EXTENT OF DISCRIMINATION BETWEEN CONCRETE AND FORMAL OPERATIONAL STUDENTS AS REFLECTED BY ACHIEVEMENT ON TEACHER-MADE TESTS OF HIGH SCHOOL SCIENCE

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ABSTRACT

Piaget's theory of cognitive development suggests that there may be a disparity between the cognitive level of the student and the content of the Introductory Physical Science (IPS) Course. Teacher-made tests may accommodate to this disparity by requiring logical operations only at the concrete level in spite of the fact that many of the concepts in IPS require logical operations at the formal level.

The purpose of this study was to determine what operational level was required for high achievement on teacher-made tests of IPS and to determine whether formal and concrete operational high achievers on teacher-made tests could maintain this level of achievement on experimental test items designed to require formal operational ability for a correct response.

Two hypotheses were stated for this study;

(1) that high achievement on teacher-made IPS tests that are intended to test understanding of concepts requiring formal operations does not require formal operational ability on the part of the learner.

(2) that on the experimental test items only students who have achieved the substages of formal operations will be high achievers.

The sample initially consisting of 108 grade 10 students at Gordon Bell High School in Winnipeg was reduced

to 25 concrete operational students and 14 formal operational students through loss of samples from the study group.

To test the first hypothesis the subjects were classified into their operational level by a group pencil and paper test entitled Rods. The Rods test is designed to discriminate between concrete and formal operations. The data indicated that teacher-made tests were discriminating.

It was suggested that lack of support for the first hypothesis was due to the unwillingness or inability of concrete operational students to carry out the memorization required to answer correctly items on the teacher-made tests.

The data for the second hypothesis indicated that performance on the experimental test items was independent of operational level. Small sample size and the possibility that the experimental test items were based on IPS material not covered thoroughly or omitted by the classroom teacher could have affected the results.

The study indicated that grade 10 science teachers can expect up to 50% of their students to be concrete operational and demonstrated how poorly concrete operational students are able to achieve on IPS concepts. It suggests that science teachers recognize the proportion of concrete operational students in their classes and adjust curriculum to match concrete operational ability. By providing these students with tasks they can accomplish successfully their transition to formal operations might be facilitated.

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CHAPTER I

Introduction

The educational implications of Jean Piaget's theory of intellectual development are evident in its current wide application to elementary and junior high curriculum and instruction. However, the same application has not taken place to the same extent in senior high school. A possible reason could be that curriculum developers assume that high school students are in the final stages of intellectual development. If curriculum is structured on this assumption it follows that little concern will be directed towards the intellectual levels of the student but rather almost entirely towards a logical organization of content.

This investigation was initiated by the belief that the present process-oriented high school science courses placed demands on students that many are intellectually incapable of achieving. Empirical evidence cited in the review of related literature (chapter 2) and data collected from the sample used for this invesitgation (chapter 3) support this belief. Consequently, the general question with which this research began was: How do teachers cope with a situation wherein they are expected to teach concepts that require formal operations for meaningful understanding to students still in the concrete operational stage?

It seemed plausible that teacher-made test items would accurately reflect what transpired in the classroom.

If teachers taught requiring rote learning procedures and designed test items that could be answered without meaningful comprehension then concrete operational students could view memorization as their only method of achievement. While this might lead to high achievement as measured by teacher-made tests, valuable time and energy would be expended in memorization that otherwise could go toward development of formal operational ability.

Therefore, the overall direction of this research was to investigate the degree of memorization by concrete operational students in attempting to obtain credit for understanding formal concepts. Data for this study were gathered from grade 10 students at a large urban high school taking the Introductory Physical Science (IPS) course. IPS seemed appropriate since, as the following course description indicates, it was designed to prepare students for later courses in science.

Course Description: Introductory Physical Science (IPS)

In 1967 a student text and a teacher's guide written by the IPS Group of Educational Services Incorporated was published. (IPS Group, 1967) The following course description will refer to the above two publications as either; student text or teacher's guide.

Purpose

The authors state in the text that the purpose of IPS is to;

> give all students a beginning knowledge of physical science and to offer some insight into the means by which scientific knowledge is acquired. The course is designed to serve

> as a solid foundation both for those students taking later courses in physics, chemistry, and biology and for those taking no further natural science in high school. (IPS, 1967, P. v)

The implication of the last sentence in the preface is that the IPS course was designed for junior high school. The Manitoba Department of Education Curriculum Guide recommends that the course be used in granting a science 100 credit thus serving as a high school credit as well as a university entrance course. Otherwise the Department is in full agreement with the purpose as stated in the text (Manitoba Department of Education, 1968, p. 1).

Philosophy

The authors' philosophy is apparent in the significance placed on laboratory activity as stated in the Teacher's Guide (1967):

> Our knowledge of physical science is the result of years of experimentation. No student can experience all the discoveries that have been made, but whenever possible we should like him to learn physical science in the laboratory.
>
> In this course, the laboratory work is an integral part of the text. Some of the significant conclusions the student arrives at in the laboratory do not appear explicitly in the accompanying text. In other words, it is assumed in many cases that the student has found in the laboratory facts or laws on which following sections of the text are based. (1967, pp. 5-6)

It is clear that for teachers of IPS to implement the philosophy of the course a laboratory approach is essential. To deviate from this approach is clearly in conflict with the means of realizing the stated objective.

Rationale

The course was designed to meet the needs of those teachers involved in the process-oriented high school physics (PSSC) and chemistry (Chem Study) courses:

> The course had its genesis in the Physical Science Study Committee physics program. Reports from PSSC, CBA, and CHEM Study teachers over the past few years have clearly indicated that an understanding of the nature of experimental physical science and some of the basic scientific skills could and should be acquired by the students before they take these courses in the senior high school. (Student text, p. v)

Recommended Level for Comprehension

Obviously since the authors designed the course for junior high students one can only assume they do not envision a sophisticated level required for comprehension. In fact, in the preface of the student text they stated; "the course has enough flexibility built into it to serve a wide variety of students" (p. vi).

Summary

IPS is not a content-oriented course. In fact, the content is minimal and could be covered in a much shorter time period than one year. The reduction in content is due to the fact that the course is designed to develop science process skills. It is the intention of this study, however, to show that the concepts that the course expects students to master require a higher level of intellectual development than most of the students have achieved.

The organization of this thesis reflects the direction taken in attempting to understand reasons for the frustrations felt by many grade 10 students taking IPS. Obviously, it was believed that Piaget's theory of intellectual development provided possible solutions. However, hypotheses could not be formulated until an in-depth study of his theory was conducted. Thus the assumptions, definition of terms, rationale, and research hypotheses for this study are located after the ensuing discussion of Piaget's theory.

PIAGET'S THEORY

Introduction

Piaget's theory is concerned with the development of mental structures which must precede observable behavior. Piaget sees mental development as occurring by stages rather than by a process of accretion. It is the development of stages and how an individual progresses through them that have educational significance.

Structure of the Intellect

Piaget's theory posits four major stages of human intellectual development: sensorimotor stage, preoperational stage, concrete operational stage, and formal operational stage. Each stage is characterized by certain mental or cognitive structures. As development progresses earlier structures are incorporated into later more complex structures (Piaget, 1971b). It is this alteration and accumulation of mental structures that constitutes intellectual development. Whether or not an individual is aware of his mental structures is not important, rather, the educator by analyzing the child's behavior should be able to determine the presence of particular mental structures. The following illustrates how Piaget envisions a mental structure. A five-year-old child will likely have no difficulty in pointing out the longer of two sticks presented to him (stick A > stick B). Similarly he will correctly designate stick B as being longer than stick C (B > C). However, he will be unable to compare the lengths of stick A and C if he is not allowed to observe them next to each other. This same problem poses no difficulty to most eight-year-olds since they possess the mental structures to make the correct deduction that Stick A must be longer than stick C (Lawson and Renner, 1975).

The types of mental structures present determine at which level an individual is functioning intellectually. The association of structure, stages, and development can best be described in Piaget's own words:

> Thus stages are characterized by overall structures which become necessary but which are not so initially. Formal structures become necessary when the concrete structures are complete; concrete structures become necessary when the structures of identity, of functions, etc. are complete. But nothing is given in an a priori or innate fashion; nothing is preformed or predetermined in the activity of the baby. (Piaget, 1971b, p. 9)

The meanings Piaget assigns to words like necessary and complete are clearly represented by the following:

> As soon as a structure is sufficiently complete for closure to occur, in other words, once the internal compositions of the structures become interdependent and independent of external elements and are sufficiently numerous to allow for all types of arrangements, then the feelings of necessity manifests itself. I believe it is this feeling of necessity which constitutes evidence of the existence of the overall structures which characterize our stages. (Piaget, 1971b, p. 5)

Piaget proposes that an individual develops mental structures through a process of self-regulation. As the term implies, the establishment of these structures is dependent upon an active interaction between the individual and his environment. It is this component of Piaget's theory that is one of the most relevant to education.

Piaget rejects the notion that structures will develop from within at an appropriate stage of maturation. He also rejects the notion that environmental conditions can invoke structural development through mere exposure. Rather he envisions these structures as developing only if an individual actively internalizes the environmental situation and acts upon it with existing mental structures. If the mental structures are inadequate for the incoming stimuli disharmony results and more complex mental structures may develop. Piaget proposes that this increased complexity is only possible if the existing structures require slight modification to handle the new situation.

Thus, in order for educators to plan learning activities that develop the learner's intellect, the learner's present level of intellectual functioning must be assessed. This interpretation of the learning process is supported by Piaget:

> I find myself opposed to the view of knowledge as a copy, a passive copy, of reality. To my way of thinking, knowing an object does not mean copying it-it means acting upon it. (Piaget, 1970, p. 15)

In short, development is a dynamic, ongoing process with an active interaction between the learner and the environment.

Function of the Intellect

Intellectual functioning has two basic components, organization and adaptation. Organization refers to the stage of equilibrium between the individual and the environment. Consequently, an individual's organization invokes mental structures which in turn consist of schemes that are in harmony with the environment. According to Sullivan (1967), Piaget defines schemes as "essentially repeatable psychological units of intelligent action" (p. 3): schemes are what an individual has at his disposal when interacting with the environment. Baldwin (1967) maintains that a scheme is the element of a structure that changes due to an environmental encounter. Through such encounters, schemes are altered by becoming more general in application and more discriminatory in terms of the appropriate application. For example, a baby may use his grasping scheme for an increased variety of objects within his reach but will not mobilize it for objects beyond his reach.

To prevent terminology from becoming too burdensome, it is possible to consider schemes and mental structures as one. In other words, the existing behavior of an individual is due to the mental structures or schemes present at that time. Obviously, the state of organization must change for development to occur and it does so by the second element of intellectual function, adaptation through the process of equilibration.

If an individual is faced with a situation which he acts on internally, i.e., mentally, he is said to have assimilated the environmental situation. If his cognitive structure is such that no change is necessary Piaget considers that structure in its present state as being adapted; the individual's cognitive structure is in equilibrium with the environmental encounter. However, assimilation to existing structures may be incomplete. This may be considered as a stress on the state of equilibrium or as a challenge to the individual; for assimilation to be complete the mental structure must adjust to accommodate the new situation thus restoring equilibrium. This process, beginning with incomplete assimilation followed by accommodation enabling the mental structures to complete assimilation, is referred to as equilibration. Those schemes which adjust resulting in the new structure are those which are activated by the encounter. Clearly, the purpose of educators is to provide experiences that invoke this equilibration process. Experiences that are completely assimilated do not invoke any growth and those that cannot be even partially assimilated are equally useless.

The sequence of disequilibration--equilibration states brought about through assimilation and accommodation is the method by which the intellect moves through one stage and on to the next. It is evident that Piaget's model involves a heirarchical organization of preceding and successive stages; the lower stage is co-ordinated and integrated into the next higher stage. The cognitive structure of any stage differs qualitatively from that of another. The sequence through which the intellect develops is invariant but the ages at which an individual moves from one stage to another varies.

The following paragraphs will briefly discuss the structures characteristic of Piaget's first two stages, sensorimotor, and preoperational. However, major emphasis will be placed on the structures of concrete and formal operations since the transition between them frequently occurs in the adolescent.

Stages of Intellectual Development

Stage I: Sensorimotor. Piaget (1962) has described sensorimotor intelligence as functioning "like a slow motion film, representing one static image after another instead of achieving a fusion of the images" (p. 238). Thus, there is no understanding of the system as a whole since the only relationship is between successive movements. Because of this Piaget (1962) maintains:

> Sensorimotor intelligence aims at success and not at truth; it finds its satisfaction in the practical aim pursued and not in recognition (classification and seriation) or explanation. It is intelligence that is only "lived"--and not thought. (p. 238)

He considers sensorimotor intelligence as only acting upon real objects since the subject cannot relate to objects through signs or symbols. Consequently it is an active intelligence always with short distances between subject and object.

Piaget (1970) clearly demonstrates how sensorimotor intelligence is preparatory for higher levels of thinking. For example, it is in the sensorimotor period that two essential components of operational thinking, conservation and reversibility, have their roots. It is Piaget's belief that the notion of the permanence of an object is the sensorimotor equivalent of conservation. Similarly, the beginnings of reversibility are evident in that the child recognizes toward the end of the sensorimotor stage his position in space; he recognizes that a movement in one direction can be cancelled by a movement in another and that a single point in space can be reached by one of several different routes.

Sensorimotor intelligence can be summarized as one that is guided by immediate goals. The child's adaptation processes are strictly behavioral, hence, the intellectual processes are limited to physical manipulations and not mental. Finally, the ability to plan ahead is severely limited.

Stage II: Preoperational. The preoperational stage is entered when sensorimotor intelligence begins to be internalized. This internalization means that intelligence can be represented by thought rather than by an actual carrying out of actions. This representation can be in the form of language, gestures, drawing, painting or modeling (Piaget, 1970). Deferred imitation (ability to imitate behavior of absent persons or of objects the child is reminded of) and memory have their beginnings. Thus, the child is no longer tied to what is physically present and can represent internally objects that are absent.

The child is operating with structures that are not reversible but that work in one direction only. Although children lack reversibility they do discover relationships and that variations in one object are correlated with variations in another (Piaget, 1970, 1971). Consider the following:

> We have a piece of string attached to a small spring. It extends out horizontally, goes around a pivot, and hangs down vertically. Now when we put a weight on the end of the string, or increase a weight already there, the string is pulled so that the part that is hanging down vertically is lengthened with respect to that part that is horizontal. Five-year-olds are perfectly able to grasp the relationship that with the greater weight the vertical part is longer and the horizontal part is shorter; and that when the vertical part becomes shorter the horizontal part becomes longer. But this does not lead to conservation. The sum of the vertical part and the horizontal part does not stay the same for these children. (Piaget, 1970, p. 51)

This is clearly an example of a function, meaning that thinking is directed in one direction only. For conservation, there must be reversibility, so that the child can recognize that the sum of the vertical and horizontal parts stays the same. Finally, reversibility is lacking because the child focuses on a particular aspect of the problem and doesn't relate the horizontal and vertical lengths to the whole or entire length of string.

Perhaps it is best to think of the preoperational stage as one of transition. The sensorimotor period is culminated with the child in equilibrium with his environment on the behavioral level. With the development of language and other symbols, in the preoperational stage, the child can function on materials not physically present. However, his reasoning is transductive (inference from the particular to the particular) as opposed to adult thinking which is inductive or deductive. His thought processes are centered on one aspect of a situation and are incapable of simultaneously considering two or more aspects of a situation. Reversibility is lacking in his judgements. Inhelder and Piaget (1958) attribute the following beliefs to the preoperational child as an indicator of the egocentric and global nature of preoperational thought; "he believes that the sun moves because 'God pushes it' and the stars, like himself, have to go to bed" (p. xii). When the child is capable of freeing his logic from his own viewpoint he is nearing the end of the preoperational stage and entering the concrete operational stage. Usually the child is six or seven years of age at this point.

Stage III: Concrete Operational. Reversibility of thought has its beginnings in this stage. A classical test to determine whether a child is capable of reversibility is to present him with a ball of plasticine. If, upon flattening the ball into a rod-like shape, the child reasons that there is the same quantity of plasticine regardless of shape, he is capable of reversibility. In his mind the child can reverse the flattening out process and return the plasticine to the spherical shape. The preoperational child is not capable of reversibility and would suggest that the quantity of plasticine changed because the shape changed.

The rigidity of thinking processes characterizing the preoperational child is lessened with the onset of reversibility. This "thawing out" of thought processes results from the type of thought characterizing concrete operations.

By concrete operations Piaget means ;

> actions which are not only internalized but also integrated with other actions to form more general reversible systems. Secondly, as a result of their internalized and integrated nature, concrete operations are actions accompanied by an awareness on the part of the subject of the techniques and coordinations of his own behavior. (Inhelder and Piaget, 1958, p. 6)

Consequently, the concrete operational child is not only concerned with achieving his goal but just as concerned with why he was successful.

Piaget (1971a) clearly demonstrates the new capabilities concrete operational thought provide over preoperational thought:

> Thought is no longer tied to particular states of the object, but is obliged to follow successive changes with all their possible detours and reversals; and it no longer issues from a particular viewpoint of the subject, but coordinates all the different viewpoints in a system of objective reciprocities. (p. 142)

In other words, actions based on concrete operations are different from the actions of the preoperational child in that they are coordinated with all other elements of cognitive structure. Recalling the ball of plasticine, the preoperational child centers his attention on shape whereas the concrete operational child can simultaneously consider change of shape with the fact plasticine was neither added or removed in the transformation. Piaget's reasons for using the term concrete is evident by the restriction he places on the operations in this stage. He states, "concrete operations are bound up with objects to which they apply, or operations in which form is inseparably bound up with content" (Inhelder and Piaget, 1964a, p. 149).

Raven and Guerin's (1975) work in testing the sequence of development of certain schemes as predicted by Piaget's model provide a suitable framework to examine operations of the concrete stage. These operations are classification via class inclusion, seriation, logical multiplication, and compensation. Classification and seriation appear early. Classification is an operational system involving the inclusion of groups under each other. Seriation involves the linking of asymmetrical transitive relations into a system. With development through the concrete state logical multiplication and compensation operations appear. Logical multiplication is an operation involving the construction of correspondence between at least two sets of variables. Compensation operations involve the balancing of two or more changeable variables. Examples of the above operations are in order.

Part of Piaget and Inhelder's (1958) experiment entitled "The Law of Floating Bodies and Elimination of Contradictions" will serve as an example of classification. In this experiment a subject is given a variety of objects and is asked to classify them according to whether or not they will float in water. He is then asked to explain his classification system. Next, he performs a series of experiments whereby he tests his system. Explanations are invoked for each observation in this series. The interviewer carefully analyses the responses to determine the kinds of operations at the disposal of the subject.

Preoperational children run into a series of contradictions because their classification system involves placing small objects as "floaters" since they are thought to be light and large objects as "sinkers" since they are thought to be heavy. However, upon entering the concrete stage their classification system can distinguish between all and some and thus can include the part in the whole. They realize that small objects are not always light but rather some are heavy. Similarly, some large objects are light, not all are heavy. Thus, the child realizes that by removing all the small light objects he does not remove all the small objects.

The following experiment, in attempting to establish the concept of the equality of two angles, is an example of seriation.

The experimental apparatus consists of a kind of billiard game. Balls are launched with a tubular spring device that can be pivoted and aimed in various directions around a fixed point. The ball is shot against a projection wall and rebounds to the interior of the apparatus. A target is placed successively at different points, and subjects are simply asked to aim at it. Afterwards, they report what they have observed (Inhelder and Piaget, 1958). The preoperational child is mainly concerned with either hitting or missing the target. Because of this goal directed behavior he does not look for reasons for success or failure and is therefore not cognizant of the angles at the rebound point. With the advent of concrete operations, and consequently an awareness on the subject's part in terms of his own behavior, the subject begins to formulate relations between the inclination of the plunger and the line of reflection. In fact, the concrete operation, seriation, becomes obvious when the subject realizes that increasing inclinations of the plunger cause an increase in the angle of reflection. In addition to this serial ordering, they are also capable of correspondence operations. He is aware that the angle at which he holds the plunger will correspond to the angle of reflection.

Consider the following experiment as an example of the operation, logical multiplication. The experiment involves rod flexibility and the subject is asked to identify the factors that permit a rod to bend. In fact, the flexibility of a rod depends on the material it is made of, its length, its thickness, and the form of its cross section. These four factors being equal, the degree to which it bends varies as a function of the weight that is placed at its tip.

With the preoperational child lacking classification and serial ordering operations he is once again restricted to precausal explanations--the rod bends because "it has to". With the onset of concrete operations the subject is capable of studying each variable independently. However, to work with more than one variable he must progress beyond a one-to-one correspondence. With the application of logical multiplication the subject can consider the effect of material, of thickness, and of length:

(A same metal as B) x (thicker) x (longer) = same inclination (Inhelder and Piaget, 1958).

Or, the subject realizes that thickness can be overcome by an increased length providing he is working with a rod of the same material. Clearly, the subject is now establishing correspondences with at least two variables.

Finally, the same experiment provides an example of a compensation operation:

(less thin) x (longer) = (thinner) x (shorter)

The subject realizes a balance can be maintained by working with two variables simultaneously.

The following statement should explain why Piaget considers the above subjects as concrete thinkers.

> In fact, the same children as reach the operations just described are usually incapable of them when they cease to manipulate objects and are invited to reason with simple verbal propositions. The operations that are involved here, then, are "concrete operations" and not yet formal ones; being constantly tied to action, they give it a logical structure, embracing also the speech accompanying it, but they by no means imply the possibility of constructing a logical discourse independently of action. (Piaget, 1971a, p. 146)

Thus, to deny a child in the concrete stage of development the opportunity to work with concrete materials would be to hinder his progress through this stage which is essential to attaining the operations characteristic of the upcoming formal stage.

Stage IV: Formal Operations. Formal operations represent the highest level in the development of mental structures. The beginnings of formal thought can be expected between 11 and 15 years but can be delayed considerably as the review of the literature will indicate. This delay will be investigated but at this point it is essential that the types of thought characterizing formal operations be outlined. Hypothetico-deductive reasoning is the most commonly encountered term describing this final stage.

> The adolescent, unlike the child is an individual who thinks beyond the present and forms theories about everything, delighting especially in considerations of that which is not. This reflective thought, which is characteristic of the adolescent, exists from the age of 11-12 years, from the time, that is, when the subject becomes capable of reasoning in a hypothetico-deductive manner, i.e., on the basis of simple assumptions which have no necessary relation to reality or the subject's beliefs, and from the time he relies on the necessary validity of an inference (via formae), as opposed to agreement of the conclusions with experience. (Piaget, 1971a, p. 148)

Clearly, a formal operational thinker can reason symbolically unlike concrete operational thinkers who require objects present. However, to formulate and test hypotheses, requires the identification of all relevant variables. Also, these variables must be controlled such that in an experiment only one is varied. Recall that in the rod flexibility experiments the concrete operational thinker identified the variables but was not capable of controlling them to test the effect of a single factor. On the other hand, the formal thinker spontaneously conducts a controlled experiment. To further establish the difference between concrete and formal thinkers consider the following:

> Although concrete operations consist of organized systems (classifications, serial ordering, correspondence, etc.) they proceed from one partial link to the next in a step-by-step fashion, without relating each partial link to all others. Formal operations differ in that all of the possible combinations are considered in each case. Consequently, each partial link is grouped in relation to the whole; in other words, reasoning moves as a function of a "structured whole". (Inhelder & Piaget, 1958, p. 16)

Hence, the formal thinker is capable of considering all of the possibilities of a situation, thus providing the ability to formulate hypotheses.

Piaget has adapted the symbolic system of formal logic to a model representing the cognitive process. In this system statements are in such a form that they can be asserted or denied, and are called propositions. They are indicated symbolically by small letters (e.g., p,q). Relationships between propositions are via logical operators. The operators most frequently encountered are:

$-$	not (Negation)	$\bar{p}$	not p
$\vee$	or (Disjunction)	$p \vee q$	p or q or p and q
$\cdot$	and (Conjunction)	$p \cdot q$	p and q
$\supset$	if--then (Implication)	$p \supset q$	if p then q

For example, let p be the statement that a force is operating and q be the statement that a stationary object starts to move. The following three cases may then be observed:

(1) $(p \cdot q)$ a force is present and the object starts to move,

(2) $(\bar{p} \cdot \bar{q})$ a force is not present and there is no movement,

(3) $(p \cdot \bar{q})$ a force is present but there is no movement,

from these the implication $(q \supset p)$--if there is movement then a force is present--is formulated. If the fourth case $(\bar{p} \cdot q)$, where there is motion but no force, is observed no implication exists. Thus such a combinatorial system provides a means of testing the implication.

The ability to consider all possible combinations enables the formal thinker to reason verbally from the hypothetical to reality. Formal operations confer the ability to plan and conduct controlled experiments testing hypotheses. A more specific look at the operations characterizing formal thought can be obtained from work done by Raven and Guerin (1975) in interpreting Piaget.

Proportional thinking involves the construction of ratios such that if a change occurs in one of two factors the resulting effect on the other factor can be predicted. For example, the pressure of a gas increases in linear proportion to a decrease in volume all other factors being held constant. A reduction to one-half the original volume will result in double the original pressure.

Probability thinking is a result of the combinatorial system characterizing formal thought. Once again ratios must be constructed, but in this case, the ratio reflects the frequency of the occurrence of events. For example, The probability of the occurrence of a particular event is given as:

$$\text{Pr (event)} = \frac{\text{No. of favorable combinations}}{\text{All possible combinations}}$$

With this ability to isolate relevant factors out of all those possible the formal thinker can minimize the amount of trial and error used in problem solving.

Finally, correlative thinking involves the construction of a rule describing the relationship between two sets of events that have a probability attached to their occurrence.

A more detailed look at Piaget's logic system is required if a clear understanding of terms like "structured whole" and "hypothetico-deductive reasoning" characteristic of formal thought is to be obtained. His system of logic is built upon two logical models, the 16 binary operations and the INRC group.

The 16 Binary Operations. Figure 1 constructed by Harris (1973), describes the 16 binary operations.

Name of Operation	Four Possible Outcomes	Relationships Empirically Observed	INRC Group		
	$p\ p\ \bar{p}\ \bar{p}$				
	$q\ \bar{q}\ q\ \bar{q}$		N	R	C
1. Negation	F F F F	0	16	16	16
2. Conjunction	T F F F	$p \cdot q$	15	5	12
3. Inverse of implication	F T F F	$p \cdot \bar{q}$	14	4	13
4. Inverse of converse implication	F F T F	$\bar{p} \cdot q$	13	3	14
5. Conjunctive negation	F F F T	$\bar{p} \cdot \bar{q}$	12	2	15
6. Independence of p to q	T T F F	$p \cdot (q \vee \bar{q})$	11	11	6
7. Independence of q to p	T F T F	$(p.q) \vee (\bar{p}.q)$	10	10	7
8. Reciprocal implication	T F F T	$(p.q) \vee (\bar{p}.\bar{q})$	9	8	9
9. Reciprocal exclusion	F T T F	$(p.\bar{q}) \vee (\bar{p}.q)$	8	9	8
10. Inverse of independence of q to p	F T F T	$(p.\bar{q}) \vee (\bar{p}.\bar{q})$	7	7	10
11. Inverse of independence of p to q	F F T T	$\bar{p}. (q \vee \bar{q})$	6	6	11
12. Disjunction	T T T F	$(p \vee q)$	5	15	2
13. Converse implication	T T F T	$q \subset p$	4	14	3
14. Implication	T F T T	$p \supset q$	3	13	4
15. Incompatibility	F T T T	p/q	2	12	5
16. Tautology	T T T T	$(p.q) \vee (p.\bar{q}) \vee (\bar{p}.q) \vee (\bar{p}.\bar{q})$	1	1	1

Figure 1. Sixteen Binary Operations. (Harris, 1973)

The truth or falsity of the relationship between propositions is established through observations. The reason for 16 Binary Observations is that each pair of propositions can give rise to four possibilities. For example,

p= the rod is long (T or F)

q= the rod bends (T or F)

Four possibilities: pq, $p\bar{q}$, $\bar{p}q$, $\bar{p}\bar{q}$

Since each of the above pairs can be either true or false there are 16 different arrangements of true and false as indicated by the table.

Due to the above operations the adolescent's decision depends upon what he observed and what he did not observe. For example, a conclusion that long rods and bending go together, i.e., conjunction, can only be verified by the hypothetical re-results shown in row 2, of table one. In other words, to establish conjunction he must experimentally exclude the other three possible associations.

The INRC Group. This second component of formal thought can be introduced by the following quotation from Piaget (1971a).

> Now, reasoning formally and with mere propositions involves different operations from reasoning about action or reality. Reasoning that concerns reality consists of a first-degree grouping of operations, so to speak, i.e. internalized actions that have become capable of combination and reversal. Formal thought on the other hand, consists in reflecting (in the true sense of the word) on these operations and therefore operating on operations or on their results and consequently effecting a second-degree grouping of operations. (p. 148)

The INRC group represents the second order operations. Each letter refers to a particular operation, i.e., identity (I), negation (N), reciprocity (R), correlativity (C). It is also the framework in which the binary operations are formed and interrelated.

The identity operator (I) leaves the result unchanged. Negation (N) and reciprocity (R) are both forms of reversing operators. The correlate operator changes conjunction (.) to disjunction (v) and vice versa.

Consider the following example, taken from Ginsburg and Opper (1969), of a formal thinker discovering inertia with the application of the second order operation, negation (N). Essentially the principle of inertia states that if no factors impede the motion of an object it will keep going at the same speed. Experimentally, students discover many factors that do in fact impede motion and hence slow the object down.

Symbolically:

p = the object's stopping	s = factor 3
q = the presence of friction	t = factor 4
r = the presence of air resistance	etc.

The binary operations, $p \supset q$, $p \supset r$, $p \supset s$, and $p \supset t$,...,show that the student has successfully identified the factors that slow the object down. For example, $p \supset q$, indicates that if the object stops then friction is present. By combining the above, $p \supset (q v r v s v t.....)$, the student exhibits his understanding that any or all of a number of factors can impede motion.

However, to discover inertia we must carry out the second order operation of negation (N). The result, $(\bar{q}.\bar{r}.\bar{s}.\bar{t}---)\supset\bar{p}$, implies that in the absence of the impeding factors motion will not slow down. To arrive at this conclusion thought was based on reasoning rather than on reality. More important, without the ability to isolate the factors involved and then transform them through negation (operating on operations) the inertia principle would never have been discovered. Or, since the subject's cognitive systems are synthesized into a structured whole, he is able to reason by hypothesis through application of second order operations. Following hypothesis formation, he then conducts an experiment based on deductions from the hypothesis (hypothetico-deductive reasoning).

Summary of Concrete & Formal Stages

To summarize the basic differences and characteristics of concrete and formal stages consider once again the floating object experiments. The concrete thinker is capable of reversibility both through negation and reciprocity but that these operations are not part of a structured whole. Consequently, he can classify through manipulation of reality and conclude that some large objects float and some small objects sink. However, his failure to depart from reality and carry out second order operations results in his inability to coordinate the weight-volume relationship with water displacement. The concrete thinker may refer to the amount of water in the container rather than the abstract concept of the volume of water displaced.

With formal thinking and coordination of operations via second order operations the ability to hypothesize about water displacement is possible. Consequently, the individual can conduct experiments based upon a hypothesis which is envisioned as possible and not upon direct observation. The weight of the object is then related to the weight of an equal volume of water and the non-contradictory law, that objects float if their density is less than water, can be discovered.

In conclusion, formal thought with its accompanying characteristics is essential if the concepts of science, which are frequently abstract, e.g. atomic theory, are to be understood. According to Piaget's model individuals do not develop formal operations through maturation only. Rather, maturation in association with experience and social interaction control development. Finally, as the review of literature will indicate, individuals who may be physiologically prepared for formal thought may not reach it for many years. The obvious implication is that limitations with respect to the other two factors, experience and social transmission, have not properly prepared the individual for formal thought. Perhaps, the educational environment could do more in maximizing cognitive growth. It is this possibility that has fostered this research project.

Application of Piaget's Theory to IPS

A look at the IPS course in light of Piaget's theory reveals that little concern was given to the student's ability to handle content and a particular teaching style. For example it is the authors' apparent assumption that through development of certain skills in the laboratory the IPS course will be understood by all who take part.

> Your students will ask for answers, and will continue to ask for them if you give them. If you let your students find their own answers, they will not only learn more but gain confidence in their ability to make useful decisions. At first you may find this difficult, but after hearing from you a few answers like, "How can you find out?" "Try it," "Look it up," "You have to decide," and "Are you satisfied with the data?" your students will become more resourceful. (Teacher's Guide, p. vi)

It is quite possible that the above technique could frustrate a confused student if the questions the teacher poses are too far beyond his level of cognitive development. If students are not capable of answering the above kinds of questions the teacher is forced into the position where he must ask more direct questions which may fail to lead the student to the required generalization from the lab. Then the teacher is forced to provide the generalization and this is in direct conflict with the philosophy of the course.

Another example of the tendency of the authors to be unrealistic in terms of student progress is the following:

> As they progress in the course, they learn to enjoy doing experiments whose results they do not know in advance, even though they realize that someone has faced and answered the same problem before. (Teacher's Guide, p. vi)

If experiments repeatedly challenge students for generalizations they are not capable of formulating, it is doubtful that they will look forward to further experimentation. From analysis of the course in terms of Piaget's theory it is apparent that many of the concepts require formal operational ability; e.g., laws of constant and multiple proportions. If a teacher could assume the majority of students involved were formal operational then the IPS course would be suitable. However, as the review of literature will indicate this is not a valid assumption at the grade 10 level.

Design of the Study

Rationale

Teachers faced with IPS curriculum content and learning objectives requiring the use of logical operations beyond the level of cognitive development of the learner may be forced to accept student achievement at a level inconsistent with the objectives of the curriculum. This study will attempt to show that the disparity between the learner and the content of the curriculum is reflected in teacher-made tests. Possibly these tests will require logical operations only at the concrete level in spite of the fact that many concepts in IPS require logical operations at the formal level. This mismatch could lead to the following:

1. Concrete operational students may view memorization as their only method of achievement and expend valuable time and energy in memorization that might

otherwise go toward development of formal operational capability.

2. Formal operational students may not be challenged in ways that will assist them in achieving their full potential.

On the other hand, if school experiences were appropriately matched with the cognitive level of the student, development of logical structures of formal operations might be facilitated.

Problem Statement

The purpose of this study will be to answer the following questions:

1. What level of cognitive operations is required for high achievement on teacher-made tests?
2. Will both formal and concrete operational high achievers maintain this level of achievement on experimental test items requiring formal operational ability?

Definition of Terms

Concrete operational students:	Students whose responses on Rods are scored such that they are categorized concrete following Harris's (1973) outline for identification of response patterns.
Formal operational students:	Students whose responses on Rods are scored such that they are categorized as formal.

High achievers:	Students who average a B grade or higher on teacher-made tests.
Hypothetico-deductive reasoning:	Reasoning occurring within a combinational system, as defined by Piaget, making it possible to generate hypotheses based on all possible combinations.
Formal concept:	A concept which logical analysis, in terms of Piaget's model, is demonstrated to require hypothetico-deductive reasoning for meaningful comprehension.
Experimental test items:	Items designed to determine whether a student is capable of applying hypothetico-deductive reasoning to questions of concepts requiring formal operations.

Hypotheses

Two hypotheses flow from the rationale and purpose of this study.

I. High achievement on teacher-made IPS tests that are intended to test understanding of concepts requiring formal operations does not require formal operational ability on the part of the learner.

II. On the experimental test items only students who have achieved the sub-stages of formal operations will be high achievers.

Evidence Required for Support of These Hypotheses

I. It will be possible for concrete operational students to score above the median of formal operational students on teacher-made IPS tests.

II. The formal operational high achievers will score higher than the concrete operational high achievers on the experimental test items.

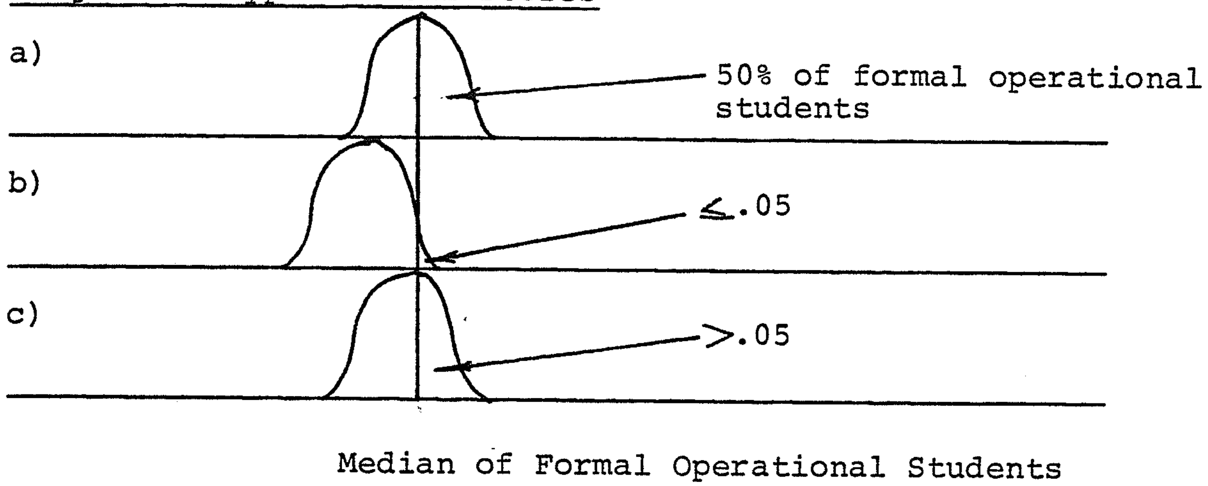
The evidence for the second hypothesis can be provided by a test of independence, however, the first hypothesis requires some discussion.

If it were possible for significant numbers of concrete operational students to score above the median of formal operational students on teacher-made tests, the tests are failing to discriminate between concrete and formal operational students. The logic behind this approach is as follows:

1. The median is the score most representative of achievement by formal operational students on teacher-made test items.
2. It seemed reasonable that if a higher proportion of concrete operational students could exceed this point than predicted by chance the tests were not requiring formal operational ability.
3. Formal operational students may tend to be superior in other factors which contribute to achievement on teacher-made tests (e.g., motivation, intelligence, attendance ....).

Therefore, merely testing for differences between scores of formal and concrete operational students would not be appropriate.

<u>Diagram of Hypothetical Scores</u>



Where:

a) the hypothetical distribution of scores of formal operational students on teacher-made test items.

b) hypothetical distribution of scores of concrete operational students on teacher-made test items that discriminate between concrete and formal operations.

c) hypothetical distribution of scores of concrete operational students on teacher-made test items that do not discriminate between concrete and formal operations.

Figure 2. Diagramatic representation of achievement on teacher-made tests that do discriminate (b) and those that do not discriminate (c) between concrete and formal operations.

CHAPTER II

Review of the Related Literature

Introduction

This study was undertaken to discover reasons why there was poor understanding and retention by pupils of certain science concepts included in the IPS course. Piaget's theory of cognitive development suggests possible reasons for and offers some solutions to the problem. Following is a review of those studies which have given direction to this research.

Harris (1973), in reviewing the works of Elkind (1961), Lovell and Shields (1968), Field and Cropley (1968), and Lovell (1971) has proposed the following:

1. It is not evident that individuals from adolescence upwards can apply hypothetico-deductive reasoning to every task requiring it.
2. Prediction of scholastic achievement for indivuals and groups is far from dependable if based on assumed norms for adolescence.
3. Chronological age is not necessarily an index of developmental level.

Although in Piaget's studies formal operations were demonstrated in early adolescence studies to be cited later reveal that this is not universal. A serious conflict arises if the level of intellectual development of the students taking IPS is below that which is required for understanding of the concepts it presents.

The teacher has the choice of lowering his expectations by teaching formal concepts as though they were concrete thereby requiring pupils to memorize verbal statements of the concepts for the solution of specific kinds of problems. On the other hand, the teacher could ignore the intellectual level of his students and teach for formal mastery, failing large numbers of students who can reason only at the concrete level. Either approach leads to a poor understanding of the concepts by students and a sense of frustration on the part of the teachers and pupils alike. Piaget refers to learning by memorization of facts without linking them together for an understanding of the concept as figurative thinking. Kaufman and Konecek (1972) quote Piaget as stating that figurative thinking is "an imitation of stages taken as momentary and static" as opposed to operative thought which "deals not with states but with transformations from one state to another" (p. 5).

Tomlinson-Keasey (1972), in discussing the work of Elkind (1970), states that most subjects of normal intelligence reach the level of concrete operations. However, referring to work by Lovell (1961, 1968) and Jackson (1965), she suggests that formal operations represent "a potential to be reached rather than an assured stage of development" (p. 2).

Studies Dealing with Age of Acquisition of Formal Operations

As part of a study conducted by Tomlinson-Keasey (1972), three groups of females with mean ages of 11.9 years, 19.7 years and 54 years were tested on three tasks, the pendulum, the balance, and rod flexibility. A description of each of these tasks is in Inhelder's and Piaget's (1958) work on logical processes from childhood to adolescence. The percentages of each group operating formally were 32% of the girls, 67% of the college-aged girls and 54% of the women. The advance in cognitive level from the sixth grade to college is in agreement with Piaget's developmental sequence but it also indicates that 33% of the college students are not operating formally. Combining this with information about the proportion of women operating formally supports the hypothesis that formal thought may not necessarily be achieved by the average person.

It is the contention of Renner and Lawson (1973a, b) that science teaching should promote formal thought. They believe that it is only when students have achieved the ability to think formally that a teacher should deal with the abstractions of science. They further state that propositional logic characteristic of formal thought is essential if the hypothetico-deductive process of, "if--then--therefore", can be correctly applied. Accordingly, Lawson and Renner (1974) conducted a quantitative study of three groups to see what proportion of each group was operating formally.

The first group consisted of 588 students representing a cross-section of grades 7-12 in Oklahoma. Percentages of concrete thinkers by each grade were found to be: Grade 7 - 85%, 8 - 77%, 9 - 82%, 10 - 73%, 11 - 71%, and 12 - 66%.

Of the second group consisting of 143 college freshmen with a mean age of 18.6 years 22% were operating formally.

The third group consisted of 51 biology students (mean age 16.4 years), 50 chemistry students (mean age 17.3 years), and 33 physics students (mean age 17.9 years). Results indicated that 35.2% of the biology students, 28% of the chemistry students, and 63.3% of the physics students were formal thinkers.

From their results it is evident that a high proportion of high school students are not formal operational; indeed, over one-half the grade 10 students are not formal operational.

Karplus and Karplus (1970) also conducted a study of intellectual development beyond elementary school. It involved a puzzle which they constructed to measure abstract reasoning ability. Some 449 subjects from 5th graders to college physics teachers were tested. Results indicated that abstract reasoning reached a plateau in high school and did not progress much further beyond. Also, the plateau was at a "disappointingly low level" (p. 403). In a followup study by Karplus and Peterson (1970) a test to measure a student's ability to apply the concept of ratio (or proportion) was administered. The subjects ranged from grades 4 to 12 and ages 9 to 18 years. As expected, successful proportional reasoning was not evident until the last years of high school. Considering that problems involving formal operations like working with ratio and proportions are common in junior and early high school there is a serious gap between curriculum and students' reasoning ability.

A study by Ball and Sayre (1973) involving 419 students in grade 7 through 12 provides evidence that non-formal thinkers do not do as well scholastically as formal thinkers. It indicates that there is a relationship between scholastic success of eighth, ninth, tenth (biology) and eleventh grade (chemistry) students and their developmental levels. Relationships for seventh and twelfth grades were not evident according to the authors due to the low proportion of formal thinkers in the seventh and the high proportion in the twelfth.

Apparently some adolescents simply do not acquire formal operations. Also concepts in science frequently require formal thought. These two statements imply that science teachers should aid students across the transition from concrete to formal thought or adjust the curriculum by lowering it to the cognitive level of the students, i.e. predominantly concrete. As the following studies will indicate, there has been little success in assisting students in achievement of the transition. Thus it would appear that curriculum at the high school level must be more carefully planned so that it parallels the intellectual level of the students.

Studies Designed to Facilitate Formal Operations

Tomlinson-Keasey (1972) attempted to facilitate the acquisition of formal operations through a short-term training procedure. The technique was used on three groups of females with mean ages of 11.9, 19.7 and 54 years. They were given a pretest, training experience, and an immediate posttest on the same three tasks (pendulum, balance, and rod flexibility). To test for transfer a delayed posttest consisting of a more complex flexibility task, chemical combinations, and an inclined plane was used. The control group consisting of six girls from each of the younger groups and five from the older was given the pretest and delayed posttest. Results indicated that the training procedure was effective in raising scores on the immediate posttest but any gains due to training were not generalized to the different tasks on the delayed posttest. A factorial analysis indicated that the experimental and control groups did not differ on either the pretest or delayed posttest.

Perhaps the generalization tasks were not similar enough to allow subjects to apply newly acquired operations. This is possible if formal thinking involves operations which can be applied to some tasks and not others (horizontal decalage) but is not if formal thinking involves the same basic operations for all tasks.

She assumes that the operations acquired via the training procedure were present but not applied to the delayed posttest. A delayed posttest involving the pretest and training tasks would have indicated if such an assumption was valid.

A study conducted by Bass and Montague (1972) attempted to incorporate Piaget's developmental sequence into instructional objectives and instructional sequences. Their instructional objectives were arranged in an hierarchy based on Piaget's (1958) analysis of the balance and inclined plane problems. Their experimental group consisted of one hundred and thirty-three grade nine physical science students. The students were pretested to determine their intellectual level followed by a self-instructional sequence based on the tasks and a posttest. The results are contradictory as to the hierarchical nature of objectives and the effectiveness of an instructional sequence. The objectives for the balance task were arranged in a hierarchy and the instructional sequence was effective in leading students up the hierarchy. However, for the inclined plane the objectives were not so arranged and no evidence existed to support the effectiveness of the instructional sequence.

The study is subject to criticism because the authors do not provide any information on their methods of pre and posttesting. Therefore, it cannot be replicated. It is imperative that the method of testing be reported. No other studies were found which suggested that an instructional sequence can aid development through intellectual levels.

Jones (1972) found that boys who were deficient in verbal ability and who used few hypothetico-deductive statements in speech showed no less ability to think in hypothetico terms than did those who were not deficient in verbal ability. This finding is in agreement with Piaget's contention that the level of cognitive development attained is not dependent on a concurrent language development (Inhelder and Piaget in Jones, 1972).

Harris (1973) designed a test to identify students who were in the transition between concrete and formal operations. She also developed a treatment method to facilitate formal operational thought involving the application of a consistent procedure to solving problems. Her experimental and control groups each consisted of thirty-three students in grade eight or nine. Results indicated that the treatment was effective for girls but not for boys. She attributed this result to lack of motivation on the part of boys and on the inappropriateness of the method for the boys. Her results do show it is possible to facilitate transfer to formal thought but this study is not conclusive due to the significant sex-treatment interaction.

Brainerd and Allen (1971) tried to determine if the concept of density conservation could be taught to subjects who were non-conservers of solid and liquid volume. To conserve density a subject must realize that an object will float or sink depending on the material and not on its size or shape. A feedback training procedure proved effective in inducing density conservation to non-conservers. This technique enabled a subject to test whether his prediction that an object would float or sink was correct. To test for transfer posttests were designed for solid and liquid conservation. Results indicated there was transfer to solid conservation but not liquid conservation. Similarity of materials (clay) used in the training procedure and solid conservation was provided as an explanation for the transfer. Due to the lack of transfer to liquid volume conservation there was limited inter-concept generality.

The authors follow their results with a theoretical argument suggesting that a formal operation is more readily induced since it requires only a coordination of operations acquired during the concrete stage. This is opposed to the difficulty of inducing a mental operation in the concrete phase. They suggest that through training of formal conservation (e.g. density) a transfer of training to dissimilar and untrained formal conservations (volume) is predictable. Unfortunately, the argument is theoretically sound but lacks support from their data.

Of the above four studies the studies of Tomlinson-Keasey and Harris were less conclusive as to the benefits of training than were the other two. However, the study by Bass and Montague was poorly reported and Brainerd and Allen over-generalized their findings.

In addition to the experimental approach several papers proposed methods based on theory to promote formal thought. Ball and Sayre (1974) address themselves to the idea of readiness. They suggest that many of the tasks students fail are those which require a mental maturity above their present level; students may not be capable of learning what is being taught. It is these authors' contention that teachers should diagnose the mental capacities of students and then prescribe proper learning sequences for mental development.

A study by Kolodiy (1974) has serious implications for science teachers. Part of his study involved freshmen college students. Of twenty-five students, the seven who dropped out of the study, were all earlier designated as non-formal thinkers. He believes that unless non-formal thinkers resort to memory they cannot assimilate the concepts which are frequently taught via the lecture method. Also, in agreement with Ball and Sayre, he believes that science has meaning only if there is an interaction between subject matter and the student's mind.

Lawson and Renner (1974, 1975) address themselves to the problem of failure by many adolescents to achieve formal operations. They contend that if teachers would confront concrete thinkers with concrete problems and conduct meaningful inquiries a higher incidence of formal operational students would ensue. Their design for inquiry sessions is essentially that of the Science Curriculum Improvement Study at the University of California at Berkley. It involves three phases: 1) exploration, 2) invention, and 3) discovery.

The exploration phase is designed to promote disequilibration through the students' experiences with concrete materials. This phase may be highly structured or relatively unguided. The invention phase is marked by the introduction of a structure to accommodate the above experiences. This phase is designed to promote equilibration. The third phase, discovery, is designed to reinforce and enlarge the content of invention through repeated application to different situations.

They operationalize the design with concepts from high school physics and biology courses.

The purpose of citing these articles despite their lack of quantitative data is that they offer an alternative which at least has a theoretical basis. Compare their method to what in Herron's (1975) opinion, is presently occurring in most high school science programs.

> We present the material at an abstract level with few concrete props for even the better students to grasp; because the students are intellectually unable to understand the ideas, they memorize; we give a test from which we discover that students have learned only what can be learned by memory; we conclude that the students cannot really think so we had better just be content with teaching what we can teach by rote; because we limit our instruction to that which involves rote memory, students are never forced to develop their thinking to the level of formal operations; because they do not develop to the level of formal thought; they cannot understand the abstract material we present. (p. 150)

Summary Study on Acquisition of Formal Reasoning

Lawson, Blake and Nordland (1975) attempted to teach high school biology students to control variables. More important they tested for training effects and generalization. Testing hypotheses is a formal operation as it involves the recognition of the necessity of controlling variables. Their sample consisted of 65 high school biology students (29 males and 36 females) with a mean age of 15.5 years. The experimental group (33 students) received training on the ability to control variables and the control group (32 students) did not. The training procedure followed the exploration-invention-discovery mode of instruction. They were all pre and posttested using a pencil and paper test developed by Longeot (1962 and 1965). This test enables the experimenter to classify the students into concrete, transitional and formal stages of development. Their results indicated that the experimental group performed at a higher level on the trained task, however, there was no difference between the experimental and control groups on the tasks designed to measure transfer of training. The suggestion then, is that the higher ability on the trained task is due to rote learning and not through growth of intellectual ability. This result is in agreement with Piaget since he believes that the child must discover the method by himself and having the teacher demonstrate it is completely useless (Piaget in Lawson, et al., 1975).

The authors attribute the lack of transfer to the failure of students to carry on self-regulation or equilibration processes. The other three factors in intellectual development, 1) maturation, 2) concrete experience, 3) social transmission, were met in the training session. They suggest that a variety of concrete experiences and sufficient time must be provided to allow a student to resolve problems by himself. It is the teacher's demands for immediate understanding and desire to cover material that hinders self-regulation. Finally, without this essential component growth to formal thought is severely limited.

Summary

The preceding literature review firmly establishes two points. First, as many as 50 percent of high school students fail to acquire formal reasoning. Second, no hard evidence suggests that a student physiologically prepared can be taught propositional reasoning characteristic of formal thought. However, the literature does provide a theoretical basis educators can use if they wish to work with Piaget's ideas on intellectual development. Also, several group tests have been designed which are effective in determining levels of thought. This frees the experimenter from the tremendous time burden required to conduct individual interviews.

In fact, one group test called Raven's Test of Logical Operations, designed by Ronald J. Raven who refers to it as RTLO, is said to be capable of determining "the developmental pattern of logical operations in children across grade levels" (Raven, 1973). Of course, with such an instrument teachers could determine the reasoning patterns children have most difficulty with and design instructional sequences accordingly. Raven himself uses this instrument in at least three other studies (Raven and Polanski, 1974; Raven, 1974; Raven and Geurin, 1975) to determine logical thought processes in children. This test would have value in this study and an attempt was made to obtain a copy. However, it was not possible to obtain a copy of this test from Dr. Raven. Since the studies in which RTLO was used cannot be replicated, their conclusions are being omitted from the literature review.

Finally, the results of the preceding studies indicate a void exists between what is expected of science students and what is actually occurring. If the attainment of reasoning about natural phenomena at the level of formal operations beyond high school is an objective of science education, then this objective is not being met. The consequence of students not reasoning formally implies that students could leave high school with a sense of frustration and bewilderment rather than with a life-long interest in science.

CHAPTER III

EXPERIMENTAL DESIGN, PROCEDURE, ORGANIZATION OF DATA

Experimental Design

In order to provide support for the first research hypothesis it is necessary to show that teacher-made test items are not discriminating between concrete and formal operations. If the tests are not discriminating it should be possible for concrete operational students to do as well as the formal operational students. Consequently, a test of a single proportion involving a distribution with two categories is required. In this case, category 1 represents those concrete operational students scoring above the median of subjects with formal operational ability while category 2 represents those concrete operational students scoring below the formal median. The hypothesis that the true population proportion in category 1 is p can be tested by;

$$z = \frac{NP - Np}{\sqrt{Npq}}$$

P = observed proportion in category 1,

p = expected proportion in category 1,

q = expected proportion in category 2

N = number of concrete operational students.

(Hays, 1963, p. 585)

Since the hypothesis is concerned with only one tail of the hypothetical distribution of concrete operational students the z value encompassing 5% of the distribution is of concern. For this case z = 1.645 (Ferguson, 1966, p. 405). Once the sample size is known the proportion of concrete operational students that must exceed the formal median in order to support the research hypothesis can be calculated. For example, by applying the above formula and letting p = .05, 9 of 100 concrete operational students would be required to suggest that teacher made test items are not discriminating between concrete and formal operations.

To support the second research hypothesis it is necessary to show that formal operational high achievers can score higher than concrete high achievers on the experimental test items. A test of independence can be used to determine whether or not operational level has any association with achievement on the experimental test items. Chi-square is a test of independence but its use is not recommended if expected frequencies are small (Ferguson, 1966, p. 208). Fisher's exact test of significance for a 2 x 2 contingency table can be used as a test of independence (Ferguson, 1966, p. 208).

For example, if the data collected for the second hypothesis are organized in the following fashion where A, B, C and D are the cell frequencies, Fisher's exact test can be applied.

Achievement on Experimental Test Items

	High	Low	
Formal Operational Students	A	B	A + B
Concrete Operational Students	C	D	C + D
	A + C	B + D	N

$$p = \frac{(A + B)\,!\,(C + D)\,!\,(A + C)\,!\,(B \& D)\,!}{N\,!\,A\,!\,B\,!\,C\,!\,D\,!}$$

where p = the exact probability associated with the arrangement of observed data.

If $\underline{p}_{obs} > .05$ the hypothesis of independence between high achievement and operational level cannot be rejected.

If $\underline{p}_{obs} \leq .05$ then the probability of every other arrangement giving as much or more evidence for association must be calculated. If the probability of these arrangements is less than .05 then evidence suggests an association between achievement on experimental test items and operational level.

Small cell frequencies are predicted by the review of literature. Fifty percent of the Grade 10 students can be expected to be concrete operational. Of these students only a small proportion will be high achievers. Finally, as the research hypothesis predicts the concrete high achievers will not maintain this level on items requiring formal reasoning. Consequently, Fisher's exact test of independence seems appropriate.

Procedure

Collection of Data

All grade 10 students at Gordon Bell High School in Winnipeg taking IPS and present on January 10, 1977 wrote the Rods test. Anonymity was requested. Ninety-six students were involved. The items were scored following the scoring criteria for Rods and students were subsequently identified as being in a particular substage according to Piaget's model. Appendix A contains sample questions from the Rods Test and the rationale behind each sample question.

From the above students those who completed chapter 5 in the IPS text wrote a teacher-made test. Experimental test items were embedded in this test. Students were unaware of their presence and consequently would approach them as they would any other question on the test. The test consisted of 10 items, however, the teacher did not have the students attempt question 3. Questions 9 and 10 were experimental test items. The teacher scored the teacher-made items in his usual fashion and recorded the student mark as a percentage. The experimental items were scored by this writer and were each given all or part of 5 points. Twenty students were involved in this phase of the study. The experimental test items and a sample teacher-made test are in appendix B.

Those IPS students who completed chapter 9 of the IPS text wrote a teacher-made test with the experimental items being numbers 6 and 8 of an 11-item test. The same procedure as above was used in scoring teacher-made items and experimental items. Sixty-eight students took part in this phase.

Those students completing chapter 6 in the IPS course wrote a teacher-made test with experimental items being embedded as the first and last question. Seventeen students were involved.

Those students completing chapter 10 in the IPS course wrote a teacher-test with experimental items being embedded as items 3 and 7. Scoring of items followed the established pattern. Forty-seven students were involved.

The results from previous teacher-tests given since the beginning of school term (September, 1976) were collected and recorded as percentages. If teachers assigned letter grades the middle of the range for each letter grade was taken as the percentage; e.g., D (50-59) would be assigned a percentage of 55.

Organization of Data

Categorization of Students

Based on the results from Rods students were categorized into their operational level.

Table 1

Categorization of Students into Operational Levels

	Concrete	Formal	Transitional	Total
Number of Students	52	19	37	108
Proportion of Sample	.48	.18	.34	1.00

Selection of Subjects

From the above 108 students those who met the following criteria were selected:

1. In either the concrete or formal stage of development, i.e. were not transitional.
2. Participated in two teacher-made tests each containing two experimental test items.

Thirty-nine students met these criteria. Table 2 illustrates how they were distributed in the IPS course and their operational levels.

Table 2

Distribution of Formal and Concrete Operational Students Within the IPS Course

	Chapters	
Operational Level	5 and 6	9 and 10
Formal	4	10
Concrete	7	18

Teacher-Made Test Results

The mean percentage on teacher-made test items from the beginning of the school year through to the completion of this study was determined for each of the 39 students. It was then possible to determine the number of high achievers (students whose mean percentage was $\geq 70\%$) and low achievers (mean percentage $< 70\%$). Table 3 illustrates the number of formal and concrete operational students within each achievement level.

Table 3

Number of High and Low Achievers on Teacher-Made Test Items and Their Operational Level

Operational Level	High ($\geq 70\%$)	Low ($< 70\%$)
Formal	12	2
Concrete	6	19

The median of the formal students on teacher-made test items was 82.5. This statistic is important in providing evidence for the first research hypothesis. Two of the six concrete operational high achievers were above this value.

Experimental-Test Item Results

The mean percentage on experimental test items was calculated for those concrete and formal operational students who were high achievers on teacher-made tests. Table 4 illustrates the number of formal and concrete operational high achievers who were able to maintain this level of achievement on the experimental test items.

Table 4

Number of High and Low Achievers on Experimental Test Items and Their Operational Level

Operational Level	High	Low
Formal	8	4
Concrete	1	5

Where achievement was high if the mean percentage on experimental test items was $\geq 70\%$ and low if it was $< 70\%$.

CHAPTER IV

ANALYSIS OF DATA, FINDINGS AND DISCUSSION

This chapter will report the results obtained from data collected, organized and analyzed in accordance with the experimental design.

Analysis of Data

Stating the first research hypothesis in statistical form:

The proportion of concrete operational students exceeding the formal median (*P*) will be less than or equal to the proportion expected by chance (*p*):

H_o: $P \leq p$ (i.e., the teacher-made test discriminates between concrete and formal operational students)

As previously indicated, once the sample size is known the proportion of concrete students that must exceed the formal median in order to reject the null hypothesis can be calculated.

$$z \text{ crit} \leq \frac{N(P-p)}{\sqrt{Npq}}$$

where $p = .05$, $q = 1 - p = .95$, $N = 25$ students, and the one-tail .05 level of significance is $z = 1.645$. Thus:

$$1.645 \leq \frac{25\ (P - .05)}{25(.05)(.95)}$$

and Proportion $\geq .1217$ for rejection of H_o.

The observed $P = 2/N = .08$ which is not greater than the critical rejection level. Thus, H_o cannot be rejected and there is not substantial evidence to indicate that teacher-made tests do not discriminate.

Stating the second research hypothesis in statistical form:

The level of achievement on experimental test items is independent of operational level;

From the data:

$\underline{p}_{obs} = .06$

where $\underline{p}_{obs}$ = exact probability of obtaining the observed data given the marginal frequencies.

Therefore the null hypothesis cannot be rejected.

Findings

The first research hypothesis predicted that high achievement on teacher-made test items of concepts requiring formal reasoning was possible by students in the concrete operational stage. In other words, it predicted that teacher-made tests were not discriminating between the formal and concrete operational students. However, the results do not provide evidence for support of this hypothesis.

The second research hypothesis predicted that only formal operational high achievers would maintain this level of achievement on experimental test items. In other words, an association between operational level and achievement on items requiring formal reasoning was expected. Once again, the results do not provide evidence for support of this hypothesis.

Discussion

One result of the research is consistent with that of other researchers. Approximately one-half of the grade 10 student population can be expected to be non-formal. In fact of 108 grade 10 students who wrote Rods 48% were designated concrete, 18% formal, and 34% transitional. These results have additional meaning when the achievement on teacher-made test items of these three groups is compared in table 5.

Table 5

Operational Level and Achievement on Teacher-Made Tests

	Operational Level		
Achievement	Concrete	Transitional	Formal
Above 70%	6	7	12
Below 70%	19	15	2

Over 85% of the formal students were above 70% on teacher-made test items. Only 32% of the transitional and 24% of the concrete students were above this level of achievement. Since IPS is not a content oriented course one would expect higher levels of achievement for the concrete and transitional students if the concepts were suited to their level. Consequently, in agreement with Harris (1973), Tomlinson-Keasey (1972), Karplus and Karplus (1970), Karplus and Peterson (1970), Lawson and Renner (1974, 1975) an adolescent cannot be assumed to be in the formal operational stage. In fact, as predicted by them, a significant proportion can be expected to be in the concrete operational stage. Also, the study supports the assertion of Ball and Sayre (1973):

> Piagetian cognitive development, a physiological as well as psychological process, appears to be a major factor in determining grades received by science students. (p. v)

However, the study did not support the arguments of Herron (1975) and Kolodiy (1974). They recognized the conflict between curriculum content and cognitive level. They both suggested that learning was frequently by rote since the concepts require abstract reasoning which of course concrete operational students are incapable of applying. Herron further suggested that teachers are willing to accept memorization as evidence for understanding.

The data do not provide evidence that extensive memorization has taken place. In fact, the teacher-made test items discriminate so extensively that only two concrete operational students were able to exceed the median of the formal students on teacher-made tests.

The results relating to the second hypothesis could have been affected by the small number, six, of concrete operational students exceeding 70% on teacher-made test items. One of the six maintained this level of achievement on the experimental items. As a result there was insufficient evidence to support the suggestion that memorization was a concrete operational student's path to high achievement.

To account for such a small proportion of the concrete operational students exceeding 70% on the teacher-made test items it is suggested that they are so frustrated by the IPS concepts that they are incapable or unwilling to carry out the memorization required to answer correctly the items on the teacher-made tests. This of course is speculation and is merely an impression acquired through working with students who have difficulty with the concepts presented in IPS.

The concrete operational students make up 48% of the students tested throughout the study and have a median percentage of 51.4%. The results show that their reasoning ability on items that frequently require abstract reasoning is correctly reflected by teacher-made tests. However, since the students cannot accept total responsibility for their operational level the curriculum should be matched more carefully to their operational level. They cannot be held responsible since studies designed to test methods of facilitating formal thought, e.g. Harris (1972) and Tomlinson-Keasey (1972) have been inconclusive.

Rather, in agreement with the results of Lawson, Blake and Nordland (1975), a concrete operational student must have a variety of concrete experiences and time to resolve problems in order to self regulate, an essential component for intellectual development to occur within Piaget's model. It now seems evident that IPS is too difficult for the average grade 10 student and should be used only with students who are formal operational.

Reasons for the above statement come from combining the results generated by the two research hypotheses. Apparently, if a student is a high achiever on teacher-made test items this achievement can be maintained on items testing for transfer. Consequently, if teachers group according to test results those students who are high achievers on teacher-made test items are likely suited to the IPS material. An obvious question arises; did any low achievers on teacher-made test items do well on the experimental test items?

No student in this study with below 70% on teacher-made test items exceeded 70% on the experimental test items. The test results for these students are in appendix C. It would seem that restricting IPS to high achievers as defined in this study would not exclude students capable of formal thought and thus suited for IPS.

In short, formal operational students can be expected to do well with IPS. However, most non-formal students, who constitute over half the grade 10 students, cannot achieve the objectives. Therefore, it is suggested that the IPS course be taught as outlined by the authors to only the top level student. Otherwise because of the mismatch between cognitive level and curriculum content frustration and low achievement will continue to be a problem.

CHAPTER V

Summary and Conclusions

Summary

IPS is a course designed to provide students with a solid foundation for later courses in science. The content of IPS is minimal which the authors believe allows time for development of science process skills. For example, arriving at conclusions through laboratory work rather than having them appear explicitly in the text. Although this technique meets the needs of some students it is not effective for many grade 10 students.

The thrust of this study has not been to question the method by which the authors of IPS envision science process skill development, but to determine the types of generalizations and laws they expect early adolescents to work with.

Jean Piaget's theory of intellectual development has provided a theoretical basis of testing the viewpoint that IPS is inappropriate for many grade 10 students. Piaget sees development of the intellect as moving through four major stages. The focus of this study was on the third and fourth stages of his theory, concrete and formal operations. Individuals in the formal operational stage can deal with abstractions and are capable of thinking in hypothetical terms, sometimes quite unrelated to reality. The concrete operational thinker does not have this freedom of thought but rather, as the term implies, is much more restricted in his thinking.

This study attempted to determine if IPS contains concepts which can only be fully understood by students in the formal operational stage. Although many studies indicate that as high as 50% of the grade 10 students are concrete operational there has been little done to see how teachers cope with this situation. It was hypothesized that teachers would teach formal concepts via rote procedures and design tests on which any student could attain high achievement via memorization. If this were occurring students would be receiving credit for understanding concepts that would be required for later courses in high school, which in fact they do not understand.

This study also investigated the distribution of levels of cognitive development in terms of Piaget's model in grade 10. If over half the students are non-formal, then a course such as IPS which is taught in accordance with the philosophy and objectives of its authors is not suited to their level of intellectual development.

Students taking IPS were classified according to their level of cognitive operations by means of a pencil and paper test entitled Rods designed by Harris (1973). This test purports to discriminate between students who are concrete and formal operational as well as identifying those students transitional between the two major stages. With such a group test it was possible to test the first hypothesis of this study; high achievement on teacher-made IPS tests that are intended to test understanding of concepts requiring formal operations does not require formal operational ability on the part of the learner. Those students who were high achievers on the teacher-made IPS tests constituted the sample for testing the second hypothesis; the formal operational high achievers will score higher than the concrete operational high achievers on the experimental test items.

Experimental test items embedded in the teacher-made tests were designed so that a correct response would require hypothetico-deductive reasoning, i.e., formal reasoning on the part of the student to obtain full credit. Piaget's theory leads to the prediction that only the formal operational students should respond correctly to experimental test items. Concrete operational students who were capable of high achievement on teacher-made items by resorting to memory should not have been able to answer these questions.

Findings

1. Teacher-made IPS tests did discriminate between formal and concrete operational students.
2. There was not an association between achievement on experimental test items and teacher-made test items for formal and concrete operational high achievers.

Conclusions

Contrary to hypothesis 1, this study showed that formal reasoning is required for high achievement on teacher-made test items. With respect to hypothesis 2, the results are also contradictory since performance on experimental test items by formal and concrete operational high achievers is independent of their operational level.

Discussion

Although both hypotheses lack support there are findings in this study which are meaningful. The belief which generated the hypothesis that over half the grade 10 students are non-formal, has been affirmed. In fact based on Rods only 18% were formal operational with 48% being concrete operational and the remaining 34% in the transition zone. Consequently, the split in operational levels was such that the groups in each sample were of adequate size. However, the prediction was false that there would be a sufficient number of concrete operational students doing as well as formal operational students to claim that teacher-made tests were not discriminating between operational levels. In fact only two of 25 concrete operational students were above the median of the formal operational students on teacher-made test items. Consequently, the data do not support the hypothesis but certainly do present a situation that must be considered by teachers of IPS.

With regard to the second hypothesis it was not that concrete operational high achievers did well on experimental test items but rather was the poor performance of the formal operational high achievers that may have resulted in lack of support. In fact four of 12 formal operational high achievers on teacher-made tests could not maintain high achievement on the experimental test items. Only one of six concrete operational high achievers could maintain this level of achievement in experimental test items. A possible reason for the poor performance of the formal students is that the experimental test items were not shown to the teachers of the students taking part in the study. Consequently, when covering the chapter in class, sections relating to the experimental test items could have been omitted or passed over lightly. Students of any operational level are not likely to prepare themselves in such areas for tests administered by their classroom teacher. Also, if 29 students had not been lost to a separate study the data may have shown an association between achievement on experimental items and operational level. It is appropriate at this point in the discussion to recognize other limitations of this study.

By restricting the study to students at Gordon Bell, generalization of these results is limited to students with similar experience, background, and ability as those in the study.

A study of this kind would be better conducted by a team of researchers. Although every effort was made to be as objective and consistent as possible when scoring responses to <u>Rods</u> and experimental test items it is recognized that cross checking the scoring with that of others might have been advisable.

Using <u>Rods</u> as the only instrument in identifying a student's operational level presents a limitation on the study. Even though the distribution of students is consistent with other research conducted on grade 10 students, interviews would validate the results of <u>Rods</u>.

Although the above limitations are significant this study does provide direction for future research. The research design is promising in that the results are consistent with that of other researchers. It is this writer's belief that a replication of the study with a larger sample would provide more conclusive results.

Recommendations for Future Research

1. The ambiguities in this study due to small sample size could be resolved through a replication study. Also, any generalizability of results would be increased by following through with the same research design on a second generation.
2. A similar study could be conducted with students involved with other high school science courses. The purpose would be to investigate the extent of the mismatch between cognitive level and curriculum content.
3. A study designed to investigate the relationship between attitudes toward and interests in science and operational level would have value. Through such a study it could be determined whether teaching techniques designed to develop interest in science would facilitate acquisition of formal operations.
4. A study designed to determine if there is a relationship between teacher behavior and operational level of the students would be possible. Measureable

behaviors like questioning techniques, delivery of lessons and testing techniques could be used to reveal relationships between teacher behavior and formal operational thinking that may exist. Any such relationships should be made known to a teacher who is concerned with matching the level of his presentation of a science course with the operational level of his students.

REFERENCES

References

Baldwin, A. L. Theories of child development. Department of Psychology, New York University, New York: John Wiley & Sons, Inc., 1967.

Ball, D. W. and Sayre, S. A. Relationships between student Piagetian cognitive development and achievement in science (Doctoral dissertation, University of Northern Colorado, 1972).

Ball, D. W., & Sayre, S. A. Piaget and the secondary science teacher. School Science and Mathematics, 1974, 4, 331-336.

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

Brainerd, C. J. & Allen, T. W. Training and generalization of density conservation: Effects of feedback and consecutive similar stimuli. Child Development, 1971, 42, 693-704.

Elkind, D. Quantity conceptions in junior and senior high school students. Child Development, 1961, 32, 551-559.

Elkind, D. Children and adolescents. New York: Oxford University Press, 1970.

Ferguson, G. A. Statistical analysis in psychology and education. New York: McGraw-Hill, 1966.

Field, T. W. & Cropley, A. J. Structures of thought among senior science students: science and non-science. Australian Science Teachers' Journal, 1968, 14, 27-32.

Ginsburg, H. & Opper, S. Piaget's theory of intellectual development. Englewood Cliffs, N. J.: Prentice-Hall, 1969.

Harris, A. A problem solving technique to facilitate concrete formal transition (Doctoral dissertation, University of Calgary at Calgary, Alberta, 1973).

Hays, W. L. Statistics for psychologists. United States: Holt, Rinehart and Winston, 1963.

Herron, J. D. Piaget for Chemists, explaining what good students cannot understand. Journal of Chemical Education, 1975, 52, 146-150.

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

Inhelder, B. & Piaget, J. The early growth of logic in the child. London: Routledge and Kegan Paul, 1964a.

IPS Group of Education Development Centre, Inc. Introductory physical science. Englewood Cliffs, New Jersey: Prentice-Hall, 1967.

IPS Group of Education Development Centre, Inc. Introductory physical science teacher's guide. Englewood Cliffs, New Jersey: Prentice-Hall, 1967.

Jackson, S. The growth of logical thinking in normal and subnormal children. British Journal of Educational Psychology, 1965, 35, 255-258.

Jones, P. A. Formal operational reasoning and the use of tentative statements. Cognitive Psychology, 1972, 3, 467-471.

Karplus, E. F. & Karplus, R. Intellectual development beyond elementary school I; deductive logic. School Science and Mathematics, 1970, 70, 398-406.

Karplus, R. & Peterson, R. W. Intellectual development beyond elementary school II; ratio, a survey. School Science and mathematics, 1970, 70, 813-320.

Kaufman, B. A. & Konicek, R. D. The applicability of Piaget to contemporary curriculum reform? Revision of a paper presented at the Piaget symposium at William James College at Grand Valley State College, Allendale, Michigan, May, 1972.

Kolidiy, G. The cognitive development of high school and college science students. Journal of College Science Teaching, 1975, 5, 20-22.

Lawson, A. E., Blake, J. D. & Nordland, F. H. Training effects and generalization of the ability to control variables in high school biology students. Science Education, 1975, 59, 387-396.

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

Lawson, A. E. & Renner, J. W. Piagetian theory and biology teaching. The American Biology Teacher, 1975, 37, 336-343.

Longeot, F. Un Essai d'application de la psychologie genetique a la psychologie differentielle. Bulletin de l'Institut National D'Etude, 1962, 18, 153-162.

Longeot, F. Analyse statistique de trois tests genetiques collectifs. Bulletin de l'Institut National D'Etude, 1965, 20, 219-237.

Lovell, K. A follow-up study of Inhelder and Piaget's growth of logical thinking. British Journal of Psychology, 1961, 52, 143-153.

Lovell, K. Some recent studies in cognitive and language development. Merill Palmer Quarterly, 1968, 14, 123-138.

Lovell, K. Some problems associated with formal thought and its assessment. In D. R. Green, M. P. Ford, & G. B. Flamer (Eds.), Measurement and Piaget. New York: McGraw-Hill, 1971.

Lovell, K. & Shields, J. B. Some aspects of a study of the gifted child. British Journal of Educational Psychology, 1967, 37, 201-208.

Manitoba Department of Education. Curriculum guide, science 100, university entrance course. Authorized by the Minister of Education, 1968.

Piaget, J. Play dreams and imitation in childhood. New York: Norton, 1962.

Piaget, J. Genetic epistemology. New York: Columbia University Press, 1970.

Piaget, J. The psychology of intelligence. London: Routledge and Kegan Paul, 1971. (a)

Piaget, J. The theory of stages in cognitive development. In D. R. Green, M. P. Ford, & C. B. Flamer (Eds.), Measurement and Piaget. New York: McGraw-Hill, 1971. (b)

Raven, R. J. The development of a test of Piaget's logical operations. Science Education, 1973, 57, 377-385.

Raven, R. J. Programming Piaget's logical operations for science. Journal of Research in Science Teaching, 1974, 2, 251-261.

Raven, R. J. & Guerin, R. Quasi-simplex analysis of Piaget's operative structures and stages. Science Education, 1975, 59, 273-281.

Raven, R. J. and Polanski, H. Relationships among Piaget's logical operations, science content comprehension, critical thinking and creativity. Science Education, 1974, 58, 531-544.

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

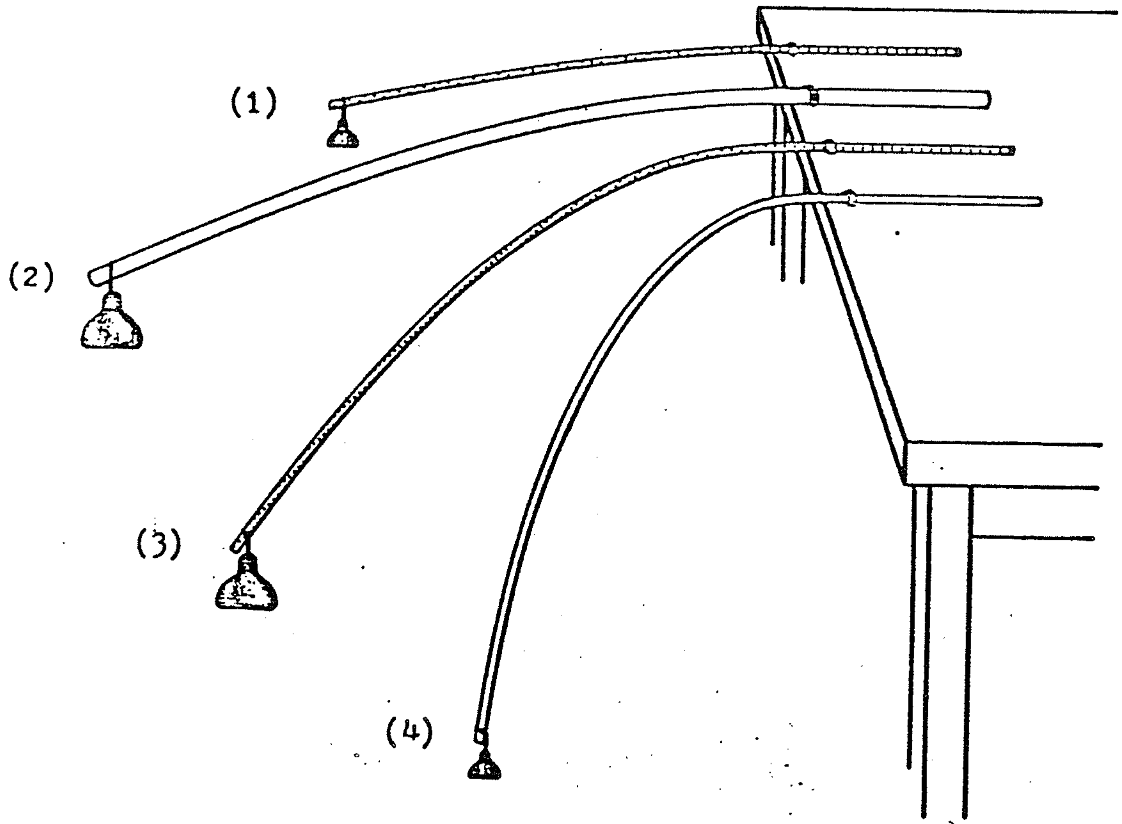
Renner, J. W. & Lawson, A. E. Promoting intellectual development through science teaching. The Physics Teacher, 1973, 11, 273-276. (b)

Sullivan, E. V. Piaget and the school curriculum - a critical appraisal. Ontario institute for studies in education, 1967, bulletin 2.

Tomlinson-Keasey, C. Extended report of brief article in Developmental Psychology, 1972, 6, 364.

Appendix A

1. Sample Questions From Rods
2. Rationale For Sample Questions



QUESTION 2 Probably (3) bent more than (2) because

QUESTION 3 Probably (4) bent more than (1) because

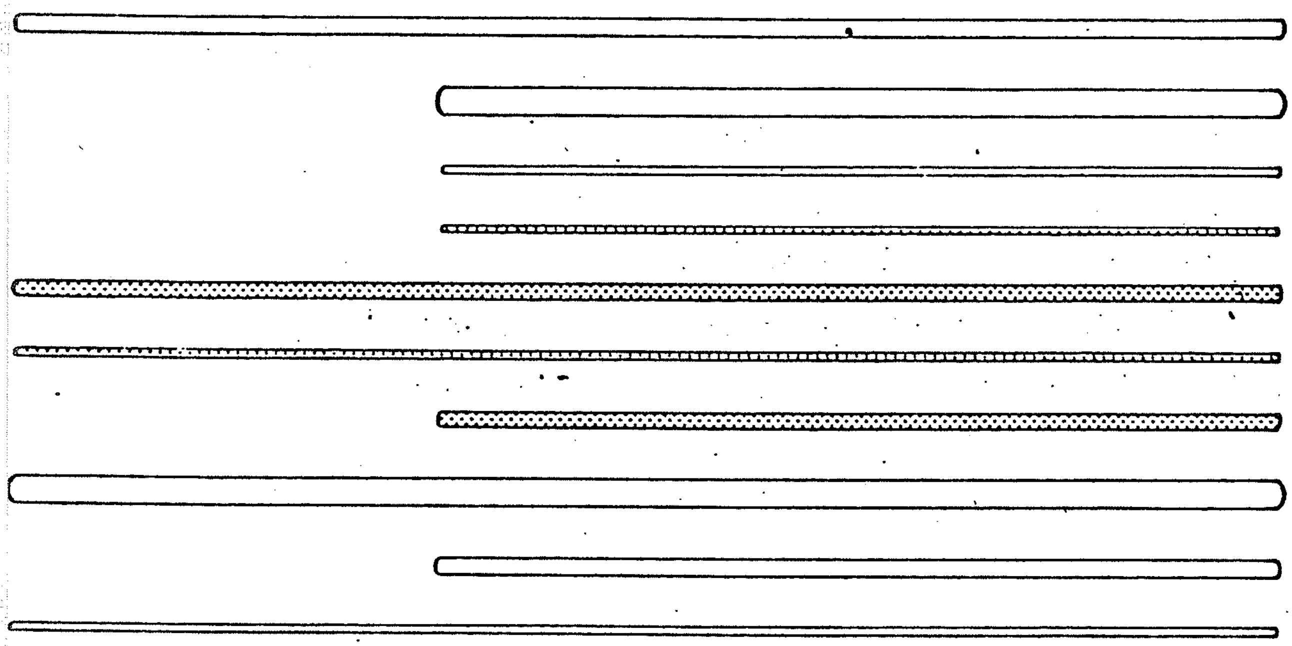
QUESTION 4 Probably (3) bent more than (1) because

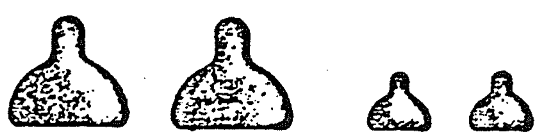
QUESTION 5 Suppose you think that a difference in material (that is, metal or wood) might cause one rod to bend more than another.

Mark X's on the two rods you would use to prove that bending depends on the kind of material.

Mark X's under the two weights you would use.

(You should use four X's, two for rods and two for weights.)





Rationale

Question 2 Question 3 Question 4 (Concrete)	Two different rods were used for each question and subjects were asked to explain why one rod bent more than the other for each comparison. The items require concrete operations since the information can be read from the diagrams.
Question 5 (Formal)	The question asks subjects to use X's to indicate the rods and weights they would use to show the influence of material on bending. This question requires the ability to conduct a controlled experiment--holding variables constant--which is a formal operation.

Appendix B

1. Experimental Test Items.
2. A Teacher-made Test Containing Experimental Test Items.

Experimental Test Items

Chapter 5

1. Helium has a boiling point below $-218^{\circ}C$. Could it be used in a gas thermometer to measure the freezing point of oxygen? Explain your answer with complete statements.

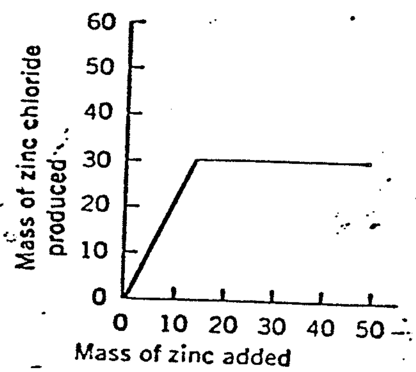
2. The following quotation is taken from page 94 of your text:

   "We skim off the floating material whose density is obviously less than water."

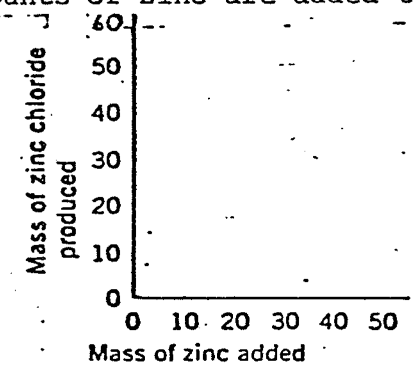
   To some people the concept of density is not obvious. Without using the word density describe how you would explain why some substances float on water.

Chapter 6

1. When increasing amounts of zinc are reacted with a given amount of hydrochloric acid, the amount of zinc chloride produced is described by the following graph:



On the coordinates below describe the amount of zinc chloride produced if increasing amounts of zinc are added to twice as much hydrochloric acid.



2. Two different gases, each of which is a pure substance, can be obtained from ammonia gas. In the chart below put an "X" under the possible heading or headings which describe these substances.

	Element	Mixture	Compound
Ammonia			
Gas 1			
Gas 2			

What was the reasoning behind your selection (s) for ammonia?

Chapter 9

1. The volume of a single molecule of oleic acid can be estimated by

   a) squaring the thickness of the film.

   b) cubing the thickness of the film.

   c) finding the square root of the thickness of the film.

   d) finding the cube root of the thickness of the film.

   e) multiplying the thickness of the film by the density of oleic acid.

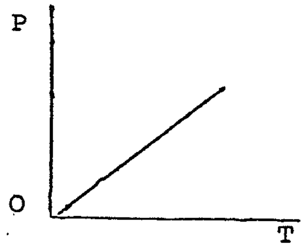
   Explain the reasoning used in making your choice.

2. A gaseous compound of nitrogen and oxygen is analyzed and found to have a ratio of 7/4 for the mass of nitrogen to the mass of oxygen. If the mass of an atom of nitrogen is 14 amu and the mass of an atom of oxygen is 16 amu, what is a possible molecular formula for this compound?

   Show all steps used in arriving at your answer.

Chapter 10

1.

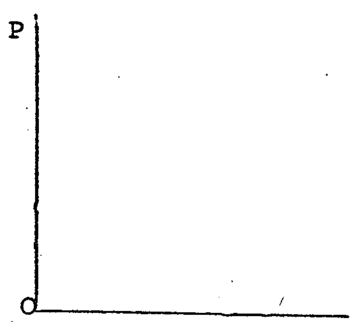


The above graph represents pressure as a function of temperature for a sample of gas at constant volume.

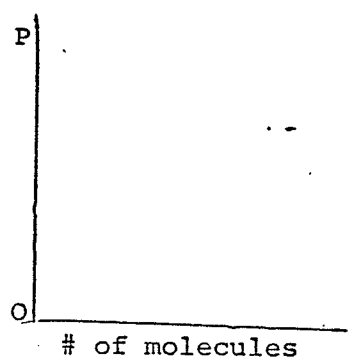
On the coordinates below describe:

a) pressure as a function of volume for a sample of gas kept at constant temperature.

b) pressure as a function of the number of molecules for a sample of gas kept at constant volume and temperature.



(a)



(b)

2. Explain in terms of the atomic model why compressibility and thermal expansion are characteristic properties of gases under very high pressures but are not under atmospheric pressure.

IPS

Chapter 10 Test

Name ________________

1. If the temperature of a gas in a sealed tube is increased,

   a. the density of the gas will decrease.
   b. the density of the gas will increase.
   c. the pressure of the gas will increase.
   d. both the density and the pressure will remain constant.
   e. both the density and the pressure of the gas will increase.

2. According to the atomic model, atoms are in motion

   a. in gases only.
   b. in gases and liquids only.
   c. in gases, liquids, and solids
   d. only when there is a temperature difference.
   e. only when diffusion takes place.

3. All of the following depend on molecular motion EXCEPT

   a. dissolving sugar in water,
   b. pressure experted by a gas,
   c. difference in density for different solids.
   d. evaporation of water.

4. A volume of 80 cm^3 of nitrogen is enclosed in a cylinder. The initial pressure inside the cylinder is 5.0 atmospheres. If the volume is increased to 100 cm^3, and there is no temperature change, the final pressure inside the cylinder will be

   a. 8.0 atmospheres
   b. 6.25 atmospheres
   c. 5.25 atmospheres
   d. 4.0 atmospheres
   e. 3.0 atmospheres

5. The relationship between the pressure and the volume of a gas at constant temperature, known as Boyle's Law, is an accurate description of the behaviour of gases

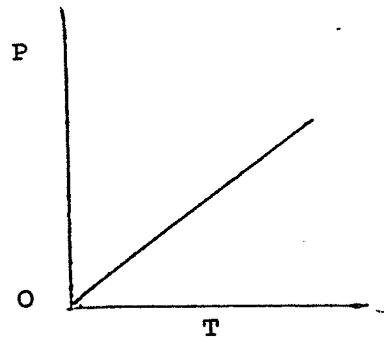
   a. only if the gas has a very low boiling point.
   b. only if the molecules of the gas are far apart compared with their diameter.
   c. only if the gas is a pure substance,
   d. only if the gas is an element.
   e. for all gases under all conditions.

6. If the pressure on a gas in a cylinder is increased and temperature remains constant,

   a. the density of the gas will decrease.
   b. the density of the gas will increase.
   c. the volume of the gas will increase.
   d. both the volume and the density will increase.
   e. both the volume and the density will remain constant.

Chapter 10 Test

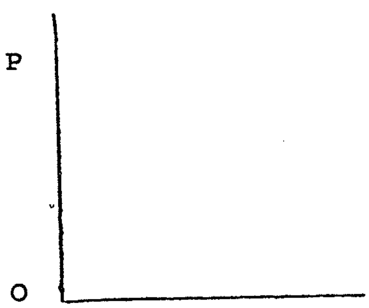
7. What evidence leads us to believe that atoms are in motion and not stationary?



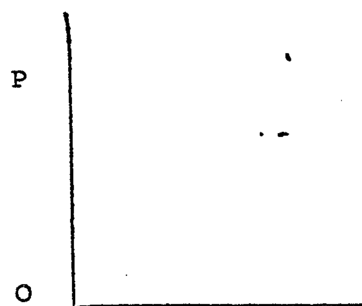
8. The above graph represents pressure as a function of temperature for a sample of gas at constant volume. On the coordinates below describe:

(a) pressure as a function of volume for a sample of gas kept at constant temperature.

(b) pressure as a function of the number of molecules for a sample of gas kept at constant volume and temperature.



(a)



(b) # molecules

9. Name 3 ways you can increase the pressure of a gas.

10. A short time after a bottle of ammonia is opened at the back of a room the odor can be detected at the front of the room.

(a) The process by which the molecules of ammonia spread through air is called ______________________.

(b) Why do the molecules of ammonia move through the air slowly?

Chapter 10 Test

11. Explain in terms of the atomic model why compressibility and thermal expansion are characteristic properties of gases under very high pressures but are not under atmospheric pressure.

12. The following is data from an experiment similar to the one you performed with copper sulfate.

The object of this experiment is to determine the number of water molecules that combine with 1 molecule of cobalt chloride ($CoCl_2$) to form crystals.

Data

Mass of cobalt chloride crystals	9.00 g
Mass of dehydrated cobalt chloride	5.00 g
Mass of 1 molecule of cobalt chloride	130 amu
Mass of 1 molecule of water	18 amu

Calculations: (Show all your work!)

(a) Calculate the number of molecules of water that combined with 1 molecule of cobalt chloride.

(b) Calculate the number of molecules of water that combined with 1 molecule of cobalt chloride.

Conclusion:

(c) The formula for hydrated cobalt chloride is $CoCl_2 \cdot$ ______ H_2O.

(d) Why must your answer to c be a whole number?

Sources of Error:

List at least 3 sources of error in this experiment.

Appendix C

Data Table Showing Results Of Those Students, From 108 Who Wrote *Rods*, That Were Relevant To The Purpose Of This Study

Student No.	Operational Level	Mean of teacher-made test items (%)	Mean of experimental test items (%)
2	Formal	83.3	70.0
3	Formal	88.0	80.0
9	Formal	88.5	60.0
23	Formal	100.0	76.0
53	Formal	56.8	38.0
54	Formal	80.0	82.0
55	Formal	67.3	50.0
56	Formal	79.6	62.0
57	Formal	88.4	78.0
60	Formal	81.8	92.0
61	Formal	88.6	72.0
67	Formal	84.0	70.0
69	Formal	74.0	36.0
76	Formal	77.6	60.0
4	Concrete	83.8	50.0
5	Concrete	83.3	70.0
7	Concrete	76.3	50.0
10	Concrete	51.7	46.0
17	Concrete	76.7	60.0
19	Concrete	42.6	35.0
22	Concrete	51.4	30.0
59	Concrete	30.5	28.0
63	Concrete	64.6	50.0
64	Concrete	52.4	28.0
68	Concrete	36.2	28.0
70	Concrete	24.2	28.0
74	Concrete	75.2	40.0
80	Concrete	46.4	26.0
82	Concrete	40.0	38.0
84	Concrete	50.4	30.0
83	Concrete	24.3	20.0
85	Concrete	78.2	38.0
87	Concrete	48.3	36.0
88	Concrete	51.3	30.0
89	Concrete	37.8	20.0
95	Concrete	55.3	36.0
100	Concrete	62.0	38.0
101	Concrete	66.5	38.0
104	Concrete	34.0	28.0

Where student no. refers back to original 108 students who wrote Rods.