consists mainly of teacher talk.

T6. Demonstrates scientific principles by manipulating apparatus himself (demonstrating a new technique not included).

T7. Tells class in advance the concept or rule that they are going to "prove", e.g. Today we are going to observe that ...

T8. Withdraws from interactions with class and simply supervises students with no verbal interactions except to maintain discipline.

velopment of more complex reasoning structures from simpler ones. Items numbered S7 to S11 described student activities less likely to promote self-regulation. Similarly, in the section which focused on teacher activities in the science classroom, items T1 to T4 were activities considered likely to cause disequilibrium in students' thinking patterns and thereby cause the development of more complex structures. Items T5 to T8, however, were activities which were considered less likely to induce self-regulation.

Validity of the Instrument

Validity refers to the degree to which the measures obtained by an instrument actually describe what they purport to describe.

> Validity criteria include those which pertain to the observability of behaviors, to the objectivity of the instrument and the related problems of inference, context and observer effects, to the representativeness of instrument items of the behaviors under study, and to the determination and reporting of reliability and validation procedures. (Herbert & Attridge, 1975, p.6)

First the observability of the student and teacher activities was examined. Most of these were directly observable and were therefore low inference items. For example, the student activities numbered S5 and S8, which required the observer to decide whether the students were manipulat-

ing materials themselves and following text book instructions while doing so, were easy to observe and record accurately. Student activity item S3, however, promised to be more difficult to code, particularly if students were carrying out laboratory activities. Discussions might be occurring but it would not always be easy to judge whether the topics being discussed were centred on the science activity or something else. If the teacher deliberately organized his class to encourage the discussion of science activities the coding would be straightforward. In most cases, however, it was anticipated that the coding of any student discussions would involve moderately high inference judgements.

Content validity of the instrument was established by seeking a judgement of the items it included from a science educator and another graduate student. Both persons were conversant with the intent of the coding schedule and had closely followed the literature review which had led to the selection of the items it contained. A trial coding session using a randomly selected lesson led to alteration of the wording of several of the items in the instrument. Subsequent recodings of the same lesson by an independent coder were used to ascertain whether the revised wording of the items did increase the consistency and accuracy with which the instrument could be used. The final form of the instrument which resulted is included in Appendix C.

The Coding Method Used on the Instrument

Instruments for observing continuing classroom events may employ either sign or category recording procedures (Borich, 1977). A sign system records an event only once in a given time interval regardless of how often it occurs, whereas a category system records a given behaviour each time it appears and hence provides a frequency count of the occurrence of specific behaviours. Since some of the activities in the instrument developed in this study were moderately high inference behaviours, it was decided to use a modified sign system, known as a rating system, when employing it to code a lesson. When using this instrument, the coders were required to make a judgement, on a 1 to 5 scale, of the degree to which each behaviour occurred during each nine-minute segment of the lesson.

If the activity did not occur during any nine-minute interval, then column 1 was checked. If the behaviour occurred at least once column 2 was checked, whereas if it occupied approximately half of that time interval, column 3 was checked. Column 4 was used whenever a behaviour occurred most of the time. Column 5 was checked whenever an activity continued throughout the entire nine-minute period (or if its effect was dominant in that time period even though it only occurred once or twice).

Reliability of the Instrument

To determine the reliability of the instrument, that is, the consistency with which it was capable of measuring the proportion of time spent on each activity, another graduate student was asked to code two randomly selected lessons. After instruction was given in the use of the schedule, the coding was carried out. To measure the correlation between the judgements of the two raters, Kendall's tau was calculated using the correction for tied observations. The correlations obtained were .66 and .77.

Method of Calculating Item Scores on the Instrument

Each of the columns 1 to 5 on the science teaching practices instrument was assigned a numerical rating of 0 to 4 respectively. This rating was then multiplied by the number of times the column was checked during a lesson. The numbers thus obtained in each column were summed across each item to give a total score for each item for each lesson. A sample item score calculation is set out in Table 5. The total score for an item could vary from 0, for an activity which did not occur at all during a lesson, to 24 for an activity which occurred continuously throughout the whole lesson and was therefore checked six times for the lesson.

Table 5

Calculation of Item Score

	Column				
	1	2	3	4	5
Numerical value	0	1	2	3	4
Item T5	✓✓		✓	✓	✓✓

$$(2 \times 0) + (2) + (3) + (2 \times 4) = \frac{\text{Total Score}}{13}$$

Method of Analysing the Data

Identification of Teaching Types According to Frequency of Occurrence of Activities

One purpose of this study was to identify teaching practices presently being used in junior secondary science classrooms so that they could be compared with Piagetian-derived practices. The concern was with how teachers were organizing their students and in what activities the teachers and students were engaged. The data collected were aimed at producing a frequency count of such behaviours from which a description of the teacher and student activities in the classroom could be drawn. The analysis of the data therefore required methods which would enable common teaching styles or types to be identified based on the frequency

of use of the activities listed in the schedule.

As a first step in the identification of types of teaching practices or overall teaching strategies used by the teachers in this sample, grouped frequency distribution graphs were constructed for each teacher for each lesson. These were intended to serve several purposes. They allowed identification of teaching types which had common student and teacher activities. They allowed the number of teachers who used each teaching strategy to be determined. They showed whether a teacher consistently used the same teaching strategies. Finally, they allowed a comparison of the teachers' current practices with the Piagetian-derived practices identified from the literature.

For the purpose of constructing these graphs the total scores computed for each item in a whole lesson were divided into four arbitrary categories. If the total score of an item was between 16 and 24, it was considered to have a high frequency of occurrence. If the total score was between 7 and 15, its occurrence was considered to be moderate. A score of 1 to 6 during a lesson was taken to indicate a low frequency of occurrence. If the activity did not occur, its frequency was zero and a fourth category was used to indicate its absence.

Since a frequency of occurrence of each activity was determined for each lesson, then the mean of this frequency was calculated for each item within each teaching type

identified by the method just outlined. Further, an overall mean was calculated for each item for all lessons coded but before these means could be compared with a mean for a Piagetian-oriented teaching strategy, it had to be derived.

Frequency of Occurrence of Piagetian-derived Activities

Not all the activities listed on the schedule (as desirable for promoting formal thought) could occur continuously for a whole lesson. For example, the activity in item S4, which referred to students making conclusions or proposing their own hypotheses, could not occupy an entire lesson. Item S5, however, which refers to the time during which students set up and use their own apparatus, could occur throughout a whole lesson. In order to allow for these differences it was decided that some measure of optimum frequency of occurrence of each activity was needed.

Accordingly, several educators and science teachers were approached for their judgement of the percentage of time which could be occupied by each student and teacher activity listed on the schedule over a period of three routine lessons (see Appendix D). For the purposes of this exercise each person was asked to consider that items S1 to S6 and T1 to T4 constituted a desirable teaching practice and that the items S7 to S11 and T5 to T8 constituted undesirable teaching practices when teaching to promote

formal reasoning patterns. From their responses a mean frequency of occurrence for each item was calculated. It was used for comparison with the means of the other teaching styles identified in this study.

The types of teaching practices identified by this method of analysis and their comparison with Piagetian-derived practices are presented in the next chapter.

CHAPTER IV

RESULTS

This chapter presents the results of the study. The sample is described first, then the teaching practices as recorded by the observation schedule are examined. Finally, the types of teaching practices commonly found to be used by this sample of teachers are compared with the Piagetian-type practices derived from the literature.

The Sample

Before the end of the 1978-79 school year, the science staffs in twelve junior secondary schools had been approached with requests to allow observations of science lessons in their classrooms. From the six schools which agreed to participate in the study, 18 teachers were obtained as the final sample. The teaching practices of each of these teachers were observed and audio-taped on three separate occasions resulting in 52 coded lessons.

Of the 18 teachers in the sample, 16 had taken science teaching methodology courses and 17 had taken more than eight courses during their teacher training. As shown in Table 6, all but two of the teachers had at least four

years' science teaching experience and had been teaching experience and had been teaching science throughout their careers.

Table 6

Experience of Teachers

Years of experience	Number of teachers	
	Any teaching	Science teaching
1 - 3	2	2
4 - 7	5	5
8 - 14	8	8
$\geq$ 15	3	3

Types of Teaching Practices Identified in the Sample

As explained in the previous chapter, grouped frequency distribution graphs were constructed for each lesson for each teacher. An examination of these graphs (see Appendix E) indicates that there were basically three different types of teaching strategies being used in junior secondary science classrooms in the sample. The first strategy identified (Type I) was characterized by student involve-

ment in a laboratory activity which was carried out according to text book instructions and for which a written report was expected. The second practice (Type II) typically involved a teacher demonstration of scientific phenomena and included a large amount of lesson time in which the teacher talked to the class. The third practice (Type III), however, was identified by an absence of student and teacher laboratory activity. Instead, it included a moderate amount of teacher talk coupled with student written work, solving problems, or applying recently learned science principles. The frequency distributions of student and teacher activities coded in each of these teaching types (see Figure 1) are now described in more detail.

Type I: Laboratory Activity/Write-up Style

In this type of lesson, which occurred in 26 of the 52 lessons coded, a laboratory activity occurred which involved all students for at least fifteen minutes of the lesson (see Item S5, Teaching Type I, Fig.1). In these lessons all students in the classroom worked at the same activity and followed directions for the activity either from the text book or from instructions provided by the teacher on an overhead projector or a blackboard. On completing the activities outlined for them, students then commenced write-ups of the activities (see Item S9), again

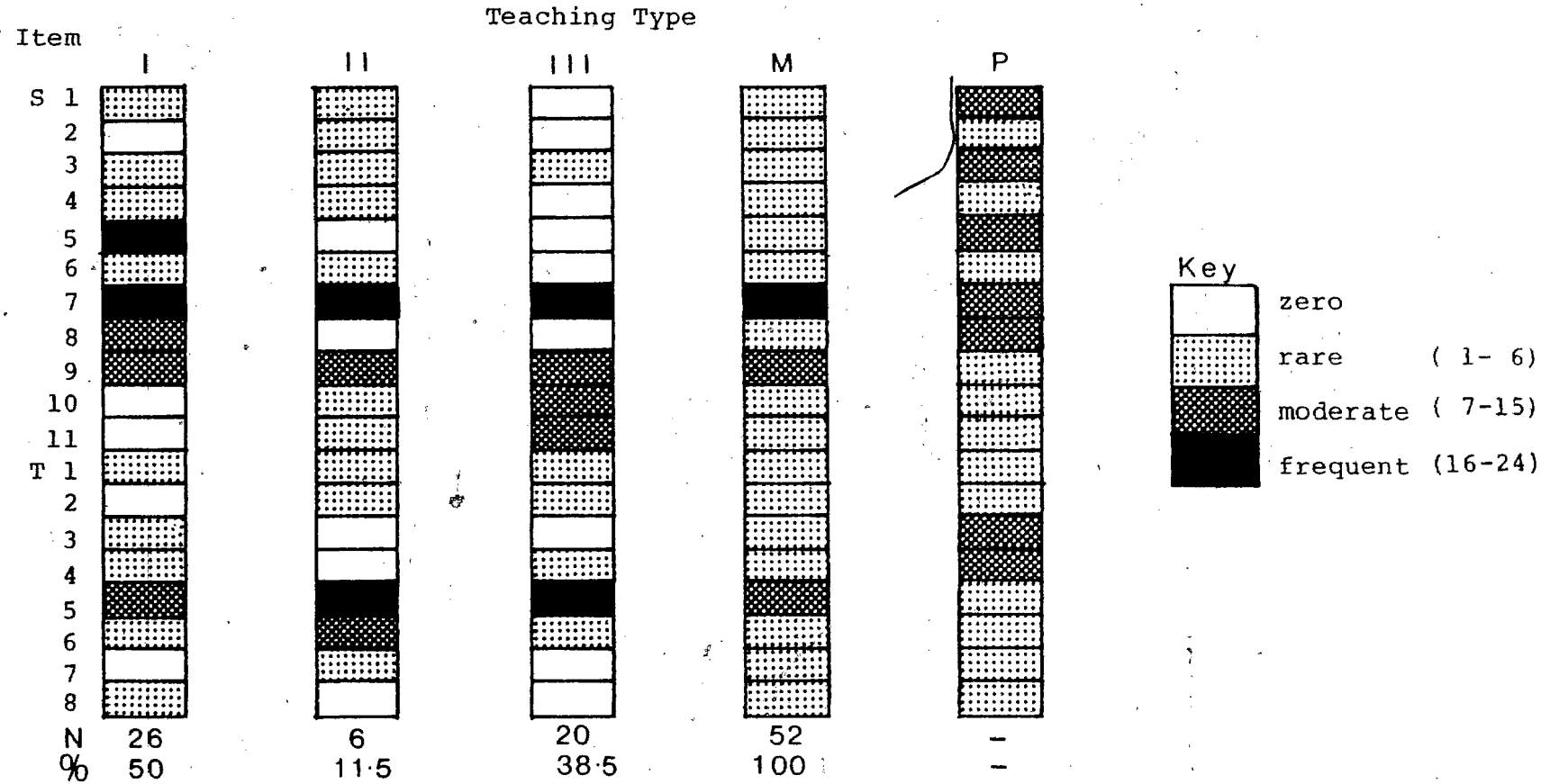


Figure 1 Frequency distributions of activities in science classrooms by teaching types

following text-book instructions. If the text asked questions about the activities just done, then students were required to include written answers to the questions in their write-ups. During these student activities the teacher sometimes walked around questioning or helping individual students. In 7 of these lessons, teacher interactions with students occurred often enough for the total frequency score of that teacher activity item to be high enough to be considered as occurring moderately often.

In 4 of these laboratory activity-oriented lessons, the teacher discussed the students' conclusions with the whole class and attempted to elicit hypotheses from the students about these observations. In the other 22 lessons of this type, conclusions and hypothesis were not discussed.

Type II: Teacher Talk/Demonstration Style

This type of teaching was characterized by two teacher activities which occurred frequently during each lesson. The teacher occupied a large amount of time during the lesson talking to the class and claiming the attention of the whole class (see Item T5, Teaching Type II, Figure 1). During some of this time the teacher demonstrated chemical reactions or scientific principles by handling and manipulating apparatus (see Item T6, Teaching Type II, Figure 1). Students in these lessons sat in their seats either listening to events being described or recording details and observations of the

teacher's demonstration as directed by the teacher; they had no opportunity to carry out the reaction, or handle the apparatus, themselves. Any lessons in which students carried out their own activities were not included in this teaching style even when there may have been demonstration activities carried out by the teacher in the lesson.

The low frequency scores for items T1 to T3 (Teaching Type II, Figure 1) show that teachers who used this teaching style in their teaching practices did not often ask questions of students; verbal interactions between teacher and students were few (Item T4). Further, teachers using this style rarely attempted to elicit conclusions about the observations from the students; Item T3 occurred in 1 of the 6 lessons categorized as Type II.

Type III: Teacher Talk/Student Written Problem Work Style

This type of teaching involved neither laboratory activities carried out by students, nor demonstrations done by the teacher. Instead, the lessons were characterized by frequent teacher talk (see Item T5, Teaching Type III, Figure 1) and students spending a moderate proportion of the lesson time doing written answers to text-book problems or questions involving recently learned scientific principles (see Items S9,10,11, Figure 1). Teachers used this type of teaching practice in 20 of the 52 lessons coded.

Students in these lessons were all expected to be doing the same work and progressing through a topic at the same rate. Teachers spent very little time questioning students, either individually or as a whole class.

Teaching Type by Grade Level

Table 7 shows the distribution of the current teaching types identified in this sample by the grade level of the students in the science classes. The Laboratory Activity/ Write-up (Type I) practice occurred more frequently with grade eight and nine classes than with grade ten classes. Grade ten classes were more frequently observed doing problem solving activities, or listening to the teacher talk or explain and describe scientific principles.

Distribution of Type and Grade Level by Teacher

Table 8 shows that most teachers in this study (14 out of 18) used more than one type of teaching style in the lessons observed. Only two teachers used all three teaching types and both of those teachers were observed teaching all three lessons to the same grade level of students. Three teachers, however, used the same teaching practice for all three lessons observed.

Table 7

Teaching Type by Grade Level

Type	Grade Level					
	8		9		10	
	N	%	N	%	N	%
I	12	71	10	67	4	20
II	1	6	2	13	3	15
III	4	23	3	20	13	65
Total	17		15		20	

Table 8

Distribution of Type and Grade Level by Teacher

Teacher	Type			Grade Level		
	I	II	III	8	9	10
1	1		2	1		2
2			3		1	2
3	1	1	1	3		
4	*		2		2	1
5	1	*	1	2	1	
6	2	1			2	1
7	3			2	1	
8	3				1	2
9		1	2	1		2
10	2		1	1	1	1
11	2		1		2	1
12	2		1	2		1
13	1		2	1	1	1
14	1	1	1			3
15	1		2		1	2
16	3			3		
17	1	2		1	2	
18	2	1			2	1

* 1 lesson not coded.

Having described current teaching practices in the junior secondary science classes sampled, the third objective of this study can be carried out; the observed practices can be compared with the Piaget-oriented practices derived from the literature.

Discussion of Means of Student and Teacher Activity Items

The three teaching types discussed describe the teaching practices which were observed in the junior secondary science classrooms in this sample. Tables 9 and 10 show the means of the frequencies of occurrence of each of the student activities and teacher activities, respectively, by teaching style. The tables also include the mean frequency for each item on the schedule taken over all the lessons observed as well as the theoretical means for a Piaget-derived teaching practice obtained as outlined in the previous chapter.

Comparison of the Observed Teaching Practices with the Piaget-derived Practice

By referring to Table 9, the student activity means of the current teaching practices can be compared with the student activity means of the Piaget-derived teaching practice.

Table 9

Means of Student Activity Items by Teaching Type

Type	N	Item Means										
		1	2	3	4	5	6	7	8	9	10	11
I Lab. Activity/ Lab. Write-up	26	3.42	.11	.65	.58	12.4	1.2	23.6	10.3	6.15	.19	.50
II Teacher talk/ Demonstration	6	.67	.33	.33	.17	1.83	.17	23.7	.00	8.83	.83	4.83
III Teacher talk/ Student written work	20	.05	.05	.25	.00	.05	.00	22.85	.55	16.55	2.45	5.00
All types	52	1.81	.12	.42	.31	3.77	.48	22.46	5.26	10.65	1.13	2.73
IV Piaget-derived		11.73	5.6	9.6	8.00	14.4	4.53	13.06	7.00	.53	1.33	1.33

The mean frequency of occurrence of Item 1, which measures the amount of time in lessons during which peer interactions and discussions of work are deliberately organized is much less in current teaching practices than one would plan if following Piaget's theory.

Similarly, the frequency of occurrences of students planning their own laboratory procedures (Item 2) occurs much less often than it would be planned for in a Piaget-derived teaching practice.

Students did not often discuss text-book questions and application of scientific principles before doing written answers to such questions. Neither did they often verbally attempt to discuss their conclusions or make hypotheses. Both of these student activities (Items 3 and 4) would be encouraged to occur more frequently if one were planning to promote development of formal thought.

In current teaching practices, the observed frequency of students manipulating their own apparatus and carrying out their own experiments (Item 5) in laboratory activity lessons (Type I) comes very close to what would be planned in the Piaget-type teaching practice.

Very little time is currently devoted to students repeating laboratory activities to allow assimilation of new principles and to enable new thinking patterns to become firmly established (Item 6).

Whereas students in a large percentage of the classes observed were all organized to carry out the same activities

at the same time (Item 7), this would occur less often in a Piaget-oriented teaching practice. Students in the latter would more often be working through topics at their own rate and in any one lesson, particularly after the topic introduction, the students would be involved in different activities.

The amount of time in which students would follow textbook instructions for laboratory investigations (Item 8) is slightly less for the Piaget-derived teaching practice than for the Type I lessons which involved students in laboratory activities.

Laboratory write-ups and individual student written work (Item 9) occurred much more frequently in all the lessons than would be planned for in the Piaget practice.

The overall frequency of occurrence of the activity in which students answered problems by applying algorithms (Item 10) is close to what would be expected in the Piaget-derived style of teaching. The amount of time in which students would utilize memorized definitions would occur less often in the Piaget-type strategy (Item 11). Both of these activities, however, would occur less often than was observed in the Type III teaching strategy.

By referring to Table 10, which lists the means of teacher activities by teaching type, it can be seen that for a Piaget-type teaching strategy the amount of time occupied by the teacher questioning students to determine

Table 10

Means of Teacher Activity Items by Teaching Type

Type	N	Item Means							
		1	2	3	4	5	6	7	8
I Lab. Activity Lab. Write-up	26	2.08	.92	.50	4.46	9.85	1.35	.15	.85
II Teacher talk/ Demonstration	6	5.83	3.83	.67	1.50	21.17	7.50	1.12	.00
III Teacher talk/ Student written work	20	3.90	1.45	.30	2.80	16.35	.95	.35	.75
All types together	52	3.1	1.5	0.4	3.5	13.7	1.9	0.3	0.7
IV Piaget-derived		5.86	5.3	8.27	9.33	2.40	1.06	.53	2.13

their level of knowledge in a subject (Item 1) is slightly higher than was observed in this sample of lessons. The frequency of occurrence of thought-provoking questions posed by the teacher (Item 2) and the amount of time in which a teacher expects verbal explanations of laboratory observations (Item 3), however, would be much higher in a Piaget-derived teaching strategy. Individual student-teacher interactions (Item 4) would also occur more frequently than observed in this study.

Item 5, which measured the frequency of occurrence of the teacher talking to the whole class at once would occur much less often in the Piaget-derived practice. The means of Item 6 and 7, which indicate the frequency of occurrence of teacher demonstrations and the teacher telling the class in advance the results of their investigations, would remain as infrequent as in the observed lessons. Occasions during which the teacher would engage in activities other than those directly involving student-teacher interactions (Item 8) would occur more frequently in a Piaget-derived practice.

To summarize these comparisons, then, the frequencies of occurrence of teaching practices observed in this study differ markedly from the frequencies which would be expected if the Piagetian-derived practices were followed. Observed practices were similar to Piaget-derived practices in the low frequency of occurrence of student activities 8 and 10,

and teacher activities 6 and 7, all of which are considered unlikely to aid the development of formal thought. Of the activities considered likely to promote the development of formal thought, the occurrence of one only was similar to the Piaget-derived occurrence. This item measured the frequency of occurrence of teachers' questions directed at finding students' existing levels of knowledge in a topic (Teacher Item 1).

CHAPTER V

CONCLUSIONS AND DISCUSSION

The first objective of this study was to derive from the literature those teaching practices which would aid the development of formal-operational thinking patterns from concrete-operational structures in adolescents in junior secondary science classes. This was accomplished by a comprehensive exploration of the literature related to both Piaget's theory and science teaching. Next, teaching practices which were considered to be most useful in promoting formal thought were used to develop an instrument. By applying this coding schedule to lessons being taught in junior secondary science classes, it was then possible to identify practices currently being used by a sample of science teachers and to compare them with the theoretical teaching practices deduced from the literature.

The results showed that the most frequently occurring student activities included students writing up laboratory reports or writing answers to questions or problems from the text book and students doing laboratory work according to written directions. All students in a class were required to do the same experiment or activity or answer

the same set of problems from their text book; they all progressed through their work at the same rate.

The most frequent teacher activity was the teacher talking, describing or explaining current work to the whole class. Less often, the teacher would direct questions to the whole class to determine their level of knowledge of a topic or the teacher would interact with or question individual students as they carried out their laboratory activities.

Conclusions

The observed practices, then, were not similar to those which one would attempt if the development of formal reasoning was a goal of science teaching. The Piaget-derived activities, aimed at encouraging disequilibrium in the student's existing structures, would include more frequent instances of students being deliberately encouraged to discuss their observations, to plan their own procedures, repeat activities which they did not fully understand at first, and to be able to progress through a topic at their own rate. The teacher attempting to use the Piagetian-oriented practices would talk less to the class as a whole but would ask more questions of the students, both of the whole class and in individual interactions with students.

The results of this study show that most of the teacher and student activities observed in junior secondary science classrooms were based on activities and topics outlined in the text books. In this respect, the study agrees with the summary report of the British Columbia Science Assessment when discussing the teaching of science in junior secondary grades.

> Students in many secondary classes seldom or never engage in activities such as preparing reports, doing projects, designing their own experiments, or discussing current materials from newspaper and magazine articles. (Summary Report, B.C. Science Assessment, 1978, p.45)

That none of these activities were observed is not to say that they do not occur. Teachers were asked to teach normal, routine lessons when being observed; lessons which included the above activities may not have been considered normal or routine or may have been considered more difficult to do when an observer was in the classroom. In fact, in at least one school there was evidence that material and articles from newspapers and science magazines were used as the basis of discussion in some science lessons because there were files and shelves in the classrooms stocked with magazines and copies of articles.

Having made some conclusions about the teaching practices observed in this study, it is now possible to return to the initial questions and ponder the answers to them.

Discussion

The literature surveyed showed that the majority of students in senior high school, probably two-thirds of them, are at the concrete-operational stage of development. Teaching practices likely to promote the development of more complex reasoning in students were then identified. In view of the first statement, it is perhaps not surprising that present teaching practices are not similar to those recommended in the literature. If the Piagetian-derived practices are based on correct assumptions and they would in fact aid in the development of formal thought, one would not expect the existing teaching practices, which differ markedly from them, to promote formal thought.

Further, the development of formal-operational reasoning patterns is probably not a goal presently being pursued by secondary science teachers despite the large amount of recent science teaching research which focuses on Piaget's theory of intellectual development. The present political climate is more likely to direct teachers' concerns towards core curricula and the most efficient ways of getting facts across to students. Teaching practices which develop formal thought or which utilize enquiry methods are outside the zeitgeist of the "back to basics" trend.

Finally, there are some personal comments on the observed teaching practices. It was surprising and perplexing to find that all students in all classes observed were required to carry out the same investigations or written work and progress at the same rate. One can only speculate on the reasons for this. At first it was considered that it was perhaps because the text book was closely adhered to and the majority of schools used the same texts. A close examination of the contents of the texts, however, revealed that, consistent with the statements in their introduction, extension activities and alternative references to other texts were provided for many of the topics covered. The authors of those texts intended that "the course (could) be tailored to the interests and abilities of individual students" (Schmid, 1970 and Schmid, 1973). One can understand that the same area of study such as, say, Light or Heat would be the focus of study undertaken by the whole class since it involves using the same types of apparatus. But, since each teacher has his own science classroom and has ready access to a storeroom and a laboratory assistant in some schools, it would seem at least feasible in terms of physical facilities that students could pursue different investigations within the same class. Students do have different abilities and are at different levels of intellectual development. These differences can be accommodated by allowing different rates of progress

within a topic. Pre-lesson preparation and organization, however, are certainly more time consuming if different rates of progress are planned.

One last comment: there were very few occasions when students asked questions of the teacher. While it might be suggested that the presence of observers inhibited students' normal activities, their other observed classroom behaviours showed that this was not the problem. Although the asking of questions was not an activity for which the frequency was judged on the coding schedule, its absence was most noticeable. The observed teaching practices apparently do not encourage student-initiated questions.

APPENDIX A

LETTERS OF APPROVAL TO DO RESEARCH IN THE SELECTED SCHOOL DISTRICTS

PROFESSIONAL DEVELOPMENT CENTRE
BURNABY SCHOOL BOARD

March 9, 1979

Dr. Marvin F. Wideen,
Faculty of Education,
Simon Fraser University,
Burnaby, B. C.

Dear Dr. Wideen:

As you are aware, the district Research Committee reviewed your research proposal on Teacher Strategies and Change Strategies Of Secondary Science Teachers at a meeting on March 8, 1979. Although there were some questions, your proposal was approved by the committee.

The next step in this project will involve the identification of the actual schools to become involved, and as I understand from your description of the study, this is to be done randomly. Once you have selected the schools you would like to contact, I would appreciate you calling me so that I can attend the meetings with the secondary departments in those schools.

The study is interesting and ambitious and we will try to assist in every way we can. I will look forward to hearing from you.

Yours truly,

Blake Ford
Chairman
Research Committee

BF/il

350 Holdom Avenue, Burnaby, B.C., V5B 3V1 Telephone 299-8464

SCHOOL DISTRICT No. 43 (COQUITLAM)

550 POIRIER STREET,
COQUITLAM, B.C. V3J 6A7

1979 02 12

Dr. M. Wideen,
Faculty of Education,
Simon Fraser University,
Burnaby, B. C.
V5A 1S6

Dear Dr. Wideen:

Thank you for your February 1st letter, and attachment, in which you outline a research proposal involving the teaching of secondary science.

Approval is given for you to contact the principals of secondary schools in the District to discuss your proposal. Participation, of course, is left to the discretion of individual principals and teachers.

We look forward to any results you are able to share with us.

Yours very truly,

A. K. Mutter,
Assistant Superintendent of Schools.

for:

G. M. Paton,
Superintendent of Schools.

GMP/jn

APPENDIX B

OUTLINE OF PURPOSES OF THE PROJECT

Secondary Science Research Project

Purpose of the Study

The purpose of this study is to determine how science is currently being taught and to determine what factors, situations and constraints influence that teaching. From this, we can then investigate questions such as: Do current strategies reflect those recommended in the literature? Do teachers find themselves constrained to use certain teaching methods because of external pressures?

Those who have studied innovation in education have shown that the process of change is enormously difficult to effect. Therefore, a second area of investigation involves identifying the barriers which teachers encounter when they try to change their method of instruction.

Thus the overall intent is to determine how science is being taught, what factors influence teachers to teach as they do, and what steps are likely to be the most productive in changing the method of instruction. As a means of initiating a line of research into this area, the following specific objectives have been set for the project:

a. To identify the teaching strategies most commonly used by a representative sample of teachers;

b. To determine the extent to which the strategies identified in "a" are related to various factors including teacher attitude toward science as inquiry;

c. To identify those strategies of change to which teachers are likely to respond;

d. To identify the barriers to improving the quality of instruction as perceived by teachers.

Procedure

In order to achieve these objectives, we propose to obtain data from a random sample of 30 teachers using interviews and a questionnaire, and collecting three audio tapes of each teacher's classroom teaching. The analysis of the audio tapes coupled with the interview data will enable the researchers to identify the teaching strategies most commonly used by the sample of teachers.

The questionnaire and interview will be structured to gather data on a range of factors that will be related to the teaching strategies and the teachers' attitudes toward these strategies and toward strategies of change. A parallel form of the teachers' questionnaire will be given to students in those classes which will be audiotaped. This administration is expected to take approximately twenty minutes of class time. The out-of-class time commitment for each teacher will be about one hour.

The data will be collected by the research team, which includes faculty members in Education, and three graduate students. All research team members are experienced educators.

Follow-up

Since the study involves the collection of empirical data about teaching strategies that the participants use, the researchers believe the teachers will be interested in receiving a summary of the findings at the conclusion of the study. Therefore, while all data will remain confidential, the research team will share the final report with the participants.

Research Team

Dr. Marv Wideen
Dr. Al Whitney
Margaret Cusack
Geok-Sim Seah
Elaine Barr

APPENDIX C

FINAL FORM OF INSTRUMENT USED FOR CODING SCIENCE LESSONS

Grade Level: _____

Topic covered during lesson: _____

Teacher Code: _____

Item	STUDENT Activities	Not at all 1	Occurred at least once 2	About half of the time 3	Occurred most of the time 4	Occurred all the time or was Dominant/ Significant 5
S 1.	Work in small groups that facilitate interactions and discussions about work they are doing					
2.	Plan their own procedures for carrying out practical work, e.g. plan how to determine the density of a solid, liquid or gas					
3.	Discuss applications of newly learned concepts or ideas with their peers, e.g. before starting to answer textbook questions would first verbally discuss their explanations with each other					
4.	Are encouraged to make conclusions or propose hypotheses based on observations made during lab activities, e.g. students are encouraged to make a generalization that only the metal samples conduct electricity					
5.	Manipulate materials themselves. Students set up and handle their own apparatus for the topic being studied					
6.	Are given time to repeat or extend their observations after discussing conclusions with other groups or with whole class					
7.	Whole class proceeds through a topic at the same rate, i.e. whole class treated as being at the same level, e.g. either all listening to the teacher or all doing the same activities during a lesson					
8.	Follow text-book instructions (or procedure written on b.b. or o.h.p. or handout sheet) for laboratory activities					
9.	Do lab write-up or written answers to questions from textbook (or b.c. or handout sheet) on their own, e.g. sit and write out answers to questions about recently learned concepts without any peer discussions					
10.	Answer problems by applying an algorithm, e.g. answer problems on density by applying $D = \frac{M}{V}$ or do heat problems by applying generalized formula					
11.	Are expected to memorize material, e.g. definitions, valence and apply them when needed without necessarily understanding the concept first					

Item	TEACHER Activities	Not at all 1	Occurred at least once 2	About half of the time 3	Occurred most of the time 4	Occurred all the time or was dominant/ significant 5
T 1.	Asks questions to determine pupil's level of understanding of topic - whole class, individually or in groups, e.g. may ask question to gauge students' understanding of energy, temperature, effect of heat					
2.	Asks questions which are not immediately answerable - questions are designed to arouse curiosity or show students that there are some parts of the topic being studied which cannot yet be understood with their existing knowledge					
3.	Encourage students to explain or account for observations made during lab activity, e.g. why did only 2 solutions change colour; why did this light go off first, what does that precipitate suggest to you?					
4.	Divides class into small groups and encourages peer interactions about their investigations or other work. Interacts himself with small groups to gauge students' understanding of present work or redirect their thinking					
5.	Claims attention of, or lectures to whole class at once. Lesson consists mainly of teacher talk					
6.	Demonstrates scientific principles by manipulating apparatus himself. Students can only observe					
7.	Tells class in advance the concept or rule that they are going to prove, e.g. today we are going to observe that metals conduct heat better than non-metals					
8.	Retreats from classroom or supervises class with no interactions except to maintain discipline. No interaction with students to gauge their progress or understanding of a topic					

APPENDIX D

SCHEDULE ON WHICH TEACHERS AND EDUCATORS INDICATED IDEAL AMOUNT OF TIME WHICH COULD BE SPENT ON PIAGET-DERIVED ACTIVITIES IN SCIENCE LESSONS

Please indicate on the scale below the amount of time that could be spent on each of the activities listed assuming that the activity would help develop formal thought and you intended using the activities to promote development of formal thought. Since the content of science lessons can vary between lab activities and discussions, it might be better to think of the percentage of time which could be occupied by each activity over a period of 3 lessons rather than a single lesson.

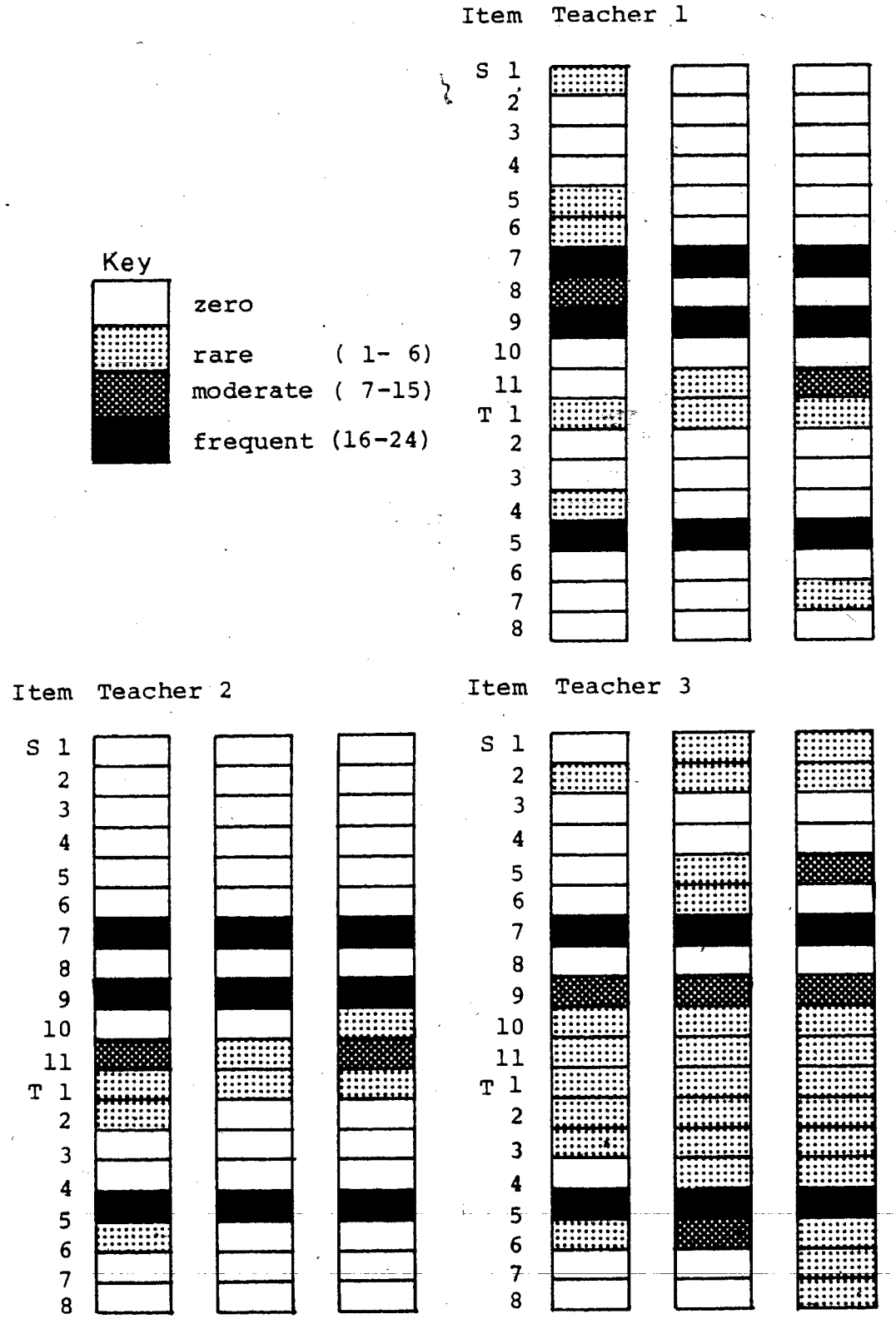
	STUDENT ACTIVITY	Percent of time it could occupy 0% 20% 40% 60% 80% 100%
S1.	Students work in groups so that they can discuss their activities, results, ideas.	
2.	Students plan their own procedures for carrying out practical work.	
3.	Students discuss their observations, or applications of a new concept, with their peers before attempting to answer text book	
4.	Students make conclusions or propose hypotheses about observations made during lab activities.	
5.	Students manipulate apparatus themselves. They set up their materials, do their own lab work, use microscopes, etc.	
6.	Students repeat or extend their observations after discussing their conclusions with their peers or the teacher. May be repetition of an activity to increase familiarity with concept.	
7.	Individual students or groups progress at own rate through a topic. Different groups would be at different stages in most lessons.	
	TEACHER ACTIVITY	
T1.	Teacher asks questions to determine the pupil's level of understanding of a topic - whole class, individually or in groups.	
2.	Teacher asks questions which are thought provoking and designed to arouse curiosity of students or designed to make students aware there are still things they cannot explain with their present knowledge of a topic.	
3.	Teacher encourages students to verbally explain or account for or make sense of their observations made during a lab activity.	
4.	Teacher interacts with individuals or small groups to ask questions, check students progress, become aware of the reasoning patterns they are using.	

Please indicate on the table below the proportion of time which you consider need be spent on each activity if (1) you considered each activity were not likely to promote the development of formal thought and (2) you aimed to develop formal reasoning in science classes.
Since the content of science lesson can vary it might be better to think of the percentage of time which could be occupied by each activity over a period of 3 lessons rather than a single lesson.

STUDENT ACTIVITY	0% 20% 40% 60% 80% 100%
S8. Students follow text-book instructions for lab activities (or a procedure written out by teacher on b.b. or o.h.p.)	
9. Students do written answers to questions from text-book on their own without any discussion with peers or teachers or do lab write-ups on their own.	
10. Students use algorithms by which they answer problems e.g. are taught how to manipulate a formula $D = \frac{M}{V}$ to find the unknown	
11. Students use memorized material e.g. definitions, valence and apply them without necessarily understanding them.	
TEACHER ACTIVITY	
T5. Teacher talks, lectures, claims attention of whole class at once. Lesson consists mainly of teacher talk.	
6. Teacher demonstrates scientific principles by manipulating apparatus himself (demonstrating a new technique not included).	
7. Teacher tells class in advance the concept or rule that they are going to "prove" e.g. Today we are going to observe that...	
8. Teacher withdraws from interactions with class and simply supervises students with no verbal interactions except to maintain discipline.	

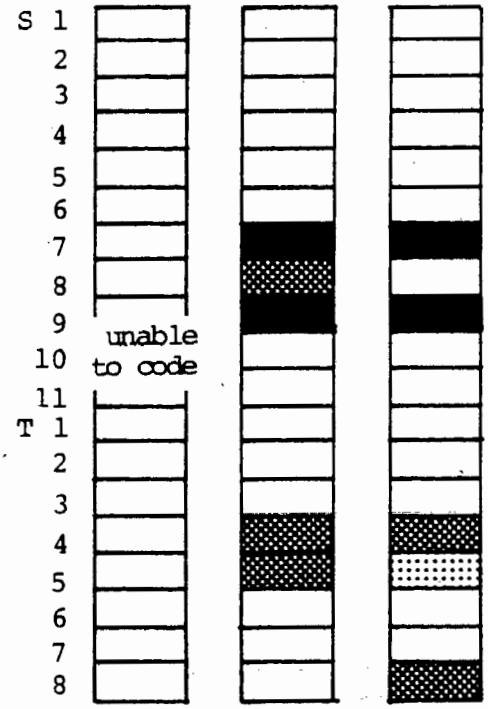
APPENDIX E

FREQUENCY DISTRIBUTION GRAPHS OF OBSERVED TEACHING PRACTICES

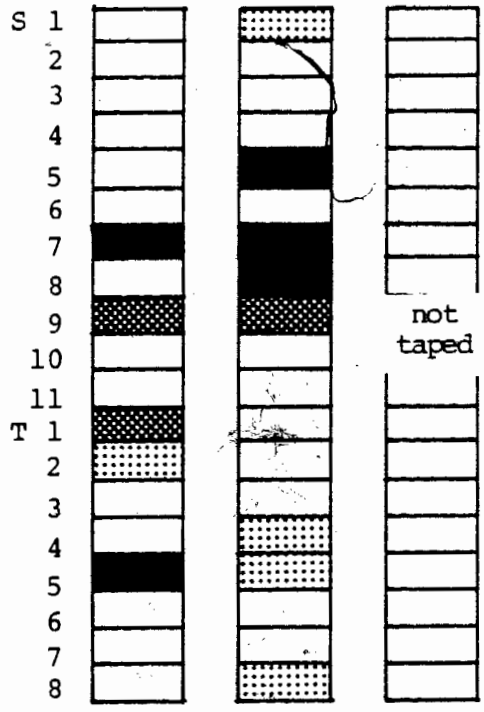


Frequency distribution graphs of observed teaching practices

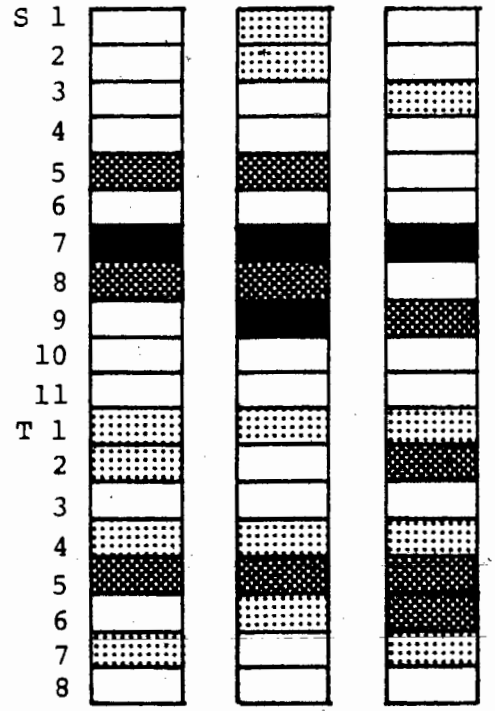
Item Teacher 4



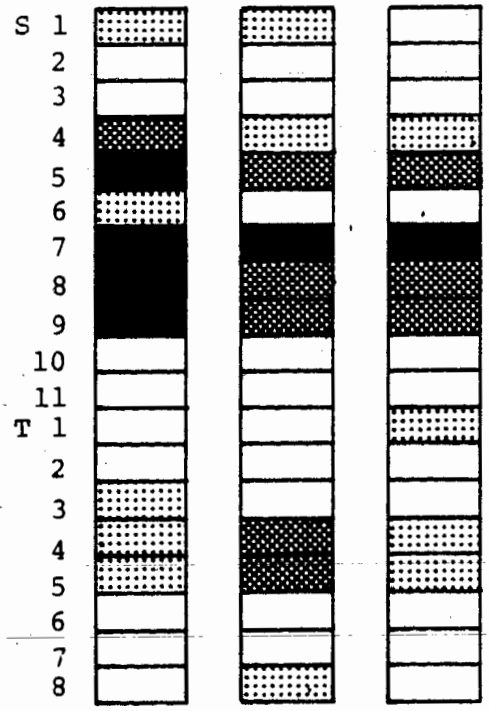
Item Teacher 5

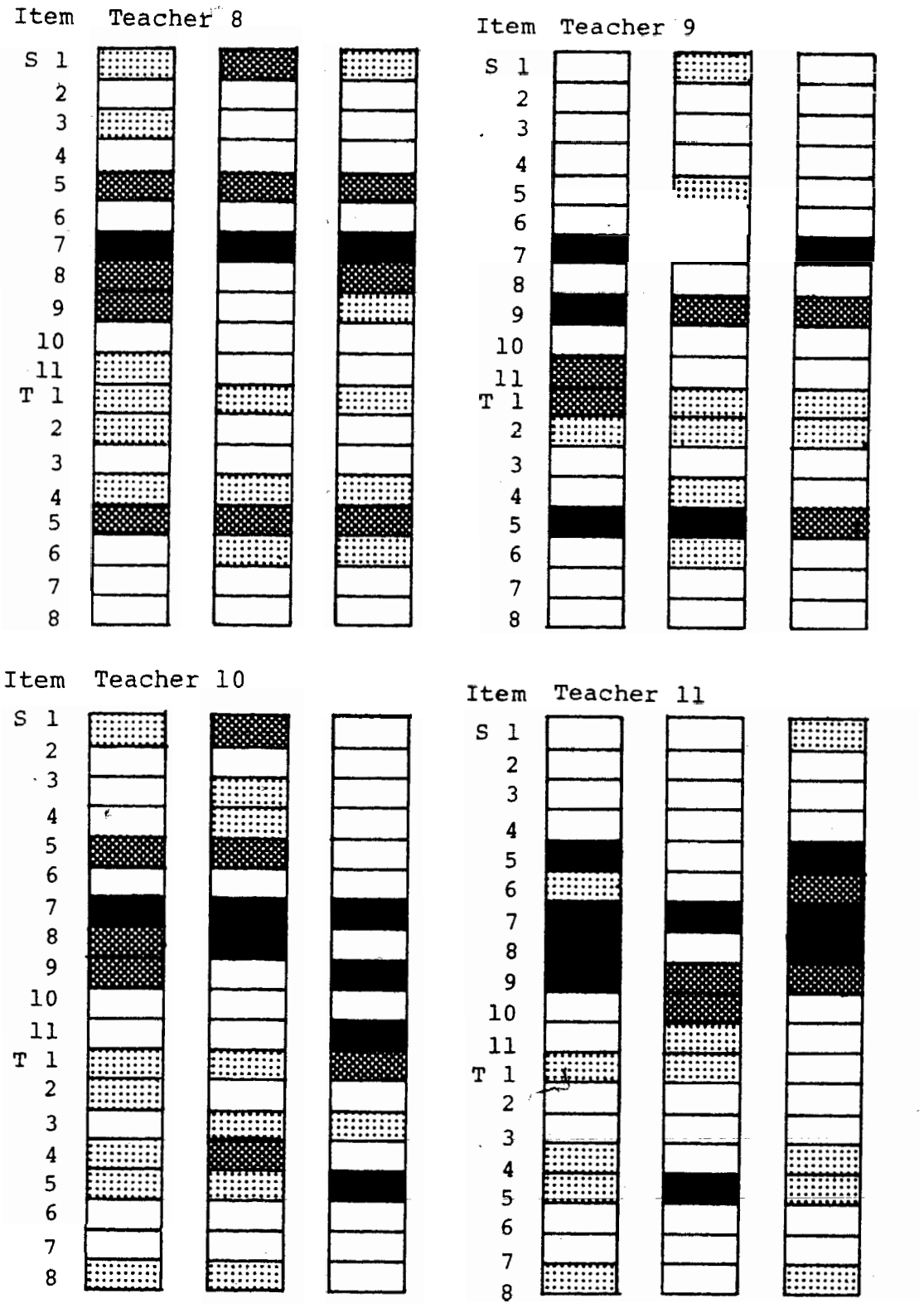


Item Teacher 6



Item Teacher 7




Item Teacher 8
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Item Teacher 9
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T 1
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Item Teacher 10
S 1
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T 1
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Item Teacher 11
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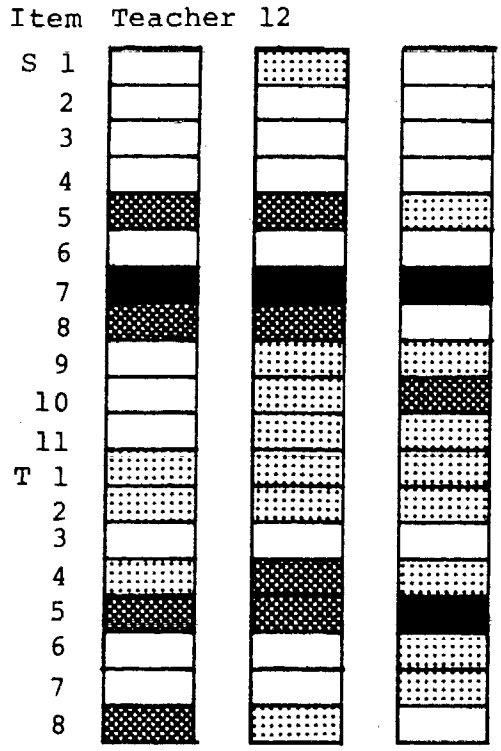
Item Teacher 12
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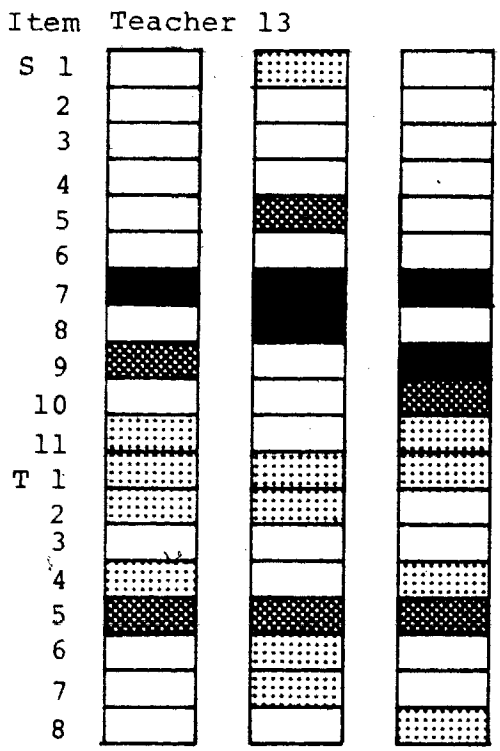
Item Teacher 13
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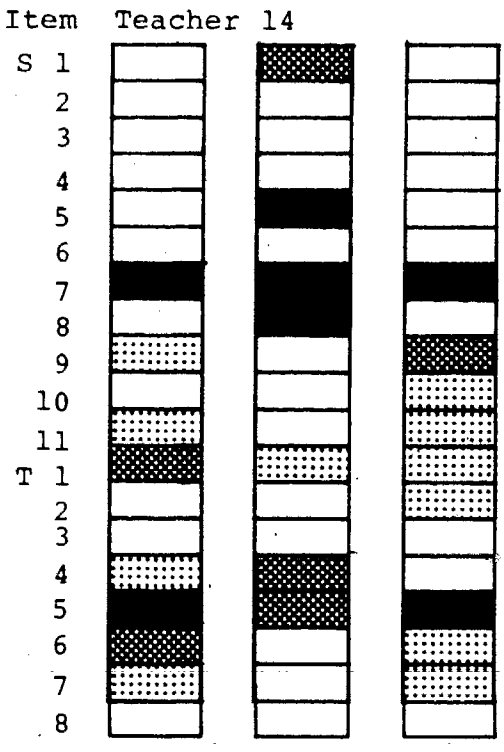
Item Teacher 14
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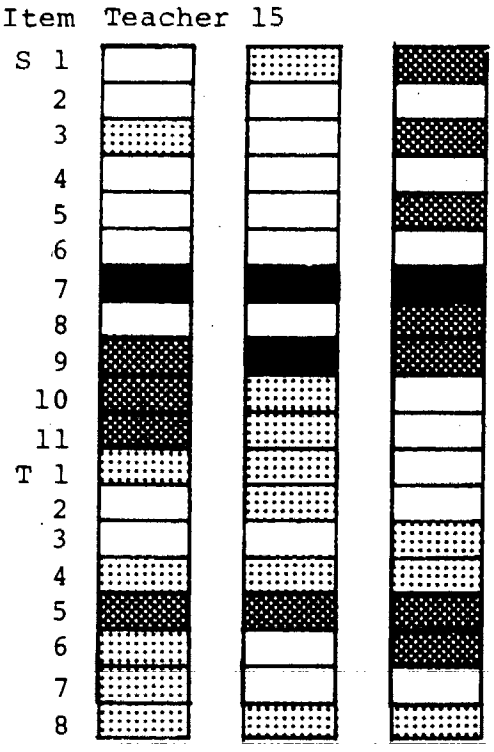
Item Teacher 15
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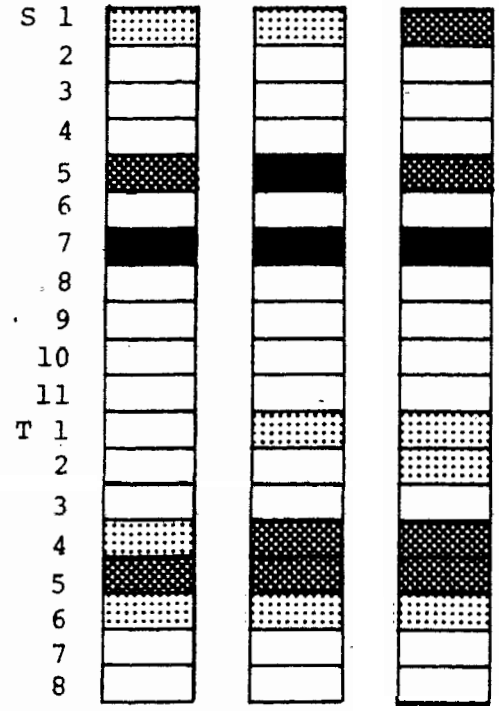
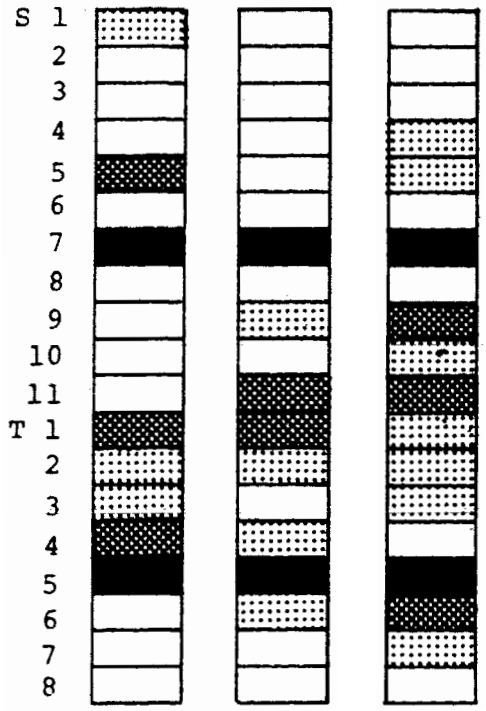
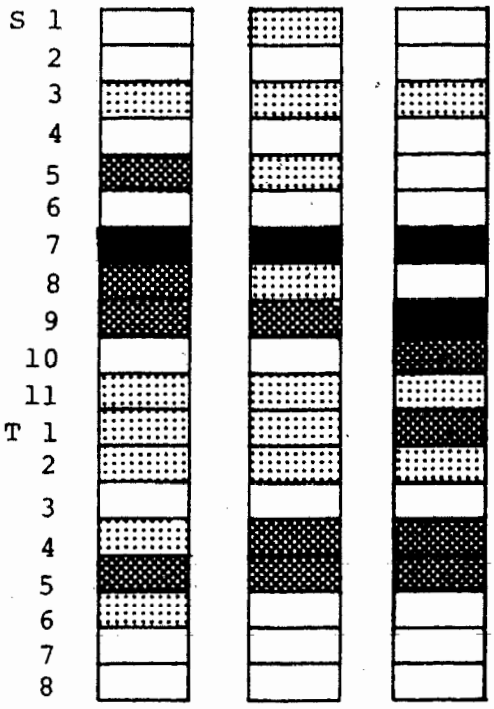
Item Teacher 16



Item Teacher 17



Item Teacher 18



BIBLIOGRAPHY

Arons, A.B. Cultivating the capacity for formal reasoning: objectives and procedures in an introductory physical science course. American Journal of Physics, 1976, 44, 834-838.

Arons, A.B., & Karplus, R. Implications of accumulating data on levels of intellectual development. American Journal of Physics, 1976, 44, 396.

Bady, R.J. Methodological issues in formal operations research: What does it mean to be formal? Science Education, 1978, 62, 233-239.

Bass, J.E., & Montague, E.J. Piaget-based sequences of instruction in science. Science Education, 1972, 56, 503-512.

Belanger, M. Learning studies in science education. Review of Educational Research, 1969, 39, 377-395.

Bellack, A.A. (Ed.) Theory and research in teaching. New York: Teachers College Press, 1963.

Blake, A.J.D., & Nordland, F.H. Science instruction and cognitive growth in college students. Journal of Research in Science Teaching, 1978, 15, 413-419.

Blasi, A., & Hoeffel, E.C. Adolescence and formal operations. Human Development, 1974, 17, 344-363.

Borich, G.D. The appraisal of teaching: concepts and process. Reading, Mass.: Addison-Wesley Publishing Coy., 1977.

Brainerd, C.J. Piaget's theory of intelligence. Englewood Cliffs, N.J.: Prentice-Hall Inc., 1978.

Bredderman, T.A. The effects of training on the development of the ability to control variables. Journal of Research in Science Teaching, 1973, 10, 189-200.

British Columbia: Ministry of Education. British Columbia science assessment, summary report. Victoria: Queen's Printer, 1978.

Cantu, L.L., & Herron, J.D. Concrete and formal stages and science concept attainment. Journal of Research in Science Teaching, 1978, 15, 135-143.

Case, R., & Fry, C. Evaluation of an attempt to teach scientific inquiry and criticism in a working class high school. Journal of Research in Science Teaching, 1973, 10, 135-142.

Chiappetta, E.L. A review of Piagetian studies relevant to science instruction at the secondary and college level. Science Education, 1976, 60, 253-261.

De Carcer, I.A., Gabel, D.L., & Staver, J.R. Implications of Piagetian research for high school science teaching: a review of the literature. Science Education, 1978, 62, 571-583.

De Vries, R. Relationships among Piagetian, IQ, and achievement assessments. Child Development, 1974, 45, 746-756.

Driver, R. When is a stage not a stage? A critique of Piaget's theory of cognitive development and its application to science education. Review of Educational Research, 1978, 21, 54-61.

Duckworth, E. Piaget rediscovered. In Piaget rediscovered, R.E. Ripple & V.N. Rockcastle (Eds.). Ithaca, New York: Cornell University Press, 1964.

Duckworth, E. Either we're too early and they can't learn it or we're too late and they know it already: the dilemma of "Applying Piaget". Harvard Educational Review, 1979, 49, 297-312.

Dulit, E. Adolescent thinking á la Piaget: the formal stage. Journal of Youth and Adolescence, 1972, 1, 281-301.

Easley, J.A. Comments on the INRC group. In Piaget rediscovered, R.E. Ripple & V.N. Rockcastle (Eds.). Ithaca, New York: Cornell University Press, 1964.

Eggleston, J.F., Galton, M.J., Jones, M.E. A science teaching observation schedule. London: Macmillan Education, 1975.

Ehindero, O.J. Formal operational precocity and achievement in biology among some Nigerian high school students. Science Education, 1979, 63, 231-236.

Fischler, A.S., & Zimmer, G. The development of an observational instrument for science teaching. Journal of Research in Science Teaching, 1967-1968, 5, 127-137.

Flavell, J.H. The developmental psychology of Jean Piaget. New York: D. van Nostrand Publishing Co. Inc., 1963.

Flavell, J.H. Cognitive Development. Englewood Cliffs, N.J.: Prentice Hall Inc., 1977.

Friot, F.E. Curriculum experiences and movement from concrete-operational thought. In J.W. Renner, D.G. Stafford, A.E. Lawson, J.W. McKinnon, F.E. Friot, & D.H. Kellogg. Research, teaching and learning with the Piaget model. Norman: University of Oklahoma Press, 1976.

Gallagher, J.J. A topic classification system for classroom observation. AERA Monograph No. 6. Chicago: Rand McNally, 1970.

Galton, M., & Eggleston, J. Some characteristics of effective science teaching. European Journal of Science Education, 1979, 1, 75-86.

Ginsburg, H., & Opper, S. Piaget's theory of intellectual development (2nd ed.). Englewood Cliffs, N.J.: Prentice-Hall Inc., 1979.

Good, T.L., Biddle, B.J., & Brophy, J.E. Teachers make a difference. New York: Holt, Rinehart & Winston, 1975.

Good, T.L. & Brophy, J.E. Looking in classrooms (2nd ed.) New York: Harper & Row, Publishers, 1978.

Good, R., Kromhout, R.A., & Mellon, E.K. Piaget's work and chemical education. Journal of Chemical Education, 1979, 55, 426-430.

Good, R., Mellon, E.K., & Kromhout, R.A. The work of Jean Piaget. Journal of Chemical Education, 1978, 55, 688-693.

Goodstein, M., & Howe, A.C. The use of concrete methods in secondary chemistry instruction. Journal of Research in Science Teaching, 1978, 15, 361-366.

Greenway, M.W., & Olliver, S.A. The development and application of a coding schedule based on Schwab's levels of open-ness. Masters Thesis, Simon Fraser University, 1976.

Hale, J.P. An investigation of two formal-operational schemata in adolescents enrolled in ISCS classrooms. Journal of Research in Science Teaching, 1976, 13, 559-564.

Hall, J.R. Conservation concepts in elementary chemistry. Journal of Research in Science Teaching, 1973, 10, 143-146.

Han, Jong Ha. An analysis of the second year Korean science text book using Piagetian concrete and formal operational thinking patterns. (Doctoral dissertation, The Florida State University, 1977) Dissertation Abstracts International, 1978, 38, 5376A. (University Microfilms No. 7801481).

Hartford, F., & Good, R. Assessment of cognitive requirements of instructional materials. School Science and Mathematics, 1976, 126, 231-237.

Herbert, J., & Attridge, C. A guide for developers and users of observation systems and manuals. American Educational Research Journal, 1975, 12, 1-20.

Herron, J.D. Piaget for chemists. Journal of Chemical Education, 1975, 52, 146-150.

Herron, J.D. Piaget in the classroom. Journal of Chemical Education, 1978, 55, 165-170, (a).

Herron, J.D. Role of learning and development: critique of Novak's comparison of Ausubel and Piaget. Science Education, 1978, 62, 593-605. (b)

Hobbs, E.D. Formal operations in secondary students. (Masters Thesis, University of Alberta, 1975) Canadiana, 1977, 3, 1086. (National Library of Canada No. 26781).

Ingle, R.B., & Shayer, M. Conceptual demands in Nuffield O-level chemistry. Education in Chemistry, 1971, 8, 182-183.

Inhelder, B., & Piaget, J. The growth of logical thinking from childhood to adolescence. New York: Basic Books, 1958.

Inhelder, B., Sinclair, H., & Bovet, M. Learning and the development of cognition. Cambridge, Mass: Harvard University Press, 1974.

Hudson, M.J. Introducing the mole. Education in Chemistry, 1976, 13, 110-111.

Karplus, R. Science teaching and the development of reasoning. Journal of Research in Science Teaching, 1977, 14, 169-175.

Karplus, R., & Karplus, E.F. Intellectual development beyond elementary school III - ratio: a longitudinal study. School Science and Mathematics, 1972, 72, 735-742.

Karplus, R., Karplus, E., Formisano, E., & Paulsen, A.C. A survey of proportional reasoning and control of variables in seven countries. Journal of Research in Science Teaching, 1977, 14, 411-417. (a)

Karplus, R., Lawson, A.E., Wollman, A.E., Appel, M. Bernoff, R., Howe, A., Rusch, J.J., & Sullivan, F. Science teaching and the development of reasoning. Berkeley: Lawrence Hall of Science, Berkeley, 1977. (b).

Karplus, R., & Peterson, R.W. Intellectual development beyond elementary school II: Ratio, a survey. School Science and Mathematics, 1970, 70, 813-820.

Kass, H., & Wheeler, A.E. Problem areas in learning chemistry in high school. Paper presented at the annual meeting of the National Science Teachers Association, Atlanta, Georgia, March 1979.

Keating, D.P. Precocious cognitive development at the level of formal operations. Child Development, 1975, 46, 276-280.

Kohlberg, L. & Gilligan, C. The adolescent as a philosopher: the discovery of self in a post-conventional world. Daedalus, 1971, 100, 1051-1086.

Kolodiy, G.O. Cognitive development and science teaching. Journal of Research in Science Teaching, 1977, 14, 21-26.

Kubli, F. Piaget's cognitive psychology and its consequences for the teaching of science. European Journal of Science Education, 1979, 1, 5-20.

Kuhn, D. Relation of two Piagetian stage transitions to IQ. Child Development, 1974, 45, 157-162.

Kuhn, D. The application of Piaget's theory of cognitive development to education. Harvard Educational Review, 1979, 49, 340-360.

Kuhn, D., & Angelev, J. An experimental study of the development of formal operational thought. Child Development, 1976, 47, 697-706.

Lawson, A.E. Combining variables, controlling variables, and proportions: is there a psychological link? Science Education, 1979, 63, 67-72.

Lawson, A.E., Karplus, R., & Adi, H. The acquisition of propositional logic and formal operational schemata during the secondary school years. Journal of Research in Science Teaching, 1978, 15, 465-477.

Lawson, A.E., Nordland, F.H., & Devito, A. Piagetian formal operational tasks: a crossover study of learning effect and reliability. Science Education, 1974, 58, 267-276.

Lawson, A.E., & Renner, J.W. A quantitative analysis of responses to Piagetian tasks and its implications for curriculum. Science Education, 1974, 58, 545-559.

Lawson, A.E., & Wollman, W.T. Encouraging the transition from concrete to formal cognitive functioning - an experiment. Journal of Research in Science Teaching, 1976, 13, 413-430.

Lawson, A.E., & Wollman, W.T. Using chemistry problems to provoke self-regulation. Journal of Chemical Education, 1977, 54, 41-43.

Levine, D.I., & Linn, M.C. Scientific reasoning ability in adolescence: theoretical viewpoints and educational implications. Journal of Research in Science Teaching, 1977, 14, 371-384.

Linn, M.C., Chen, B., & Thier, H.D. Teaching children to control variables: investigation of a free-choice environment. Journal of Research in Science Teaching, 1977, 14, 249-255.

Lovell, K. Intellectual growth and the school curriculum. In F.B. Murray (Ed.), The impact of Piagetian theory on education, philosophy, psychiatry and psychology. Baltimore: University Park Press, 1979.

Lowell, W.E. A study of hierarchial classification in concrete and abstract thought. Journal of Research in Science Teaching, 1979, 16, 255-262.

McKinnon, J.W., & Renner, J.W. Are colleges concerned with intellectual development. American Journal of Physics, 1971, 39, 1047-1052.

Medley, D.M., & Mitzel, H.E. The scientific study of teacher behavior. In A.A. Bellack (Ed.) Theory and research in teaching. New York: Teachers College Press, 1963.

Miller, W.B. Implications of Piaget's theory of intellectual development (Master's thesis, University of New Brunswick, 1974) Canadiana, 1976, 2, 842. (National Library of Canada No. 22942).

Munby, H. Piagetian research in science education. Some misgivings about its potential to improve practice. Paper presented at the 1978 national meeting of the National Association for Research in Science Teaching, Toronto, April 1978.

Neimark, E.D. Intellectual development during adolescence. In F. Horowitz (Ed.), Review of child development research (Vol. 4) Chicago: University of Chicago Press, 1975.

Nous, A., & Raven, R. The effects of a structured learning sequence on children's correlative thinking about biological phenomena. Journal of Research in Science Teaching, 1973, 10, 251-255.

Piaget, J. Cognitive development in children: development and learning. Journal of Research in Science Teaching, 1964, 2, 176-186.

Piaget, J. In Hall, E., A conversation with Jean Piaget and Barbel Inhelder. Psychology Today, 1970, 3(12),25-32.

Piaget, J. Intellectual evolution from adolescence to adulthood. Human Development, 1972, 15, 1-12.

Piaget, J. Foreward to Piaget in the classroom. M. Schwebel & J. Raph (Eds.). New York: Basic Books, 1973.

Rasmussen, W.H., & Schmid, M.C. Developing science concepts in the laboratory. Scarborough, Ont.: Prentice-Hall, 1968.

Raven, R.J., & Murray, R.B. Effect of high school chemistry experiences on Piaget's operative comprehension. Science Education, 1978, 62, 467-470.

Renner, J.W. Piaget's theory of assimilation and concept learning. E.D.R.S. No. E.D. 156 461, 1978.

Renner, J.W., Grant, R.M., & Sutherland, J. Content and concrete thought. Science Education, 1978, 62, 215-221.

Renner, J.W., & Lawson, A.E. Piagetian theory and instruction in physics. The Physics Teacher, 1973, 11, 165-169. (a).

Renner, J.W., & Lawson, A.E. Promoting intellectual development through science teaching. The Physics Teacher, 1973, 11, 273-276. (b).

Renner, J.W., Stafford, D.G., Lawson, A.E., McKinnon, J.W., Friot, F.E., & Kellogg, D.H. Research, teaching and learning with the Piaget model. Norman: University of Oklahoma Press, 1976.

Sayre, S., & Ball, D.W. Piagetian cognitive development and achievement in science. Journal of Research in Science Teaching, 1975, 12, 165-174.

Schmid, M. (Ed.), Extending science concepts in the laboratory. Scarborough, Ont.: Prentice-Hall, 1970.

Schmid, M. Introducing science concepts in the laboratory. Scarborough, Ont.: Prentice-Hall, 1973.

Schwebel, M., & Raph, J. Piaget in the classroom. New York: Basic Books, 1973.

Shayer, M. How to assess science courses. Education in Chemistry, 1970, 7, 182-186.

Shayer, M., Kuchemann, D.E., & Wylam, H. The distribution of Piagetian stages of thinking in British middle school and secondary school children. British Journal of Educational Psychology, 1976, 46, 164-173.

Sheehan, D.J. The effectiveness of concrete and formal instructional procedures. (Doctoral dissertation, State University of New York, Albany, 1970). Dissertation Abstracts International, 1970, 31, 2748A. (University Microfilms No. 70-25479).

Siegler, R.S., & Liebert, R.M. Acquisition of formal scientific reasoning by 10- and 13-year-olds: designing a factorial experiment. Development Psychology, 1975, 11, 401-402.

Sigel, I.E. The Piagetian system and the world of education. In D. Elkind & J.H. Flavell (Eds.), Studies in cognitive development. New York: Oxford Univ. Press, 1969.

Sigel, I.E., & Cocking, R.R. Cognitive development from childhood to adolescence: a constructivist perspective. New York: Holt, Rinehart & Winston, 1977.

Simon, A., & Boyer, E.G. Mirrors for behavior II. Philadelphia: Classroom Interaction Newsletter, Research for Better Schools, 1970.

Smith, B.O. Toward a theory of teaching. In A.A. Bellack (Ed.) Theory and research in teaching. New York: Teachers College Press, 1963.

Smith, P.J. Piaget in high school instruction. Journal of Chemical Education, 1978, 55, 115-118.

Talley, L.H. The use of three-dimensional visualization as a moderator in the higher cognitive learning of concepts in college level chemistry. Journal of Research in Science Teaching, 1973, 10, 263-269.

Tisher, R.P. A Piagetian questionnaire applied to pupils in a secondary school. Child Development, 1971, 42, 1633-1636.

Travers, R.M.W. Essentials of learning. (4th ed.) New York: Macmillan Publishing Co., 1977.

Wheeler, A.E., & Kass, H. Proportional reasoning in introductory high school chemistry. Paper presented at the fiftieth annual meeting of the National Association for Research in Science Teaching. Cincinatti, Ohio, March 1977, Mimeographed.

Wilson, J.T. Expanded abstract and analysis of a study by Lawson, A.E. & J.W. Renner. In S.L. Hegelson & P.E. Blosser, (Eds.), Investigations in science education, 1977, 3, 11-15. E.D.R.S. document No. 157 778.

Wollman, W., & Karplus, R. Intellectual development beyond elementary school V: Using ratio in differing tasks. School Science and Mathematics, 1974, 74, 593-611.

Wollman, W.T., & Lawson, A.E. The influence of instruction on proportional reasoning in seventh graders. Journal of Research in Science Teaching, 1978, 15, 227-232.