AN INVESTIGATION OF JUNIOR HIGH SCHOOL STUDENTS' UNDERSTANDING OF FORMAL CONCEPTS WHEN TAUGHT BY CONCRETE AND FORMAL MODES OF INSTRUCTION

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by

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ABSTRACT

Piaget's model of intellectual development constituted the theoretical background for the study. This model depicts intellectual development as occurring in four stages. The final two stages of the model, referred to as concrete and formal, were most relevant to the present study. As such, these stages received most elaboration.

A number of similar studies, recently conducted, were also based primarily on this portion of the model. Many of the studies were conducted to investigate methods of effectively teaching formal concepts to concrete and formal-operational students. Since the evidence produced by these studies is inconclusive and controversial, the present study was undertaken to further investigate the possibility of teaching concrete and formal students an understanding of formal concepts. In as much as possible, the study was conducted in a naturalistic setting.

The experimental procedures involved two teachers and four intact classes of eighth-grade science students from a junior high school in the city of St. John's. The experiment was carried out in two phases. During the first phase, one of the teachers instructed two classes of students in one of the subject areas while the other teacher instructed two different classes in the other subject area. Each teacher used a treatment designated as concrete with the class represented as the experimental group and a treatment designated as formal with the class designated as the control group. At the end of the first phase, the

appropriate achievement test, comprised of comprehension and application level test items, was administered in each subject area. Also, at approximately midway through the experiment, a test to determine level of intellectual development was administered.

The procedures followed in the second phase were similar to those used in the first. However, during this phase, the teachers switched subject areas. Each teacher also interchanged the classes previously designated as experimental and control. These cross-overs were included to control for teacher-subject and class-method interaction. Again at the end of the instructional period, the appropriate achievement tests were administered.

Analysis of covariance was employed to analyze the scores on the two subject-matter tests developed as part of the study. The results of this analysis were used to test the following three hypotheses: there will be no significant difference in the achievement test scores between subjects receiving concrete and formal instruction; there will be no significant difference in the achievement test scores between subjects at different levels of intellectual development; and there will be no significant interaction between level of instruction and level of intellectual development with respect to students' performance on the achievement tests. On the basis of the analysis, the first and third hypotheses were supported while the second hypothesis was rejected. In addition, a post-hoc analysis of the scores on the corresponding teacher-made tests, comprised of knowledge level test items, showed that students exposed to formal instruction scored higher on these tests than students taught via concrete instruction.

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THE PROBLEM

During the sixties, science educators were primarily concerned with the degree to which science curricula reflected the nature of the disciplines. Rarely did curriculum reform involve serious consideration of the characteristics of the learner (Hurd, 1971). As a consequence of this, curriculum materials developed at that time and since appear to be inconsistent with the intellectual capabilities of the majority of students. Considerable information relating to this discrepancy has accumulated as a result of investigations applying the theoretical and empirical work of the influential developmental psychologist, Jean Piaget.

Piaget's theory of intellectual development has influenced educators to focus more clearly on the intellectual functioning of the learner as one of the primary concerns in curriculum development. His theory has led educators to the realization that, in addition to reflecting an accurate image of the disciplines, effective curricula must correspond to the intellectual capabilities of the learners for whom they are developed. With reference to the accomplishment of this correspondence, the basic significance of Piaget's theory is indicated in the following statement by Ausubel (1968):

> Knowledge of the timetable of intellectual development makes possible, for the first time, the scientific, as opposed to the arbitrary or traditional, grade placement of subject matter.

The problem of how to achieve an optimum degree of correspondence has not been substantially investigated. The present study investigates one possible strategy.

Theoretical Background

Piaget's theory is essentially a model depicting intellectual development from birth to adolescence. According to Piaget, this development involves progression through four stages, although widespread attainment of the final level has been questioned by a number of researchers, including Piaget himself (Levine and Linn, 1977).

Piaget labels each stage and provides their respective age range as follows: sensori-motor (0-2 years), preoperational (2-7 years), concrete-operational (7-11 years), and formal-operational (11 years and over). The order in which the stages are listed is the sequence in which Piaget suggests they appear in the complete development of the human intellect. According to Piaget, the order of development is constant but the age at which individuals enter and leave a particular stage may vary. In other words, the ages presented by Piaget may be acceptable as guidelines but not as findings applicable to all individuals. In fact, most studies in this area have suggested age ranges consistently higher than those obtained by Piaget in research on his Geneva subjects (Howe, 1974).

The students involved in the present study were assumed to be operating at either the concrete or formal stage of intellectual development. Therefore, the remaining portion of this section will focus exclusively on these two stages.

Several criteria for identifying reasoning patterns as representative of students at the concrete and formal stages of intellectual development, respectively, have been formulated by Karplus (1977). According to Karplus, a student whose reasoning is based on "direct experience, concrete objects, and familiar actions" is classified as concrete. A student whose reasoning "is based on abstractions and that transcends experience" is classified as formal. Kalplus offers a more extensive list of clues for distinguishing between concrete and formal reasoning patterns. The following is a list of reasoning patterns that he associates with concrete-operational thinkers:

(a) Needs reference to familiar actions, objects and observable properties.

(b) Uses the following reasoning patterns but is not able to use patterns identified as formal:

(i) Applies classifications and generalizations based on observable criteria.

(ii) Applies conservation logic.

(iii) Applies serial ordering and establishes a one-to-one correspondence between two observable sets.

(c) Needs step-by-step instructions in a lengthy procedure.

(d) Is not aware of his own reasoning, inconsistencies among various statements he makes, or contradictions with other known facts.

By using these reasoning patterns, an individual is able to understand concepts that he could not comprehend while in the preoperational stage. However, there are many limitations when the concrete stage is compared to the formal stage. Karplus lists the following reasoning patterns as indicative of formal thought:

The formal thinker:

(a) Can reason with concepts, relationships, abstract properties, axioms, and theories; uses symbols to express ideas.

(b) Uses reasoning patterns associated with the concrete stage as well as the following:

(i) Applies multiple classification, conservation logic, serial ordering, and other reasoning patterns to concepts, abstract properties, axioms and theories.

(ii) Applies combinatorial reasoning, considering all conceivable combinations.

(iii) States and interprets functional relationships in mathematical form.

(iv) Recognizes the necessity of an experimental design that controls all variables but the one being investigated.

(v) Reflects upon his own reasoning to look for inconsistencies or contradictions with other known information.

(c) Can plan a lengthy procedure given certain overall goals and resources.

(d) Is aware and critical of his own reasoning; actively seeks checks on the validity of his conclusions by appealing to other known information.

According to Karplus, these are the important differences between concrete and formal reasoning patterns. Ausubel (1968) refers to these reasoning patterns in his discussion of the educational implications of both these levels of intellectual functioning. As far as concrete-operational students are concerned, he states that

> . . . . one cannot hope to reduce science to "first principles" and basic abstract laws. At the very best one can strive for a semi-abstract, intuitive grasp of these laws on a descriptive or perhaps semi-analytic level that is somewhat tied to particularized experience. On the methodological side, abstract principles of science inquiry and strategy also have much less meaning for children than a

> purely concrete-empirical explanation of how it is possible for mankind to know the facts and generalizations under discussion.

Once a student reaches the formal-operational stage, he then "becomes in large measure an abstract verbal learner." In Ausubel's words

> . . . . With his developmental dependence on concrete-empirical props removed, the only condition necessary for the understanding and meaningful manipulation of higher-order concepts and abstract propositions is that their substantive import be non-arbitrarily relatable to his particular cognitive structure, and that he adopt a set to learn them in this fashion. Hence, on developmental grounds, he is ready at the secondary-school level for a new type of verbal expository teaching that uses particular examples primarily for illustrative purposes, that is to clarify or dramatize truly abstract meanings rather than to make possible the emergence of intuitive meanings.

In summary, the different reasoning patterns of students at different levels of intellectual development warrant a corresponding difference in instructional procedures if these students are to partake in meaningful experiences in science.

Need for the Study

According to Piaget's model of intellectual development, the upper limit of an individual's mental capacity at a particular time is signified by the stage in which he or she is presently functioning. That is, the individual is not able to mentally cope with situations which require a more advanced level of intellectual operation than that distinctive of the individual's current level of development. For instance, the concrete-operational student is able to deal with concrete situations or with circumstances that require a level of thought characteristic of a previous stage. However, he is not able to completely and meaningfully understand more complex matter that requires formal thought. To attain this level of understanding, the student must progress to Piaget's final stage of intellectual development.

Many educators have emphasized this aspect of Piaget's theory in explaining some of the learning problems encountered in the high school classroom, and in suggestions for their solution. A number of studies have been conducted in an effort to produce empirical evidence relating to these learning problems and to an effective means towards their resolution based on Piaget's theory.

Since it was suspected that the intellectual demands of most high school science courses was beyond the level of intellectual functioning of most high school students, studies were undertaken that involved systematic analyses of the level of reasoning required of typical high school science concepts (Ingle and Shayer, 1970; Shayer, 1973; Herron, 1975; Lawson and Renner, 1975; Novick and Menis, 1976; Hudson, 1976; Karplus, 1977), and the level of thought characteristic of high school students (Nordland et al, 1974; Wollman and Karplus, 1974; Karplus, Karplus and Wollman, 1974; Lawson and Renner, 1975; Lawson, Blake and Nordland, 1975; Lawson and Blake, 1976). These studies suggest that much high school science content is formal, while the majority of students function at the concrete stage of intellectual development. Studies investigating the relationship between learner developmental level and achievement in science have provided empirical evidence indicating that the level of the subject matter comprising a substantial portion of high school science courses is beyond the intellectual capabilities of a large percentage of students to whom it is taught, and is therefore not meaningful to these students (Sheehan, 1970; Sayre and Ball, 1975; Lawson and Renner, 1975; Lawson and Blake, 1976; Lawson and Nordland, 1977; Wheeler and Kass, 1977; Cantu and Herron, 1978; Goodstein and Howe, 1978; Reminsky, 1979). These studies show that the performance of formal-operational students is significantly greater than that of concrete-operational students on achievement tests evaluating understanding of formal science subject matter and, in some cases, on tests evaluating achievement of concrete science content.

The above findings may be summarized as follows: research evidence indicates that the level of intellectual development of most high school students is concrete; content analyses show that most high school science courses are largely formal; and empirical results support a positive relationship between level of intellectual development and achievement in science. These three general findings demonstrate a need for further research into possible methods of making the formal science content more accessible to an understanding by concrete-operational students and thereby provide some direction in the solution of classroom problems related to this incongruency.

Some studies investigated the possibility of raising level of intellectual development over a much shorter period of time than that suggested in Piaget's theory (Tomlinson-Keasey, 1972; Bredderman, 1973; Case, 1974; Lawson, Blake and Nordland, 1975; Linn and Their, 1975; Wollman and Lawson, 1978; Case, 1978). The general lack of success experienced in these studies changed research emphasis from attempts to promote intellectual development through short-term experiences to investigations of instructional methods designed to effectively teach concrete-operational students a functional understanding of formal concepts. Research in this direction has produced more promising results (Case and Fry, 1973; Talley, 1973; Howe and Mierzwa, 1977; Cantu and Herron, 1978).

The studies attempting to raise level of intellectual functioning with respect to particular reasoning patterns exemplified in Piagetian tasks involved short-term training of students in these tasks, either as small groups or individuals. The training was usually conducted under artificial conditions by individuals other than classroom teachers. For the most part, testing was limited to the tasks used in the training.

Only a few studies have been conducted with content other than that entailed in the various Piagetian tasks, and still fewer studies have been undertaken with regular science content under ordinary classroom conditions. The small number of naturalistic studies in such a potentially fruitful area of research indicate a need for similar studies investigating potential methods of effectively teaching formal science content under realistic classroom conditions.

However, those studies, whether experimental or naturalistic, that have been carried out to investigate the teaching of formal subject matter to concrete-operational students have produced controversial results. In a critical review of studies involving training concrete-operational students to perform in formal Piagetian tasks, Nagy and Griffiths (1979) claim that the lack of any evidence of retention or transfer in the majority of studies reviewed implies that meaningful learning of the trained tasks had not necessarily occurred in these studies, despite claims made by the authors. Herron et al (1976) cite a number of studies which they assert indicate that concrete instruction is not effective in assisting concrete students to develop an understanding of abstract ideas. Levine and Linn (1977), on the other hand, review a group of studies which they interpret as reasonably supportive of the concrete approach of teaching concrete-operational students an understanding of formal concepts and principles. Chiappetta (1974 and 1976) reports that not only is concrete instruction effective in teaching concrete-operational students abstract ideas but is also effective with formal-operational students who function below their formal capability when exposed to novel formal content. The discrepancy in the above reviews demonstrates that not only is there disagreement with respect to the research results obtained but that there is also a controversy in the interpretation of these results by others.

A number of highly relevant studies have been carried out under both artificial and naturalistic conditions. Some authors, on the basis of personal experience and empirical evidence, claim that concrete-operational students can be successfully instructed in formal science subject matter (Sheehan, 1970; Talley, 1973; Herron, 1975). Other studies, which were conducted under classroom conditions, claim success in teaching formal science content to concrete-operational students (Case and Fry, 1973; Linn and Their, 1975; Howe and Mierzwa, 1977). A naturalistic study by Cantu and Herron (1978), rated as a relatively sound study by Nagy and Griffiths (1979), provides strong evidence in support of concrete instruction as an effective means of teaching concrete-operational students an understanding of formal subject matter. Goodstein and Howe (1978), on the other hand, in another naturalistic study of equally sound design, report that concrete instruction is effective with formal-operational students but not effective with students operating at the concrete level. Although, in the majority of cases, the evidence resulting from the above studies generally supports concrete instruction, the specific results obtained vary considerably from study to study.

Clearly, evidence relating to the teaching of abstract ideas to students functioning at the concrete and formal levels, respectively, is rather inconclusive. This inconclusiveness signifies a need to further research the question of whether the acquisition of formal concepts is affected by the congruence between instructional treatment and the intellectual developmental level of the learner. Because of the relatively few studies conducted in the classroom, there is a further need that the above research be carried out under real classroom conditions. This type of study would provide evidence that would be more directly applicable to the problems encountered in teaching an understanding of formal science subject matter.

Purpose of the Study

The main purpose of the study is to assess, under naturalistic conditions, the effectiveness of two different modes (concrete and formal) of teaching formal science concepts to students classified as concrete, transitional and formal-operational thinkers. The study also includes an assessment of the effect of level of intellectual development on the attainment of these formal concepts, as well as the interactive effects between level of intellectual development and mode of instruction.

Procedure

A summary of the experimental procedures is outlined in this section. A more detailed report of these procedures will be provided in Chapter Three.

In preparing for the experiment, two units from the eighth grade level of a junior high school science program were examined. The major concepts comprising these two units were identified and systematically analyzed to determine the level of thinking required to understand them. On the basis of this analysis, each of the concepts isolated was classified as concrete-operational or formal-operational. Only the formal concepts were selected to form the academic content of the experiment.

The two instructional approaches employed in teaching these formal-operational concepts differed with respect to the degree to which concrete experiences were emphasized. The more formal method was used with the control group. Regular instruction was classified as the formal approach since it primarily involved classroom discussion and lecture rather than the use of concrete exemplars and experiences. The experimental group received the more concrete instruction. This approach was categorized as concrete because it was based on student activities involving guided manipulation of physical models of selected formal concepts.

Appropriate tests were conducted to determine each subject's level of achievement of these formal concepts, and also his or her level of intellectual development. The achievement tests were administered when instruction was completed for the concepts involved. Assessment of the relative effectiveness of the two instructional modes was based on mean group scores on these achievement tests. A test designed to measure the level of intellectual development of each subject was administered during the experiment. Scores on this test and on the achievement test were used to determine the relationship between level of intellectual development and instructional approach, and between level of intellectual development and understanding of formal concepts.

The developmental test was administered mid-way through the experiment. Technically, this was the wrong time to conduct such a test. If circumstances were conducive, this test would have been administered earlier. However, since researchers have not been very successful in their attempts to train formal operations, no significant change in level of intellectual development was anticipated to have occurred during the course of the study.

In accordance with the aim of conducting a naturalistic study, the formal concepts comprising the academic content of the experiment were selected from the prescribed science program in use at the grade eight level. These concepts were taught, using both methods, by the regular classroom teacher during regular class periods. There was no interruption in the sequence or progress of teaching the concepts as a result of the study, except that the teachers taught the units in reverse order to one another.

Definition of Terms

The following terms need to be defined in the context of study:

Concrete-operational concepts: These are concepts whose meaning can be obtained directly through the manipulation of objects or events, or through reference to familiar experiences. These include such concepts as cell, tissue, plastids, etc., when these concepts are defined in terms of or with reference to observable properties.

Formal-operational concepts: These are concepts whose meanings are developed not through the senses but "through position within a postulatory-deductive system," a term which "refers to the theoretical models (systems) of science" (Lawson and Renner, 1975). These include such concepts as diffusion and osmosis when defined in terms of imperceptible properties, as well as concepts like sound waves and energy which cannot be defined in terms of directly perceptible events.

Concrete instruction: The mode of teaching employed as concrete instruction was based on structured activities involving models developed by the researcher. The various activities included manipulation of these models which served as concrete representations of the phenomena being studied.

Formal instruction: The method of instruction normally followed by the regular classroom teacher was designated as formal instruction since the teachers involved in the study followed the prescribed science program which was deemed to be largely formal especially with respect to the use of abstract examples.

Achievement tests: Two written tests were constructed to examine the subjects' understanding of selected formal concepts from the two different topics involved in the study. These tests consisted of items developed to assess understanding at levels 2 (comprehension) and 3 (application) of Bloom's Taxonomy. Both tests are discussed in more detail in a later section.

Understanding: Understanding is indicated by the student's ability to select the most appropriate responses from multiple choice test items designed to examine comprehension and application of the concepts taught.

Developmental level test: This is a paper-and-pencil test, consisting of five neo-Piagetian tasks, constructed to determine the level of intellectual development of the students involved in the study. In constructing the test, it was assumed that no subjects were less than concrete-operational. This test is further discussed in a later section.

Delimitations of the Study

The following factors may jeopardize the external validity or representativeness of the study:

1. The sample was chosen from one school and therefore may not be sufficiently representative to allow generalization to the population of junior high school students in general. In addition, the results may not be generalizable outside of the junior high level participating in the study. Such factors as age, location, etc., of the sample may not be representative of other populations.

2. The particular content may not be typical of the content of school science courses in general. The results, therefore, may not be generalizable beyond the content of the study.

3. The duration of the experiment was such that the results produced may be specific to this particular time span. The same exper-

iment conducted over a longer or shorter time period may result in a totally different set of data.

4. The classification of students into different levels of intellectual development may be specific to the particular tasks used in the study. A different set of tasks for classifying students into concrete and formal levels of intellectual development may produce different results. As such, the results obtained may not be generalizable beyond the particular tasks used in the study.

Although it is necessary to recognize the potential confounding influences represented in the foregoing delimitations, there is no reason to suspect that the results obtained in the present study are not generalizable.

Limitations of the Study

The results of the study may be influenced by the following extraneous variables:

1. The students were not randomly assigned to the experimental groups since each group was composed of an entire intact class. Therefore, the researcher did not have experimental control over the initial equality of the experimental and control groups. However, statistical control was employed through analysis of covariance.

2. The reactive effects of experimental arrangements may confound the effects of the experimental treatment. The teachers were fully aware that they were involved in an experiment and may, therefore, have changed their behavior sufficiently to influence the results. However, the study avoided reactive arrangements with the students in that none

of the students were aware that they were part of an experiment, other than for the developmental testing.

3. There are potential interactions between method and subjects, and between method and teachers. The instructional procedures employed may be exceptionally effective or ineffective with certain kinds of students and certain kinds of teachers. The results obtained may, therefore, be specific to the particular students involved in the study or the particular teachers employing the instructional methods. Some control over this interaction effect was attempted through the inclusion of a second teacher and additional groups of experimental and control subjects.

4. The validity and reliability of the instruments employed in the study may have had some influence on the results. However, since the instruments used to measure academic achievement and intellectual developmental level were non-standardized tests, steps were taken to improve their reliability and validity through piloting and consultation with appropriate specialists.

Research Questions and Hypotheses

The study was conducted to provide answers to the following three questions:

1. Does the developmental level of instructional treatment affect the achievement of formal concepts?
2. Does an individual's intellectual developmental level affect achievement of formal concepts?

3. Do developmental level and level of instructional treatment interact to affect the achievement of formal concepts?

In accordance with the questions raised above, three statistical hypotheses were tested. Based on the research evidence available, these hypotheses were stated in the null form as follows:

1. There will be no significant difference in achievement test scores between subjects receiving concrete and formal instruction, respectively.
2. There will be no significant difference in achievement test scores between subjects at different levels of intellectual development.
3. There will be no significant interaction between level of instruction and level of intellectual development with respect to students' performance on the achievement tests.

Summary

The chapter began with a brief discussion of Piaget's model of intellectual development, with emphasis on the reasoning patterns characteristic of the concrete and formal stages and their implications for classroom instruction. This theoretical background to the study was followed by the establishment of the need for further research into the effectiveness of a concrete instructional approach in teaching formal science concepts to intact classes containing a substantial population of concrete-operational thinkers. The next section outlined the purpose of the study as the investigation of the need demonstrated in the previous discussion, while the following section briefly described the procedures involved in conducting this investigation. Consideration of the delimitations and limitations of the study arising from the procedures was followed by the final section containing statements of the questions and hypotheses.

Overview

In the next chapter, the related research will be presented in an organization which shows the development of research in science education which is related to the Piagetian model. Chapter Three discusses the design of the study, the procedures followed in applying the design and the instruments used to collect the appropriate data. These data are analyzed in Chapter Four using analysis of covariance as an appropriate statistical technique. Finally in Chapter Five, the results of the analyses are summarized, appropriate conclusions based on these results formulated and the implications of the results discussed.

Chapter 2

A REVIEW OF RELATED RESEARCH

This chapter will consist of four sections. The first section reports on analyses indicating the conceptual level of high school science programs. Although some of the studies included in this section involve subject matter from senior high school science courses, it was decided to include them in the review since a large portion of the content concerned is frequently included in junior high level courses. The second section reviews studies that have investigated the level of intellectual development of high school students. This section emphasizes studies dealing with junior high school students. However, there are some studies reported involving senior high school and college students. These studies are included as relevant only in the sense that junior high school students would be expected to be even less developed. The third section summarizes research on the relationship between intellectual developmental level and achievement in science. The final section reviews studies that have endeavoured to train concrete-operational students formal Piagetian tasks and other formal concepts and principles.

Analyses of the Conceptual Level of Typical Science Content

In view of Piaget's contentions and the various research supporting his ideas, educators have become concerned over the level of thinking required to understand the concepts constituting high school science curricula. In examining the concepts comprising these curricula, many educators have concluded that the majority are formal.

This view is supported by the findings of Karplus (1977) in an analysis of a number of typical concepts from various science curricula. In a position paper dealing with the interpretation of Piaget's theory and its application to science teaching, Karplus examines nine concepts that are usually included in junior high school science courses: density, temperature, cell, gene, environment, chemical bond, periodic system of elements, acid-base, and ideal gas. His assessment reveals that five of these concepts "can only be defined in terms of other concepts, abstract properties, theories, and mathematical relationships" and as such require formal reasoning patterns for their understanding. The other four can be defined either as formal concepts or "in terms of familiar actions and examples." In the latter case, all four would be classified as concrete. However, it is the formal significance of these concepts that is frequently emphasized.

Herron (1975) lists sixteen competencies, commonly expected of students, which he claims can be successfully learned by students who are not formal-operational, and contrasts these with related "formal" extensions which cannot be meaningfully learned by students who are not operating at the formal stage. Herron suggests that it is the performances requiring formal thought that receive most attention in the classroom.

Lawson and Renner (1975) arrived at a similar conclusion in a study conducted to determine the relationships of science subject matter and the developmental levels of learners. As a part of their study, the authors isolated the major concepts from three different science programs (biology, chemistry and physics) and systematically classified them as concrete or formal. In the summary and conclusions section of their report, they state that "the majority of the concepts taught in the three science disciplines were categorized as formal."

In an analysis of the conceptual demands in Nuffield O - level chemistry, a course for 11 to 15 year olds, Ingle and Shayer (1971) discovered that many of the topics either require early formal reasoning (3A) or fully formal reasoning (3B), and that during the first part of the course "the proportion of high level concepts rises steadily" while the second part of the course is sustained at a high conceptual level. The authors claim that the high level concepts are introduced in the course at a time when they are not accessible to most students. As the students become older and develop intellectually, some of the topics become accessible, but many students never develop the intellectual capacity to comprehend these concepts.

In another report, Ingle and Shayer mention the mole concept as one of the many concepts causing much difficulty at the 'O' level. The authors indicated that the reason for this is that students need to be fully formal-operational before they can completely and meaningfully comprehend this concept. Novick and Menis (1976) and Hudson (1976) also subscribe to this opinion.

If formal reasoning is indeed necessary for the understanding of many concepts typically taught at the junior high school level, then the curriculum is only suitable for students functioning at the formal stage of intellectual development. The crucial question is what proportion of junior high school students are functioning at this level of intellectual development. The answer to this question is encompassed in the evidence provided in the next section.

Intellectual Developmental Level of High School Students

Numerous studies have investigated the developmental level of high school and college students, using different combinations of neo-Piagetian tasks in a variety of different ways (Karplus and Peterson, 1970; Kohlberg and Gilligan, 1971; Renner and Stafford, 1972; Wollman and Karplus, 1974; Karplus, Karplus and Wollman, 1974; Nordland et al, 1974; Lawson and Renner, 1975; Lawson, Blake and Nordland, 1975; Sayre and Ball, 1975; Lawson and Blake, 1976; Chippetta and Whitfield, 1976). Although the proportion of concrete and formal students varied, the studies were consistent in classifying the majority of students as concrete-operational. Only a small percentage were categorized as exhibiting formal-operational thought. Even those students who have the potential to function at the formal-operational level frequently regress to a lower level when exposed to formal science content (Chiappetta, 1976). The studies listed above will now be described in more detail beginning with studies involving primarily junior high school students followed by senior high and college studies.

Kohlberg and Gilligan (1971), in a paper relating to intellectual development, report the findings of a study conducted to determine "the percentage of persons at various ages showing clear formal-operational reasoning on the pendulums task." The study reports that only 45 percent of the sample of 265 students, ages 10 to 15, showed formal-operational reasoning. In another problem, a correlation problem, this level of reasoning was displayed by even fewer students.

Lawson and Renner (1975) cite nine recent research reports indicating that between 40 and 75 percent of junior and senior high school students failed to reach formal-operational thought.

Sayre and Ball (1975), in a study conducted to investigate the relationships between science achievement and intellectual development, classified only ten percent of the grade eight students involved in the study as formal-operational.

Nordland et al (1974) investigated the level of reasoning of 96 grade seven students. These students were randomly selected from a junior high school serving primarily a black and Spanish-American urban area. The students ranged in age from 11.7 to 12.6 years. Ten Piagetian tests were presented to each individual in an interview type situation. Based on their responses to these tasks, 84.4 percent were classified as concrete-operational and 15.6 percent were classified as formal-operational.

Wollman and Karplus (1974) investigated the intellectual development of 450 seventh and eighth graders from two schools in Orinda, California. The students were administered six problems requiring proportional reasoning for successful completion. Only 15 percent of the sample demonstrated formal-operational thought in their response to these problems. Wollman and Karplus state that they obtained similar findings in an earlier study conducted with 173 eighth graders.

Karplus and Peterson (1970) administered their Mr. Tall - Mr. Short task to 727 subjects in intact classes. Its purpose was to determine the students' ability to apply the ratio concept, considered by many as an important component of formal-operational thought. The students ranged in age from 9 to 18 years and in grade level from four to twelve. According to the findings, proportional reasoning does not occur until the last few years of high school. Eighty percent of the students in grades eleven and twelve exhibited proportional reasoning. Very few students below grade eleven were successful. Even when these students were provided with "cues" they were still not successful with the task.

Karplus, Karplus and Wollman (1974) administered another version (form B) of the ratio task to 616 students from urban and suburban schools located in the San Francisco Bay Region. An analysis of student responses to the task revealed that approximately 16 percent of the grade eight and nine students were able to apply the ratio concept on the level of formal thought. The percentage was substantially less for the lower grades.

Renner and Stafford (1972) examined the level of intellectual development of 298 junior high school students (grades seven, eight and nine) from various schools scattered throughout the state of Oklahoma. Six Piagetian tasks were administered on an individual basis. According to these interviews, 77 percent of the sample was classified as concrete-operational, 13 percent as post-concrete-operational, and six percent formal-operational.

Renner and Stafford (1972) also assessed the intellectual development of 290 senior high school students (grades ten, eleven and twelve) enrolled in schools throughout the state of Oklahoma. Again, the students were interviewed on six Piagetian tasks. Based on these interviews, 66 percent of the high school students were classified as concrete, 17 percent post-concrete and 14 percent formal.

Lawson and Blake (1976), in a study to determine whether Piagetian tasks were "content free," used three separate instruments to measure the reasoning abilities of high school biology students. A sample of 68 students was selected from a high school, located in north central Indiana, with a total population of 800 students. The subjects ranged in age from 14 years, 7 months to 17 years, 5 months, with an average age of 15 years, 5 months. One of the instruments consisted of a battery of Piagetian tasks. The other two, designed to evaluate level of reasoning ability, were referred to in the study as the biology examination and a non-science-content examination. On all three instruments, one-third demonstrated concrete-operational thought while one-fifth showed formal-operational reasoning. The remainder showed advanced concrete and early formal reasoning in a mixed pattern.

Lawson and Renner (1975) classified 133 high school students into levels of intellectual development in a study conducted to investigate the relationship between science subject matter and the developmental level of the learner. The subjects were selected from a school in Norman, Oklahoma with a total population of over 2,000 students. Fifty-one were randomly selected from the biology classes, 50 were similarly selected from the chemistry classes and all 33 from the only physics class were selected. To measure the intellectual developmental level of these students, four Piagetian tasks were administered in an interview type setting. Only 4.8 percent of the sample of 134 students were considered to be reasoning at the formal-operational level.

Lawson, Blake and Nordland (1975) attempted to train 65 high school biology students, ranging in age from 14 years, 7 months to 17 years, 10 months, to control variables. The Longeot test of logical operations was administered to determine level of intellectual development. According to performance on this test, 15 percent of the sample was classified as early concrete (11A), 42 percent as fully concrete (11B), 35 percent as early formal (111A), and eight percent as fully formal (111B). Lawson (1973) also reports similar results in his classification of a sample of high school biology students using a battery of four Piagetian tasks. He found that 18 percent were functioning at the early concrete level (11A), 47 percent at the fully concrete level (11B), 33 percent at the early formal level (111A), and two percent at the fully formal level (111B).

Chiappetta and Whitfield (1974) assessed the intellectual development of a group of 26 seniors from a high school in a suburb of Houston, Texas. The sample was selected from three academic tracks (vocational, general and college preparatory). Each individual subject was interviewed on three Piagetian tasks. Of the general group, 53.8 percent were categorized as concrete, while 46.2 percent were categorized as formal. Twenty-seven percent of the college preparatory group were classified as concrete while 73 percent were classified as formal.

Surprisingly, college level students are not much more advanced in reasoning ability than high school students. Research conducted on freshman college students reports approximately 50 percent as concrete-operational, 25 percent as transitional, and 25 percent as formal (McKinnon and Renner, 1971; Lawson and Renner, 1974).

In summary, most junior and senior high school students, as well as a large percentage of college level students, are not classified as formal-operational on Piagetian and neo-Piagetian tasks. A large proportion of these students operate at the concrete level of intellectual development.

If the above findings are generalizable, then the majority of junior high school students are concrete-operational and therefore, if one accepts the Piagetian model, may not be capable of understanding many of the concepts included in the present junior high school science curricula, since most of these appear to be formal-operational. This incongruency has led researchers to investigate the relationship between level of intellectual development and achievement in science. The following section reports the results and conclusions of these studies.

Relationships Between Intellectual Development and Science Achievement

The relationships between intellectual development and science achievement have been investigated in relatively few studies. Generally, the evidence produced supports the hypothesis that formal-operational students achieve a better understanding of science concepts than concrete-operational students. In addition, some research results also indicate that formal-operational students perform below their capacity on test items requiring formal-operational thought (Lawson and Renner, 1975; Sayre and Ball, 1975; Lawson and Blake, 1976). Chiappetta (1976) speculates that this regression occurs when students are confronted with novel subject matter. He believes that sufficient experience with the new subject matter results in students returning to their general level of intellectual development.

Raven and Polanski (1974) conducted a study to investigate the relationships among Piaget's logical operations, science content comprehension, critical thinking, and creativity. The procedure involved the administration of a battery of seven tests to 111 fourth grade students and 109 sixth grade students. These tests were designed to measure the degree to which each subject possessed the above characteristics. The relationships between the various measures were determined by correlation and regression techniques. Among other findings, the authors report a substantial correlation (0.62) between scores on the instruments employed to measure science content comprehension and the intellectual development levels of the learners as measured by a neo-Piagetian test. A regression analysis showed that 40 percent of the variance in the science content comprehension scores was explained by the level of intellectual development scores. Level of intellectual development also accounted for a substantial fraction of the variance in the scores on other tests.

Lawson and Blake (1976) investigated the relationships between achievement in biology subject matter and the developmental levels of 68 high school students. These students had a mean age of 15 years, 5 months and attended a rural high school in the Midwest. In classifying them as concrete or formal, two instruments were employed. One of the instruments consisted of three neo-Piagetian tasks (Pendulum, Balance, and Rods). The other instrument was a biology subject-matter test comprised of 13 items. This test was designed to evaluate student performance on concrete and formal items relating to material taught in a two-semester biology course. The analysis of the subjects' performance on these two instruments showed that there was a significant relationship between level of intellectual development and achievement in biology. However, some of the students who performed as formal on the developmental test (53 percent classified as formal) regressed to a lower level on the subject-matter examination (only 35 percent rated as formal). Some students apparently did not maintain formal reasoning patterns when confronted with certain subject matter.

Sayre and Ball (1975) conducted an investigation of the possible relationships between scholastic grades in science of junior and senior high students and their ability to perform five neo-Piagetian tasks. Four hundred and nineteen students were randomly selected from a population comprising a school district in Colorado, United States. Two hundred and fourteen junior high students were selected from the various science classes in grades seven, eight and nine, while 205 were selected from the grade ten, eleven and twelve science classes. The authors report a significant relationship (at the 0.01 level) between scholastic grades and ability to perform on the formal-operational tasks, both for the junior high students ($r = .33$) as well as the senior high students ($r = .46$).

Lawson and Renner (1975) also investigated the relationships between science achievement and the intellectual developmental level of the learner. Their sample included 51 biology, 50 chemistry and 33 physics students selected from a high school of over 2,000 students. The school was located in the southwestern United States. Six neo-Piagetian tasks were administered to determine level of intellectual development. On the basis of the tasks, the students were categorized into seven different levels of intellectual development: concrete substage 11A, concrete-transitional, concrete substage 11B, post-concrete, formal substage 111A, transition formal, and formal substage 111B. A multiple choice achievement test was developed for each subject area and administered immediately following the categorization of subjects. Each subject matter test consisted of two parts of 15 items each. One section of the test evaluated concrete-operational science concepts while the other section evaluated formal-operational science concepts. The results shows that, overall, formal-operational students achieved significantly higher scores than students classified as concrete-operational. Early concrete-operational students did not demonstrate an understanding of either concrete or formal concepts. Other concrete-operational students showed some understanding of concrete concepts but no understanding of formal concepts. Formal-operational students, on the other hand, achieved an understanding of both concrete and formal concepts. Generally, as level of intellectual development increased, the number of concrete and formal items answered correctly increased.

Whereas the previous studies investigated the relationship between general level of intellectual development and achievement in science, two studies which follow investigated the relationship between the attainment of a particular formal-operational reasoning pattern and science achievement. One of these studies was conducted by Lawson and Nordland (1977). They investigated the relationship between level of reasoning in a particular area and achievement in biology, by relating the subject's ability to conserve to his or her performance on achievement tests consisting of items classified as requiring either concrete or formal thought. Twenty-three BSCS biology students (20 male and three female), of above average intelligence, participated in the study. The student's ability to conserve was measured by three tasks administered at the beginning of their semester of study. Achievement of the content and skills taught was assessed by six biology tests administered during the course of the semester. The achievement scores of three groups of students at three different levels of conservation reasoning were analyzed by one-way analysis of variance. The difference between the groups was significant at the 0.10 level. The authors claim that these results support a relationship between ability to conserve, as indicated on certain Piagetian tasks, and achievement in biology. However, even those subjects who could correctly perform all three conservation tasks only scored an average of 22.4 percent on the formal test items.

Wheeler and Kass (1977) studied the relationship between proportional reasoning and achievement in science with a sample of 168 grade ten chemistry students. The proportional reasoning ability of the subjects was assessed by three different instruments. These included a test consisting of four neo-Piagetian written tasks, a general proportionality test and a chemistry test were administered to the students before they began their course of study. During the course, they were given the test of proportionality in chemistry. This test consisted of subtests which were administered after the appropriate study of the relevant subject matter was completed. The subtests were comprised of items analogous to items included in the general proportionality test. At the end of the course, another general proportionality test (equivalent to the previous test) was administered in addition to a general achievement test evaluating the whole course. The analyses of the various scores indicate a high correlation (0.76) between subject performance on the proportionality test in chemistry and scores on the chemistry achievement test. Only moderate correlations (0.48 and 0.41) were found between the scores on the other two tests and overall achievement in chemistry. In contrast to the above studies, two studies relating to students in first year college (Reminsky, 1979) and high school chemistry courses (Griffiths and Kass, 1979) found low correlations of 0.31 and 0.09 to 0.36, respectively, between science achievement and developmental level.

Although the empirical evidence is variable, most of the studies reviewed above indicate a significant relationship between level of intellectual development and achievement in science. These studies have found that under regular instructional procedures (expository type teaching) formal-operational students perform significantly better than concrete-operational students. Also, research results indicate that under some circumstances, formal-operational students regress to a lower level of reasoning. Thus, based on the evidence available on the level of reasoning of most junior high school students, the level of concepts comprising most junior high school curricula, and the relationship between level of intellectual development and science achievement, junior high school students are often confronted with concepts that appear to be beyond their level of comprehension. According to Herron (1975), "we can skirt the problem if we can make what we are trying to teach accessible to those students who are not formal thinkers and we can overcome it if we can encourage and assist students in becoming formal." The next section focuses primarily on empirical evidence and "armchair" suggestions relative to Herron's suggestion.

Teaching Concrete-Bound Students an Understanding of Formal Concepts and Principles

In a number of studies attempts have been made to train non-formal students in specific Piagetian formal tasks. Although the evidence produced is inconclusive, some indication is provided concerning the possibility of teaching concrete-operational students a functional understanding of formal science subject matter. Suggestions of concrete instructional approaches to accomplish this task have been outlined by various writers. Studies have been undertaken to examine the effectiveness of providing concrete treatment of formal content to concrete-bound students. These studies will be reviewed in the latter part of this section. First, some reviews of training studies will be presented followed by suggestions of effective means of teaching formal science subject matter to students who are not formal.

Studies in which attempts were made to train younger students to conserve quantities have been extensively reviewed by Brainerd and Allen (1971) and Beilin (1971). According to the reviewers, these studies indicated some success in training students on particular tasks but were generally not successful in promoting transfer to novel problems.

There have been a number of reviews of training studies conducted with older students. Levine and Linn (1977), in a review of such studies, most of them involving training on Piaget's controlling variables task, found it very difficult to draw definite conclusions. Some of the findings that they claim were reasonably consistent are listed as follows:

(1) Training promotes performance on the trained tasks.

(2) Appropriate presentation of strategy improves older students' performance on a task while younger students need the strategy accompanied by apparatus.

(3) Various means of motivating students, such as cognitive conflict, do not promote student performance.

(4) The teaching of strategies is not as important as teaching an effective means of recognizing and organizing relevant information.

Based on these findings, the authors suggest that the studies reviewed indicate that logical thinking improves under certain conditions. Since most of the studies reviewed did not test for retention or transfer, Levine and Linn apparently accept the gains from pre-testing to post-testing as indicative of the development of reasoning ability. Others, however, have clearly shown that such gain may not be evidence of improvement in reasoning ability but merely the results of a "testing effect" (Lawson, Nordland and Devito, 1974).

Herron et al (1976) disagree with studies claiming to have dramatically increased developmental level through training on particular formal Piagetian tasks. They argue that intellectual development cannot be accelerated through such short-term experience. Such experiences, although they may be effective in promoting intellectual development over a longer period of time, do not substantially change the level of reasoning of an individual; that is, will not cause a student to change stages. The authors claim that most of the training studies support their stand, in that their results show gains on a post-test closely related to the training but no gains on retention or transfer tests, where such tests have been employed.

Nagy and Griffiths (1979), in a critical review, condemn the majority of training studies not only for their failing to test for retention and transfer, but also for their methodological inadequacies. Only three of the studies reviewed by these authors were considered acceptable with respect to the reliability of the evidence they provided relating to the teaching of formal concepts and principles to concrete-operational students, and the results of these were in disagreement.

The studies included in the present review were selected on the basis of analyses by others and a preliminary examination of actual research reports. Only those studies considered reasonably well conducted and relevant to the present study will be reported. However, before commencing the review, "armchair" suggestions concerning the teaching of formal science concepts in an ordinary classroom setting will be presented. Most of these suggestions have been applied in the studies included in the review.

Lawson and Blake (1976) suggest that what is needed for concrete-operational students to transcend their concrete mode of thinking is interaction with carefully designed and sequenced concrete exemplars of the formal-operational notions to be taught. In interacting with these concrete exemplars, the authors suggest that the students be provoked to reflect upon their concrete experiences. This reflection should be aimed at promoting a meaningful understanding of the underlying concepts. Only when a sufficient number of concrete exemplars are used for a particular formal notion, they say, will this "reflective abstraction" occur.

Ausubel (1963) recommends concrete-empirical experiences as an effective means of teaching concrete-bound students an understanding of propositions that are basically formal. He suggests that models, employed as concrete-empirical props, are useful in teaching the theoretical concepts underlying these propositions. Primarily, these models provide for a semi-abstract or intuitive type of learning which, according to Ausubel, may serve as a basis for more in-depth learning later when the student has advanced to a desirable level of readiness.

Herron (1975), even though he believes that concrete-operational students cannot acquire a complete understanding of formal concepts, suggests that appropriate instruction will promote meaningful learning of theoretical science content as opposed to the rote learning that is presently so widespread. He contends that we can teach them "surrogate" concepts through extensive concrete experiences based on visual or concrete props such as models. According to Herron, these concepts, which serve as substitutes for real concepts, will assist students sufficiently in dealing with most of the problems posed in class. Further, the possession of a "surrogate" concept will make it easier for later development of the real concept. In accordance with Lawson and Blake (1976), Herron proposes that a variety of experiences may be necessary in the development of the "surrogate" concept. He also agrees with Ausubel (1963) in explaining that the student develops an intuitive grasp of the abstract concept based on the appropriate experiences, and uses this learning later to develop a more advanced understanding of abstract phenomena.

In a review of Piagetian related studies, Chiappetta (1976) argues that teaching, content, and assessment should match the concrete level of intellectual development of the majority of students and emphasize real objects and events on a first-hand basis. Strauss (1972), however, specifies a certain level above the student's intellectual structure at which the presentation of information is most effective both for intellectual development and learning. Shayer (1973), on the other hand, believes that no approach will be effective and that we should eliminate instruction in formal content altogether, at the school level. Thus, suggestions concerning the teaching of formal subject matter are varied. Although studies relating to these suggestions also vary, they are generally concerned with investigating possible methods of effectively teaching theoretical notions to concrete-bound students.

The remainder of this review is arranged in chronological order. The first study considered was conducted by Sheehan (1970) to investigate the effectiveness of concrete and formal instructional procedures with concrete and formal-operational students. A random sample of 104 students, ranging in age from 12 years, 6 months to 13 years, 5 months, was selected to participate in the study. The subjects were classified as concrete or formal according to tests developed by Longeot to measure level of intellectual development. Instructional procedures were based on the reasoning characteristics distinctive of each stage. Concrete instruction included real concrete material and/or events used in situations involving consideration of one variable at a time, non-hypothetical statements and non-deductive reasoning. Formal instruction, on the other hand, included propositions and hypothetical statements, deductive reasoning and a consideration of all possible variables. The effects of these instructional procedures were determined by administering a pre-test, post-test and post-post-test. These tests measured the students' understanding of equilibrium in the balance bar, of angles of incidence and reflection, and of the oscillation of a pendulum. Based on an analysis of the scores on these tests, Sheehan arrived at four general conclusions:

1. Formal-operational students showed greater achievement than concrete-operational students regardless of whether the instruction is presented through a concrete or formal mode.

2. Concrete instruction was more effective than formal instruction with either concrete-operational or formal-operational students.

3. Achievement was more durable for the formal-operational students than for the concrete-operational students with either the concrete or formal instruction.

4. Formal-operational students maintained post-test scores on test items designed to investigate the ability to generalize.

The next two studies were analyzed by Nagy and Griffiths (1979) in a review mentioned earlier.

In a relatively long training program, Case and Fry (1973) attempted to train a group of students to control variables by having them design controlled experiments and criticize experiments that were poorly controlled. The subjects consisted of 15 low socio-economic 14-year-old high school students who had not reached Piaget's formal stage on the controlling of variables task. The instructional program involved 12 training sessions, each of 40 minutes duration. The subjects were provided with written material as well as apparatus to manipulate. The written material involved presenting the students with a "fact-explanation" argument and requested the students to suggest a counter explanation which would account for the facts in an equally acceptable way. Following these written exercises, they were provided with apparatus and asked to design experiments so that no counter explanation would be possible. In addition, the subjects were asked to criticize written experimental reports by constructing alternative explanations for the results described. On a non-standardized paper and pencil post-test involving controlling variables and criticizing experiments, the experimental group did significantly better ($p < .001$) than the matched control group. The authors were cautious with respect to the interpretation of the results obtained, but they suggest that the results may offer some guidance with respect to an appropriate instructional approach in a similar setting. However, Nagy and Griffiths (1979) criticized the study on several grounds. First, it was severely criticized because of inadequate design and failure to test for retention and transfer. Further, the study was considered inadequate because of its small sample size, the creation of the control group through matching, and an experimental treatment involving giving the experimental group a sample exam.

Bredderman (1973) also studied the effects of training on ability to control variables. Twenty-six fifth and sixth graders who were not able to control variables on a pre-test were selected for the study. The subjects were divided into three groups. One group served as the control and did not receive any training. The second group was trained on the controlling variables task using external reinforcement. The third group was trained on the same task using cognitive conflict. On a post-test, the experimental groups scored slightly higher than the control. However, on a retention test one month later there was no significant difference in the scores, although the mean scores of the control group and the experimental groups were significantly greater on the retention test than on the pre-test. The author interprets this result as supportive of Smedslund's finding that behavioral changes are not necessarily dependent on external reinforcement. The test scores were further analyzed to determine the students' level of intellectual development. On the basis of this analysis, students were determined to have progressed considerably during the course of the study. Half of the students age 11.8 years were found to have progressed from late concrete and early formal in their ability to control variables to early formal and late formal. It was noted that this level was reached by Piaget's subjects at about 14 or 15 years of age. The author concluded, from this result that it is possible to raise some fifth and sixth grade students' level of reasoning on the controlling variables task, while others are unaffected regardless of whether the training is based on external reinforcement or cognitive conflict.

Talley (1973) had students construct models of reactants and products represented in all chemical equations dealt with in class in an effort to promote higher cognitive learning of abstract chemistry concepts. His sample consisted of 102 college students enrolled in a freshman level chemistry course. To test his hypotheses, he divided a semester's work into seven units and exposed two groups to the same content and units. The experimental group received the treatments (models) and the control group received regular instruction (didactic).

Tests were given at the end of each unit. Each test consisted of sections designed to evaluate different levels of cognitive learning. The author found that the experimental group performed significantly better than the control group on all the tests. However, after the first two units, the control group scored significantly higher than the experimental group on the knowledge level sub-test items. On other level sub-test items (application, analysis, synthesis and evaluation), the experimental group performed at a consistently higher level than the control group.

An elementary science program referred to as Science Curriculum Improvement Study (SCIS) has been designed to promote logical thinking ability. Linn and Thier (1975) did an extensive investigation into the development of logical thinking ability of fifth grade science students instructed in an upper-level unit (Energy Sources) of SCIS, involving separating and controlling variables. These students were taught via the SCIS learning cycle which is based upon Piaget's notion of equilibration. The instructional procedures constituting this cycle are as follows: (a) first the students are given a chance to try out their own ideas with the apparatus provided, (b) then the students are exposed to a strategy, and (c) eventually the students are given an opportunity to test the strategy with new apparatus. An analysis of the thinking ability of the students involved in the investigation showed that the experimental group was much more advanced than a control group consisting of fifth and eighth graders who had not studied SCIS. The reasoning ability of the experimental group approached that of the group of grade eight students. Nagy and Griffiths (1979) criticize these comparisons as unfair since the control groups were often not involved in any science at all and, as such, any activity-oriented science program might have produced the same results.

McIntyre and Reed (1976) conducted a study to investigate the relative effectiveness of three different types of visual devices, based on Bruner's modes of representation (through action, imagery and language), in teaching electrostatics to elementary school children. Six classes of students were randomly selected from a population of 19 grade four classes. Three different treatments were randomly assigned to three groups comprised of two classes each. The three groups were instructed with three different visual devices for a five-week period. A test was developed as part of the study to evaluate the achievement of each class. It was found that the different visual devices used were equally effective in teaching the theoretical concepts encompassed in electrostatics. McIntyre and Reed conclude that it is feasible to teach basic science concepts to fourth grade students to the extent where they can comprehend and apply these concepts. They suggest that the ability of students to function effectively with abstract concepts depends to a large extent on the quality of instruction. As such, they say, instruction need not be limited to physical objects. Sometimes pictures and symbols are just as effective. Novak (1976), in an editorial comment, claims that the work by Milton Pella, Patrick McIntyre and others shows that children can acquire abstract concepts well before they reach the stage of Piaget's formal operations, provided that appropriate instruction is offered and evaluation is related to that instruction.

Lawson and Karplus (1977), in a paper discussing the question of whether or not abstract concepts should be taught before the development of formal operations, severely criticize the McIntyre-Reed article with respect to the operational level of the achievement test, intellectual development test, and the reasoning level of the instructional approach employed in their research. They argue that because of serious weaknesses in these areas, the research does not show that abstract content can be taught to non-formal-operational students. They claim that students who are not formal-operational will not develop a meaningful understanding of theoretical concepts and principles. They strongly assert that "without the development of formal operations that include probabilistic reasoning, combinatorial reasoning and correlational reasoning, students can only accept statements about theoretical concepts as facts which to them must appear to have been asserted by authority."

If non-formal-operational students are not able to develop a meaningful understanding of abstract concepts and principles, can their level of reasoning be promoted in the particular area of concern so that they are able to cope? As previously mentioned, this question has been investigated by a number of training studies but, because of their weaknesses, the evidence they provide is rather unreliable and inconclusive. In a more recent and better attempt, Howe and Mierzwa (1977) conducted research to investigate this possibility. The purpose of the research was to determine whether the level of reasoning of a group of low socioeconomic status high school students, as indicated by a task on controlling variables, could be increased by a series of lessons under ordinary classroom conditions. The sample for the study consisted of 62 subjects, comprising three heterogeneous classes, with an average age of 13.3 years. The instructional procedure emphasized conceptually based classroom instruction with cognitive conflict as the major teaching strategy. Three different forms of the controlling variables task were employed as the pre-test, post-test and the retention test. The authors found that the instructional approach used significantly increased the level of reasoning of disadvantaged urban eighth grade students on the controlling variables task and that the ability was retained over a six-week period. The researchers do not claim to have promoted students to another stage of intellectual development. They interpret the results as showing that student performance improved substantially on the controlling variables task as a result of the instructional approach emphasizing the principle of controlling variables and using cognitive conflict as a teaching strategy.

Goddstein and Howe (1978) investigated the effect of teaching a formal-operational concept (stoichiometry) to a sample of high school chemistry students by using concrete exemplars and models of atoms and molecules. Two intact classes were designated as experimental groups and given the concrete treatment while two other classes, who were not taught through concrete exemplars and models, served as controls. At the end of the instructional period, two questions were included in the usual unit test to determine qualitative understanding of stoichiometry. The scores on the test were analyzed by means of the chi-square statistic. The analysis showed that only the upper-formal level students benefited from the concrete-based instruction. It was also found that, in the experimental group, students at the higher developmental stage achieved a higher level of understanding. However, there was no discernible relationship between level of intellectual development and level of understanding detected in the control group. On the basis of these results, the researchers concluded that

> . . . the study supports the use of concrete exemplars in the teaching of stoichiometry to formal-operational students but leaves open the question of how to improve instruction in this topic for the concrete-operational thinkers who make up a large portion of the student body. Confirmation and generalization of our findings must await replication of this study as well as further research on the use of concrete exemplars for other topics in introductory chemistry. .

Cantu and Herron (1978) investigated the use of exemplars for other topics in chemistry. In their approach they employed the concept analysis technique to determine the critical and variable attributes of the concepts to be taught. In teaching these concepts, they used examples and non-examples to illustrate the critical and variable attributes of concrete concepts, and pseudo-examples and non-pseudo-examples to focus attention on the attributes of the abstract concepts. Thus, a relatively concrete approach was applied with both levels of concepts.

Twelve concrete-operational and 16 formal-operational students participated in the study. The subjects were randomly selected from a population of 137 high school chemistry students (mean age of 16.25 years) enrolled in a high school with a population of 800 students. These subjects were taught concrete and formal concepts over a six-week period. They were post-tested at the end of each 12-minute lesson (one lesson on each concept per week) and were given a retention test three weeks following the end of instruction. The authors concluded that (a) one should expect greater achievement from formal students than concrete students, no matter what the level of the concepts; (b) even though formal students perform at a higher level than concrete students on concepts at each level, concrete students perform satisfactorily on concrete concepts; (c) the use of pseudo-examples to illustrate critical attributes enhances the achievement of formal concepts no matter what the level of cognitive development; and (d) based on the information available, no instructional approach will close the gap in achievement between concrete and formal students. Since this is the case and since many concepts in science are formal, Cantu and Herron assert that we should strive for instruction that promotes the development of formal reasoning.

Summary

In summary of the studies reviewed in the present chapter, it appears that: (1) content analyses of junior high school courses show that they are highly formal; (2) the categorization of junior high school students indicates that the majority are concrete; (3) empirical evidence indicates that there is a relationship between intellectual developmental level and achievement in science; and (4) empirical evidence concerning the effectiveness of teaching formal science subject matter to concrete-operational students is scarce and inconclusive. Some of the studies which have been successful in this endeavor used models as concrete props in conjunction with an appropriate instructional strategy. This study further investigates the use of models in teaching formal-operational science content in a concrete-operational manner.

The methodology employed to investigate this instructional approach is described in the next chapter.

Chapter 3

DESIGN, INSTRUMENTATION AND PROCEDURE

The selection of the school and subjects for the study occurred long before the actual experiment commenced. This was necessary in order that the participating teachers might be contacted for information concerning the topics they planned to teach and the approximate dates this subject matter would be taught. Once this information had become available, a decision was made, in cooperation with the teachers involved, as to which content would be included in the experiment. Following this decision, the major concepts comprising the two topics chosen were analyzed and classified as concrete or formal. Some of the formal concepts from both subject areas involved were selected, their variable and critical attributes (Herron et al, 1977) determined, and a physical model constructed for each concept based upon these attributes. An instructional strategy, designed to provoke the students to think about their manipulation of the apparatus, was employed in teaching the concepts to the experimental classes.

Four intact classes of heterogeneously grouped eighth-grade students, who would study the content in the two areas selected, were chosen as subjects for the study. Two teachers cooperated by instructing two classes each in the subject areas selected, using a relatively concrete instructional approach with the experimental class and a more formal approach with the control class. Both teachers participating in the study covered the same two areas of subject matter but at different times. They began with two different units and exchanged at approximately half-way through the experiment.

Also, at about midway through the experiment, a battery of five neo-Piagetian tasks was administered in group form. The subjects' written responses to these tasks were scored and the subjects classified into levels of intellectual development according to their scores. Details of this classification are given in Appendix B.

Two achievement tests were developed in order to evaluate understanding of the formal-operational concepts from the respective subject areas taught during the study. At the end of the first and second phase of the experiment, each teacher administered the relevant test to both experimental and control classes. Scores on these instruments were used to test the hypotheses stated in the first chapter. The statistical technique used to analyze the scores is described in the final section of this chapter.

Population and Sample

A junior high school was selected from the city of St. John's for involvement in the study. A total of 161 subjects, comprised of four classes of eighth-grade science students, and two eighth-grade science teachers were chosen from this school to participate in the experiment. Because of the naturalistic approach of the study, these classes remained intact during the entire experiment. Since the researcher could not identify any major confounding factors, the sample for the study might be considered representative of a population consisting of all eighth-grade science classes from junior high schools in general.

There were two major reasons for making the above selections. Firstly, grade eight science students were chosen because of their expected level of intellectual development (large number expected to be concrete-operational), and the nature of the concepts constituting their program of studies (large number expected to be formal). Secondly, two science teachers and two science subject areas were selected so that a certain degree of control might be exercised over the possible interaction between subject area and teacher, and between instructional treatment and teacher. The achievement of such control should enhance the generalizability of the study.

Classification of Concepts

Two units of a junior high school science program formed the content used in the study. Entitled "How Green Plants Make Food" (pp. 177-208) and "The Nature of Sound" (pp. 209-240), these two units constituted the final portion of a grade eight science program based on Exploring Science by Thurber and Kilburn (1971). The concepts included in each of these units were isolated and classified according to criteria developed by Lawson and Renner (1975) and Karplus (1977). In the following analyses, the concepts are presented in the same order as they occur in the text.

The classification of the concepts from the unit entitled "How Green Plants Make Food" are represented in Table 1.

The large number of concepts categorized as formal support the conclusion of others who have analyzed the conceptual level of junior high school science content. The results of similar procedures employed with the unit entitled "The Nature of Sound" are reported in Table 2.

Table 1

Classification of Concepts Included in the "Plant" Unit, According to Developmental Level

Concept	Classification	Criteria
Cell	Concrete	Since the program emphasized structure over function, the concept may be acquired by observing cells directly through the microscope. The function of cells and cellular parts, however, is not directly observable and therefore would not be considered concrete.
Diffusion	Formal	Since the program develops this process in terms of molecular theory, it has no directly observable attributes, and is therefore classified as formal.
Osmosis	Formal	Osmosis is treated as a specific form of diffusion involving water molecules. Since it is defined in terms of the abstract process of diffusion, it is also categorized as formal.
Digestion (based on enzyme action)	Formal	Digestion is discussed in terms of enzyme action which is an abstract process since it does not have any directly observable properties nor a basis in familiar actions or events. As such, digestion is classified as formal.
Circulation	Concrete	This is a concrete process in that students are able to directly observe the movement of liquid in plants, providing experimental arrangements are appropriate, and are able to observe the structures involved in this movement through the microscope. The cause of circulation, however, is formal since it is only accessible through mental visualization rather than direct observation.

....continued

Table 1 (continued)

Concept	Classification	Criteria
Leaves	Concrete	Since the emphasis is on structure, an understanding may be developed through direct observation or via the microscope. The function of the leaf and its parts, on the other hand, requires a higher level of mental operation because neither the operation of each part and the relationship between these various operations, nor the general functioning of the leaf, is available for direct observation. Also, like other formal concepts, an understanding of leaf functions cannot be developed through familiar actions or events.
Transpiration	Formal	Since transpiration is not directly observable, nor comprehensible through familiar experiences, understanding of the process requires a level of mental functioning classified as formal-operational.
Photosynthesis	Formal	In order to understand photosynthesis, the student must comprehend and relate the raw materials, the relevant plant structures and functions, and the by-products involved in the process. This mental exercise requires a level of functioning characteristic of formal-operational thought, because a combination of operations is involved.
Distribution (of food)	Formal	To develop an understanding of the distribution of food, the student must comprehend and relate the by-products of photosynthesis and the various plant structures and functions involved in the process. Since a second order operation is involved, the concept is classified as formal.

Table 2

Classification of Concepts Included in the "Sound" Unit, According to Developmental Level

Concept	Classification	Criteria
Sound (major concept)	Formal	Sound is developed in terms of molecular theory. Its transmission through the air is described as a train of high (molecules compressed) and low (molecules dispersed) pressure zones. Since this constitutes a rather abstract description, sound is classified as formal.
Compression waves	Formal	This concept is defined as a succession of high pressure zones (air particles closer together than normal) that travel outward from its source in all directions. Since this definition is based on the molecular theory, the concept is categorized as formal.
Rarefaction waves	Formal	Rarefaction waves are defined as a succession of low pressure zones (air particles less dense than normal) that travel outward from a source in all directions. Like the previous concept, this concept can only be specified in terms of other concepts, abstract properties and theoretical entities, and therefore requires formal-operational thought for an understanding.
Echo	Formal	An echo is defined as a reflected sound wave. Since this concept cannot be defined in terms of direct observations but only in terms of other formal concepts and properties, it is referred to as formal.
"Sound" graph	Formal	Perceiving the relationship between the formal concept, sound wave, and its representation in graphical form requires mental operations characteristic of formal reasoning patterns.

....continued

Table 2 (continued)

Concept	Classification	Criteria
Vibration	Formal	Vibration is defined in terms of the effect of a rapidly moving object on air particles. This effect is described as responsible for the production of sound. Thus, vibration is developed through the use of the abstract concepts of energy and molecule, and the abstract properties of molecular motion. As such, it is classified as formal.
Frequency	Formal	Frequency is described as the rate at which an object vibrates. Since it is presented in terms and is a functional relationship of the formal concept of vibration, it is classified as formal.
Pitch	Formal	Pitch is used to indicate how sounds of different frequencies affect our ears. Because it is defined in terms of the formal concept of frequency, it is also classified as formal.
Sound amplification (via "sounding board")	Formal	This concept is developed through discussions of the sounding board and its effect on the surrounding air particles. An understanding requires the application of the abstract concepts and properties involved in sound production. Therefore, sound amplification is classified as a formal concept.
Resonance	Formal	This concept is defined in terms of the reflection of sound waves. To understand it, one must apply other abstract properties of sound. As such, the concept is formal.

The final section of the "Sound" unit deals with the application of the above concepts to the development of an understanding of the functioning of musical instruments. This application implies a full understanding of the formal significance of the concepts previously classified. Thus, the statement by Thurber and Kilburn (1971) that "the idea of sound waves is abstract" is very much supported by the present classification scheme.

Because of the limited duration of the experiment, only certain formal concepts were selected from each unit. From the "Plant" unit, these were the concepts of diffusion, osmosis and digestion (based on enzyme action). Since the "Sound" unit consisted primarily of formal concepts, more of them were available for instruction during the course of the experiment. These concepts included the following: sound, compression waves, rarefaction waves, echoes, shock waves and sound graphs.

Instruction

Instruction of the formal concepts in the experimental classes was based on concrete activities involving models. This instructional technique was patterned after suggestions by Herron (1975) and Ausubel (1963) and supported by empirical evidence in research reports by Talley (1973) and Cantu and Herron (1978). Since a meaningful understanding of the formal concepts identified in the conceptual analysis could not be illustrated by directly observable examples and non-examples, pseudo-examples were used as concrete exemplars to focus the students' attention on critical aspects of these concepts. The formal definition of each concept, as specified in the text, guided the development of the appropriate pseudo-examples or models. These pseudo-examples were intended to be employed just as examples and non-examples might be used in the teaching of concrete concepts.

The models developed, and the necessary instruction for their appropriate implementation in the classroom, were provided to each teacher prior to the introduction of the concepts concerned. When the concepts were due to be taught, the models and the accompanying activity sheets were introduced to the class by the regular teacher who conducted the class according to suggestions received during briefing sessions with the researcher.

In most instances, groups of four or five students were provided with physical models to manipulate. In addition, simple concrete instructions were provided on related activity sheets. These instructions were designed to guide the students through their manipulation of the models so as to develop a meaningful understanding of the underlying concepts. The questions included on the activity sheets were aimed at enticing the students to focus their thinking on important aspects of the models. It was hoped that through such questioning the students would use the models to explain observable phenomena and acquire the formal-operational concepts represented by them. The models, then, were used to connect the students' observations of phenomena and the abstract explanations relating to them.

Teacher suggestions were provided in accordance with the emphasis of the questions included in the activity sheets. As such, the teachers were encouraged to ask and answer questions that would provoke the students to think about their experiences with the models, a process considered essential if the models were to be effective in developing the concepts they represented. In some cases, in addition to student manipulations, the teachers were provided with apparatus to demonstrate certain aspects of particular concepts.

The control group received regular instruction in both levels of concepts included in both units. The concepts, whether concrete or formal, were taught primarily in the usual expository manner, involving "cookbook" type laboratory sessions in conjunction with classroom discussions and lecture.

Operational Procedures

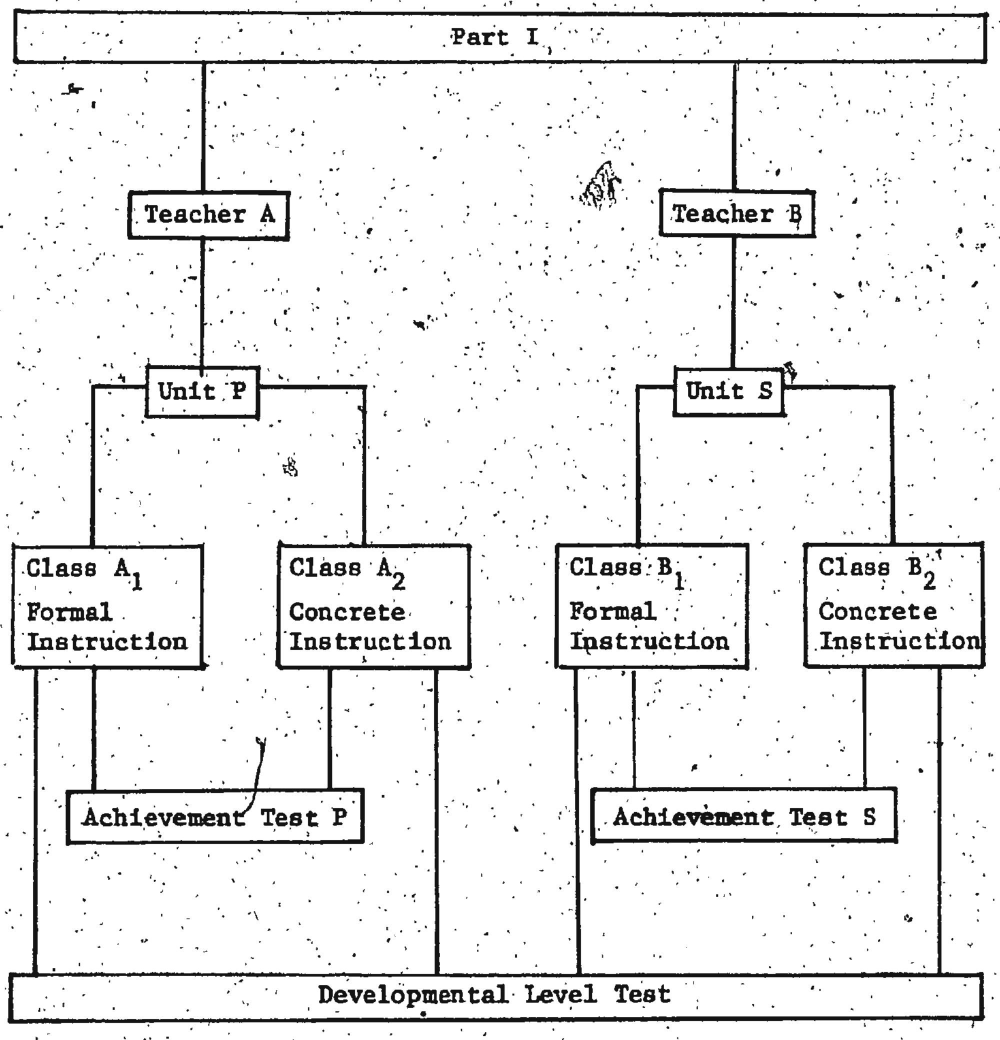
One unit was selected from each of two science discipline areas (biology and physics) studied at the grade eight level. These two units constituted the subject matter of a two-part experiment extending over approximately a two-month period. Each part was of about equal duration. As indicated earlier, the experiment involved two teachers and four classes of students. In the first part, each teacher was responsible for instructing two of the classes in one of the units. One teacher taught the sound unit, and the other teacher the plant unit, over the same time period. For each teacher, one class was designated as the experimental group while the other served as the control (see Figure 1). The control group was exposed to regular instruction according to the program prescribed for grade eight science while the experimental group received a modified form of instruction based on activities developed by the researcher. This group received a more concrete form of instruction than the control group. In as much as possible, both the experimental and control groups covered the same content and progressed at approximately the same rate. An achievement test for each unit was administered to the relevant groups by the classroom teachers about a week after the completion of the first part. Following the administration of these tests, a test to determine developmental level was administered by the researcher (see Figure 1).

The same procedures were followed during the second part except that the teachers exchanged units and interchanged the classes designated as the experimental and control (see Figure 2). Since there was no change in the instructional content, the instructional materials and achievement tests developed during the first part were also used in the second part. The cross-overs were introduced to control for interaction between teacher and subject matter, and between group and treatment.

In summary, the study was conducted in a naturalistic setting and every effort was made not to interfere with regular classroom proceedings except in the provision of the experimental materials. The students were not aware that they were involved in an experiment. Hopefully, the only difference introduced by the experiment, apart from the administration of tests, was the concrete treatment.

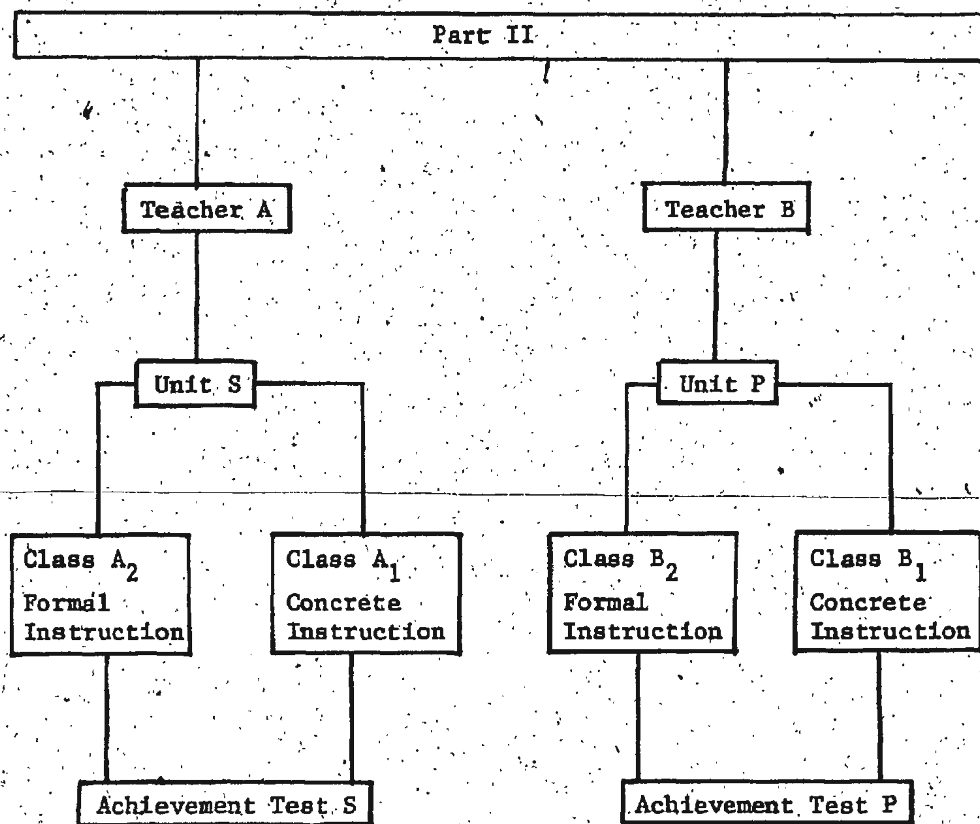
Instruments

Three tests were produced as part of the study. Two of these tests were developed to measure achievement in the two subject areas involved in the study. The other test was designed to determine level of intellectual development of the subjects participating in the study. These



Note: The symbols P and S represent "Plant" and "Sound," respectively. The other symbols are used for identification purposes only.

Figure 1: The first part of the experimental design employed in the study.



Note: The symbols P and S represent "Plant" and "Sound," respectively. The other symbols are used for identification purposes only.

Figure 2: The second part of the experimental design employed in the study.

tests are described in the subsections which follow.

Test of Developmental Level

A paper-and-pencil test consisting of five modified Piagetian tasks was used to determine the level of intellectual development of the students involved in the study. The tasks used in the test were adapted versions of the following: conservation of area task (Goldschmid, 1967), conservation of volume task (Karplus and Lavatelli, 1969), controlling variables task (Inhelder and Piaget, 1958), ratio task (Karplus and Karplus, 1970) and a combinatorial task (Bredderman, 1974). These tasks were used by previous investigators, some in paper-and-pencil form, to identify intellectual developmental levels. The test and the scoring procedures are presented in full in Appendix B.

The test was piloted at a different school from that in which the study was conducted. The major purpose of the pilot was to identify areas of the test requiring modification, the number of tasks that might be completed during a regular class period, and the appropriate administrative procedures. This information was incorporated into the final form of the test.

After the necessary modification, the test was administered by the investigator to all four classes involved in the study. Each student was provided with a test booklet and the necessary materials to perform the various tasks. Except for brief introductory remarks made by the investigator, students were guided by the instructions and questions contained in the test booklet. Each test situation lasted one 40-minute class period and occurred half-way through the study. All subjects had sufficient time to complete the items to their satisfaction.

The criteria for scoring each task were based on the practice of previous investigators who had used the same tasks (Goldschmid, 1967; Karplus and Lavatelli, 1969; Inhelder and Piaget, 1958; Karplus and Karplus, 1970; Bredderman, 1974; Lawson, Blake and Nordland, 1975; Elkind, 1961). Based on procedures employed by others, scores on each of the tasks were used to categorize students into appropriate levels of intellectual development (Lawson and Renner, 1974; Lawson, Nordland and Devito, 1974; Lawson, Nordland and Kahle, 1975; Lawson and Wollman, 1976; Lawson and Nordland, 1977; Renner, 1977). Full details of the categorization scheme employed in the study are given in Appendix B.

In summary, five neo-Piagetian tasks were selected on the basis of the assumption that the students involved in the study were either concrete or formal. These five tasks were presented in writing so that they could be group-administered and responded to in writing. Scores on each task were combined, following procedures employed in other studies, and the students classified into appropriate intellectual developmental categories.

Achievement Tests

Two tests were developed as part of the study to evaluate achievement in the two different subject areas taught. Both tests were composed solely of multiple choice items. These tests were specifically constructed to determine the extent to which students exhibited the ability to comprehend and apply selected formal concepts. Both instruments received pilot testing and close examination by subject specialists, science educators, and the teachers involved in the study. Modifications were made following feedback from these sources. Each test was administered by the classroom teacher about a week after the completion of the unit concerned. This delay was introduced to further insure that the tests evaluated understanding rather than rote memorization.

To obtain an indication of the degree to which the two achievement tests evaluated comprehension and application of formal concepts, the items comprising each test were classified according to Bloom's Taxonomy. This classification is summarized in Tables 3 and 4, and reported in more detail in Appendix C.

All but one of the items comprising the "Plant" test were classified at the application level. As such, this test examined at a level of understanding desirable in the present study.

Ten items from the "Sound" test were classified at the comprehension level of Bloom's Taxonomy and the remaining seven at the application level. Those items classified at the comprehension level were determined to require a level of understanding characteristic of the highest sublevel of this category. Thus, this test also measured understanding of the concepts involved in instruction at the level aimed for in the present study.

In the foregoing analysis, the nature of the instruction given was considered of primary importance in deciding on the level of each item. For instance, if the student was able to produce the correct term for the completion of a test item because the association between the wording of the item and a particular term was clearly spelled out in the text, then the item was classified at the knowledge level. On the other hand, a similarly structured item was classified above the knowledge level if the content of the item was determined to be novel. In this particular

Table 3

The Concept Examined by and the Classification of Each "Plant" Test Item According to Bloom's Taxonomy

Item	Concept	Bloom Level
1	Osmosis	Application
2	Osmosis	Application
3	Diffusion	Comprehension
4	Diffusion	Application
5	Diffusion	Application
6	Osmosis	Application
7	Osmosis	Application
8	Osmosis	Application

Table 4

The Concept Examined by and the Classification of Each "Sound" Test Item According to Bloom's Taxonomy

Item	Concept	Bloom Level
1	Sound transmission	Application
2	Sound transmission	Application
3	Sound transmission	Application
4	Sound transmission	Application
5	Sound direction	Comprehension
6	Shock waves	Comprehension
7	Shock waves	Application
8	Shock waves	Application
9	Sound reflection	Comprehension
10	Sound production	Application
11	Sound reflection	Application
12	Sound transmission	Comprehension
13	Vibration	Comprehension
14	Vibration	Comprehension
15	Sound graph	Comprehension
16	Frequency	Application
17	Pitch	Comprehension

case, the item may require the student to translate his or her knowledge in making a new association between a term and its definition and, as such, to demonstrate a higher level of learning.

The emphasis in writing both the "Sound" and "Plant" tests was in presenting situations new to the students, or situations including novel elements as compared to the learning experiences previously provided to facilitate understanding of the abstract subject-matter. The test items developed involved either fictional situations with a realistic-sounding setting, material from other programs (simplified if considered necessary), or a new approach to common problems. An effort was made to write the items in such a clear and simplified form that the presentation of the item itself would not interfere with the student's ability to respond.

As mentioned previously, since the researcher was interested in the development of understanding of the concepts taught, it was decided to produce two achievement tests rather than use the scores on the teacher-made tests because it was suspected that the tests developed by the classroom teachers measured primarily recall. The ability to recall information previously presented does not mean that the student understands this material. The analyses included in Appendix C show that the teacher-made tests were indeed measuring knowledge and that the tests developed as part of the study were measuring understanding at the comprehension and application levels. For comparison purposes, scores on the teacher-made tests were used in separate analyses. However, the results are reported as incidental since the tests could not be adequately statistically examined for reliability and validity as were the tests developed as part of the study. The statistical technique used to analyze the scores on all four tests is reported in the next section.

Statistical Design

Because random sampling was not possible, in order to compensate for extraneous variables, analysis of convariance was employed. For this purpose, ANOVA (Analysis of Variance), a sub-program of SPSS (Nie et al, 1975), was used. In this particular design, statistical control is exerted by extracting variation in the dependent variable resulting from the influence of the covariates. In making this extraction, the program first determines the separate and combined effects of the covariates. Each of the separate effects are calculated while adjustments are made for the remaining covariate. Then, before analyzing either factor or interaction effects, the covariate effects are combined and subtracted from the total variance. Upon completion of this phase, the analysis decomposes the remaining variance according to three sources, namely main effects, interaction effect and residual.

Analysis of the main effects of the factors follows the extraction of the covariate effects from the total variance. During the analysis of the separate effects of each of the factors, adjustments are made for the remaining factor as well as for the effects of the covariates. For example, the influence of instructional mode is determined while adjustments are made for level of intellectual development and the covariate, teacher-class effect (a compound of potentially confounding influences due to teacher, class, and teacher-class interaction).

Similar adjustments are made during the examination of the influence of the other factor, intellectual development. As with the covariates, the separate effects of the factors are combined and extracted from the variance remaining after adjustments are made for the contributions of the covariates.

Finally, the analysis determines the amount of variance in the dependent variable due to the interaction between the two factors. Adjustments are made for factor and covariate effects during the calculation of the interaction term. Analyzing the interaction between the factors involves determining which combinations of the various aspects of the independent variables have a significant effect on the dependent variable. Mode of instruction was partitioned into two categories (concrete and formal instruction) and level of intellectual development was partitioned into three categories (concrete, transitional, and formal thinking ability). The analysis indicates the degree to which concrete and formal instruction combine with concrete, transitional and formal reasoning ability to affect the dependent variable. For example, it was expected that concrete instruction would be more effective than formal instruction with students at the concrete-operational stage of intellectual development. Research results from related studies indicate other ways in which the various aspects of the independent variables may interact to influence the dependent variable.

Finally, the contribution of the interaction term to the remaining variance (after adjustments are made for the preceding sources) is extracted. The variance left over is referred to as residual variance or error variance. This is variance that is unexplained in the present study.

The information and control provided by analysis of covariance satisfies the demands inherent in the hypotheses of the study. The decomposition of the total variance according to the source of variation is a means of providing for this statistical control as well as a means of revealing information pertinent to the hypotheses.

Summary

The study involved two junior high school science teachers, four intact classes containing 161 grade eight science students, and two topics from the regular program of studies for these students. The concepts constituting the two topics were analyzed and classified as concrete or formal, according to the level of reasoning required for their understanding. In accordance with the hypotheses of the study, only formal concepts were chosen to form the academic content of the study. These formal concepts were further analyzed to determine their variable and critical attributes. On the basis of these attributes, physical models of the concepts were developed. In addition, worksheets were produced to accompany the models. This material formed the chief ingredients of the instructional approach employed in the experimental classes. The control classes received regular instruction, which was determined to be more formal in the treatment of the concepts than the approach used in the experimental classes. To test the differential effects of these two instructional approaches and, in addition, to control for various interaction effects, the experiment was designed in two phases. During the first phase, each teacher instructed two classes in one of the topics. At the end of this phase, the appropriate achievement tests were administered as well as a test designed to measure level of intellectual development. The second phase of the experiment involved similar arrangements except the teachers exchanged topics and switched the instructional approaches employed with their two classes. The scores obtained on the achievement tests and the developmental test were analyzed by a covariance design. The results of these analyses and their interpretation are reported in the next chapter.

Chapter 4

RESULTS AND DISCUSSION

In this chapter, the results of the analysis of covariance for both the teacher-made tests and the tests developed as part of the study will be reported and discussed. The results involving the latter will be discussed at length while those concerning the teacher-made tests will be only treated incidentally. Information concerning the validity and reliability of the tests developed as part of the study will be presented prior to the reporting of the actual analyses. This information includes an indication of the content validity of the achievement tests and an estimate of the reliability of both tests as determined by Cronbach's Alpha (α). Also, a discussion of the construct validity of the developmental test is provided in the final section preceding the analysis report and discussion.

Content Validity of the Achievement Tests

The achievement tests developed by the researcher were examined by junior high teachers and university professors to establish content validity. Each of the two classroom teachers involved in the study was provided with a copy of both tests and asked to assess the extent to which each examined the content taught and to make recommendations for modification based on this assessment. Two university professors were approached to further insure content validity of the tests. Each agreed to examine the test items dealing with content in their area of specialization. Following this arrangement, each professor was provided with the appropriate test and informed as to the nature of the content and instruction involved in the study. The various reactions resulting from these examinations were taken into consideration in writing the final version of each test.

Each item was also examined for its power to discriminate between high and low achievers on the overall test. According to Noll and Scannell (1972) the discrimination (d) index for each item should not be less than 0.25 where $d = (N_H - N_L) / N$. (N_H, N_L = number of students in the top and bottom 25 percent respectively, and N = 25 percent of the number of subjects.) Tables 5 and 6 indicate the values of the discrimination indices for each item in the "Plant" and "Sound" tests, respectively.

Examination of Table 5 indicates that all items in the "Plant" test can be considered satisfactory. Items 1, 5, 6, 12 and 16 in the "Sound" test do not meet the 0.25 criterion. However, further examination of these items indicates that relatively few students failed to answer items 1, 6, 12 and 16 correctly (91%, 96%, 95%, 70% correct, respectively) while item 5 was abnormally difficult (only 33% correct). Hence, in each the discrimination index was unfavourably influenced by the degree of difficulty of the item. Therefore, no items were rejected.

Reliabilities of the Achievement Tests

Cronbach's alpha (α) was used as an estimate of the reliability of the two achievement tests developed as part of the study. This estimate of reliability is equivalent to Kuder-Richardson's KR20 coefficient of

Table 5

Discrimination Index for Each Item Included in the "Plant" Test
N=132

	Number of Correct Responses		
Item	High Group (N=33)	Low Group (N=33)	Discrimination Index
1	28	3	0.76
2	17	3	0.42
3	31	19	0.36
4	30	4	0.79
5	32	16	0.48
6	30	13	0.52
7	11	0	0.33
8	32	6	0.79

Table 6

Discrimination Index for Each Item Included in the "Sound" Test N=128

	Number of Correct Responses		
Item	High Group (N=32)	Low Group (N=32)	Discrimination Index
1	32	26	0.19
2	32	21	0.34
3	30	12	0.56
4	15	3	0.38
5	14	9	0.16
6	32	29	0.09
7	27	9	0.56
8	20	4	0.50
9	27	16	0.34
10	32	19	0.41
11	17	7	0.31
12	32	27	0.16
13	32	21	0.34
14	32	23	0.28
15	32	15	0.53
16	27	20	0.22
17	31	22	0.28

internal consistency. The nature of this estimate is that it is basically the average of all possible split-half reliability estimates. The reliability estimate of each test is reported in Table 7.

In interpreting these reliability estimates, one should bear in mind that the estimate is affected by the number of items included in the test, other things being equal. That is, the addition of relevant items of a similar quality to each achievement test would increase the estimates shown in Table 7. Also, the estimate is influenced by the degree of variance in scores on a particular item. If the variance is small, for instance, the estimate will be low. Thus, there is a possibility of an underestimation of the reliability of the tests.

In addition to the tests constructed by the researcher, data from common teacher-made achievement tests, one for each unit, was analyzed. The results of this analysis are also provided in the present chapter. However, no test statistics are available for these tests. The results, therefore, are considered to be suggestive but of limited generalizability.

Construct Validity of the Developmental Test

The items included in the developmental test were not novel. These items, with slight variation, have been used by other investigators to evaluate intellectual development. Examples of their use include the following: Conservation of Area Task (Flavell, 1973; Goldschmid, 1967; Goldschmid and Bentler, 1968; Lawson, Nordland and Kahle, 1975), Conservation of Volume Task (Elkind, 1961; Karplus and Lavatelli, 1969; Bybee and McCormack, 1970; Lawson and Nordland, 1977), Controlling Variables

Table 7

Cronbach's Alpha for the "Plant" and "Sound" Tests Developed as Part of the Study

Test	Number of Items	Number of Cases	Alpha
Plant	8	134	0.61
Sound	17	129	0.55

Task (Inhelder and Piaget, 1958; Lawson and Renner, 1974; Nordland, Lawson and Kahle, 1974; Lawson and Blake, 1976), Ratio Task (Karplus and Peterson, 1970; Karplus and Karplus, 1972; Wollman and Karplus, 1974; Karplus, Karplus and Wollman, 1974), and Combinatorial Task (Bredderman, 1974; Sayre and Ball, 1975; Lawson and Wollman, 1976; Griffiths and Kass, 1979). The frequent use and refinement of these items supports their validity.

Analysis of Scores on "Plant" and "Sound" Tests

The results of the analysis of covariance on the "Plant" and "Sound" tests are represented in Tables 8 and 9, respectively. Means and standard deviations of the test scores for the constituent groups are reported in Table 10. The number of subjects (N) reported in Tables 8 and 9 and in the tables which follow are different from those recorded in Tables 5, 6 and 7. This is because there were less subjects included in the analyses than were examined by the two achievement tests, respectively. This attrition was due to student absenteeism during one or more of the testing situations.

Effect of Instruction

Hypothesis one states that there will be no significant difference in achievement test scores between subjects receiving concrete and formal instruction, respectively. According to Tables 8 and 9, the influence of instructional mode on achievement, in both the "Plant" and "Sound" sections, was negligible ($p = .310$ and $.788$, respectively). This interpretation is reinforced by the means of the concrete and formal groups for each unit. In the "Sound" unit, the test means are

Table 8

Two-Way ANCOVA of the Effect of Instructional Mode and Intellectual Developmental Level on Achievement Scores for the "Plant" Test
N=98

Source of Variation	Degrees of Freedom	Mean Square	F Ratio	Significance of F
Main Effects	3	1417.9	4.0	0.010
Instructional mode	1	365.1	1.0	0.310
Intellectual developmental level	1	2017.6	5.8	0.004
Interaction Effect				
Instructional mode x Intellectual developmental level	2	159.7	0.5	0.636
Explained	6	2867.8	8.2	0.000
Residual	91	350.8		
Total	97	506.5		

Table 9

Two-Way ANCOVA of the Effect of Instructional Mode and Intellectual Developmental Level on Achievement Scores for the "Sound" Test
N=92

Source of Variation	Degrees of Freedom	Mean Square	F Ratio	Significance of F
Main Effects	3	1506.7	10.5	0.000
Instructional mode	1	10.5	0.1	0.788
Intellectual developmental level	2	2259.6	15.7	0.000
Interaction Effect				
Instructional mode x Intellectual developmental level	2	3.9	0.0	0.973
Explained	6	763.2	5.3	0.000
Residual	91	144.1		
Total	91	182.4		

Table 10

Mean Scores and Standard Deviations for the Instructional Groups on the "Plant" and "Sound" Tests

Instructional Mode	"Plant" Test	"Sound" Test
Concrete (44)		
Mean	47.8	69.5
Standard deviation	22.4	13.9
Formal (54)		
Mean	50.3	69.2
Standard deviation	21.6	13.1
Combined (98)		
Mean	49.1	69.4
Standard deviation	22.0	13.5

Note: The figures in parentheses represent the number of subjects in the various instructional groups.

virtually identical (69.5 and 69.3, respectively). The difference between these two groups on the test for the "Plant" unit (47.8 compared to 50.4) favours the formal instruction group, but the difference between these groups is quite insignificant when compared to the variation within the whole sample. Hence, the present data suggest that the provision of concrete or formal instruction does not influence student achievement of formal concepts. As such, the results disagree with a considerable portion of the related research reported earlier which found concrete instruction generally more effective in developing an understanding of formal science subject matter than formal instruction (Sheehan, 1970; Talley, 1973; Case and Fry, 1973; Linn and Their, 1975; Howe and Mierzwa, 1977; Cantu and Herron, 1978).

However, the results agree with research by Goodstein and Howe (1978) who found that concrete instruction, based on models, was no more effective than regular instruction in teaching the majority of students an understanding of formal concepts. The results may also be consistent with a training study by Bredderman (1973) and with other studies which have been interpreted as not being successful in training concrete-operational students to achieve a meaningful understanding of formal tasks. In addition to the interpretation that the above results indicate that concrete instruction does not promote learning of formal concepts by concrete students, other explanations may be possible.

One explanation that may account for the ineffectiveness of the concrete instructional mode is that the students and teachers were not able to adjust sufficiently to the different approach. One of the areas where there may have been adjustment problems concerns the application of suggestions by Herron (1975). In accordance with these recommendations, it was emphasized that the concrete instruction employed with the experimental classes should involve considerable interaction among the students, and between teacher and student. The primary aim of these interactions was to provoke the students to think about the concrete activities so that they might develop an understanding of the underlying concepts. It is possible that the concrete approach, being unusual for these students, could have caused confusion and frustration for them. Such a situation would certainly impede the effective learning of the formal concepts concerned. Hence, a longer term intervention might have produced different results.

The results may also be explained in terms of the discrepancy between the level of intellectual development of the students (primarily concrete) and the level of the concepts (formal). As suggested by Lawson and Karplus (1977), it may be necessary to develop formal thinking ability before students are able to acquire a meaningful understanding of formal concepts. Again, this development, according to Herron et al (1976), is gradual and occurs over a much longer period of time than that taken to obtain the data for this particular study.

Finally, the concrete activities themselves might have been inadequate for the development of an understanding of the formal concepts dealt with in the study. It is possible that with different activities based on different concrete props and teaching strategies the results would be different. This possibility, along with many of the others suggested, signifies areas of further research relative to instructional mode. Despite these alternative explanations, the data under consideration indicate that in this case a concrete approach for each of two topics was no more successful than a formal approach in promoting learning of formal concepts by a sample of junior high school students.

Effect of Developmental Level

Hypothesis two states that there will be no significant difference in achievement test scores between subjects at different levels of intellectual development. According to Tables 8 and 9, level of intellectual development significantly influenced student scores on both the "Plant" and "Sound" tests ($p < .005$, .001, respectively). The direction of this difference is indicated by the means reported in Table II.

With respect to the "Plant" test, the transitional group attained the highest mean. The formal group ($\bar{X} = 53.2$) were similar to the transitional group ($\bar{X} = 55.8$) but higher than the concrete subjects ($\bar{X} = 42.9$). This was unexpected and inconsistent with most other studies. A possible explanation involves the small number of students included in the formal category. A low, non-typical performance of just a few students in this category, perhaps because of misplacement, would reduce the mean considerably since there were only a small number of students in the group. Such a performance by a similar number of students in either of the other categories would not have the same degree of influence because the groups were much larger.

The results of the analysis of the achievement scores of the various developmental groups on the "Sound" test differed slightly from the "Plant" test results. Students categorized as reasoning at the formal-operational level achieved a higher mean ($\bar{X} = 79.9$) than either the transitional group ($\bar{X} = 72.5$) or the concrete-operational ($\bar{X} = 62.8$)

Table 11

Mean Scores and Standard Deviations for the Concrete, Transitional and Formal Students on the "Plant" and "Sound" Tests
N=98

Intellectual Developmental Level	"Plant" Test	"Sound" Test
Concrete (46)		
Mean	42.9	62.8
Standard deviation	19.6	12.4
Transitional (33)		
Mean	55.8	72.5
Standard deviation	24.4	11.4
Formal (19)		
Mean	53.2	79.9
Standard deviation	18.0	7.0
Combined (98)		
Mean	50.6	71.7
Standard deviation	20.7	10.3

Note: The figures in parentheses represent the number of subjects in the various developmental level groups.

group. Also, the transitional group scored a higher mean than the concrete group. The direction of the difference in achievement between the transitional and formal groups is the reverse of what occurred on the "Plant" test, and is more expected.

In general the above differences indicate a lack of support for the second hypothesis. In the present study, achievement of formal science concepts is related to the developmental level of the learner. This finding is in agreement with a number of other studies which have investigated the relationship between intellectual development and achievement in science (Raven and Polanski, 1974; Lawson and Blake, 1976; Sayre and Ball, 1975; Lawson and Nordland, 1977; Wheeler and Kass, 1977; Reminsky, 1979).

Interaction of Instructional Mode and Developmental Level

Hypothesis three states that there will be no significant interaction between level of instruction and level of intellectual development with respect to students' performance on the achievement tests. These interaction effects were evaluated following adjustment for the influence of the covariate and the main effects. The results of this evaluation are reported in Tables 8 and 9. Tables 12 and 13 indicate the means of the various groups produced through the cross classification of instructional mode and intellectual development involving the "Plant" and "Sound" tests, respectively.

According to Tables 8 and 9, instruction did not differentially influence the achievement of formal concepts by subjects of different developmental level ($p = 0.64, 0.97$ for the "Plant" and "Sound" tests,

Table 12

Mean Scores and Standard Deviations on the "Plant" Test, According to Instructional Mode and Developmental Level of Subjects
N=98

Instructional Mode	Intellectual Developmental Level of Subjects		
	Concrete	Transitional	Formal
Concrete			
Mean	41.0 (19)	54.7 (16)	50.1 (9)
Standard deviation	19.5	24.8	13.7
Formal			
Mean	44.2 (27)	56.8 (17)	56.0 (10)
Standard deviation	19.1	23.9	20.8

Note: The figures in parentheses represent the number of subjects in the various categories.

Table 13

Mean Scores and Standard Deviations on the "Sound" Test, According to Instructional Mode and Developmental Level of Subjects
N=98

Instructional Mode	Intellectual Developmental Level of Subjects		
	Concrete	Transitional	Formal
Concrete			
Mean	62.3 (19)	72.8 (16)	78.8 (9)
Standard deviation	12.9	10.8	7.6
Formal			
Mean	63.1 (27)	72.3 (17)	80.9 (10)
Standard deviation	12.0	11.9	6.3

Note: The figures in parentheses represent the number of students in the various categories.

respectively). This is supported by the means represented in Tables 12 and 13. Thus, the third hypothesis, stating that there would be no significant interaction between level of instruction and level of intellectual development with respect to student's performance on the achievement test, is accepted.

Assuming that instruction and testing were conducted at the levels intended, these findings indicate that type of instruction does not have any differential effect upon the achievement of formal concepts by students at the concrete, transitional and formal stages of intellectual development, respectively. This is in agreement with Lawson and Karplus (1977) who state that concrete-operational students cannot acquire as good an understanding of formal concepts no matter what the level of instruction. However, it does not agree with research evidence which indicates that concrete instruction is more effective in teaching conrete-operational students than formal instruction (Sheehan, 1970; Talley, 1973; Howe and Mierzwa, 1977; Cantu and Herron, 1978). It is also inconsistent with research (Sheehan, 1970; Cantu and Herron, 1978) which indicates that formal students perform better under concrete instruction than under formal instruction. Thus, with respect to the interaction of instructional mode and developmental level, the results of the present study disagree with the majority of the findings reported in the related research.

Summary

In summary, analysis of the scores on the tests evaluating comprehension and application of formal concepts indicates that instructional mode did not significantly affect achievement. Level of intellectual development, on the other hand, did influence the scores on each of the same subject matter tests regardless of instructional mode. On both achievement tests, formal students scored higher than concrete students. Finally, no significant interaction was observed between instructional mode and learner developmental level.

Analysis of Achievement Scores on Teacher Tests

In addition to the foregoing analysis, a post-hoc analysis was performed on the teacher-made tests. Only the total scores for each student were available. Hence, it was not possible to determine the reliability of the tests. Examination of the tests (see Appendix C) indicated that all items were at the knowledge level of Bloom's taxonomy. Further, the content validity of the test, in terms of the relationship between teacher and text treatment, was high. It was possible, therefore, to capitalize on the fact that the teacher made tests, prepared by experienced and well qualified teachers, tested the same content as the researcher's tests but at a different level of the cognitive domain. A similar analysis to that for the tests designed by the investigator was performed. Tables 14 and 15 represent the results of the analysis of covariance for these tests.

Effect of Instruction

Analysis of the main effects indicate that the effect of instructional mode was significant ($p < .001$) in the case of the "Teacher Plant" test but not quite significant ($p = .08$) with respect to the "Teacher Sound" test. This is also reflected in the means reported in Table 16. The direction of the effect in each case favoured the formal instruction

Table 14

Two-Way ANCOVA of the Effect of Instructional Mode and Intellectual Developmental Level on Achievement Scores on the "Teacher Plant" Test
N=98

Source of Variation	Degrees of Freedom	Mean Square	F Ratio	Significance of F
Main Effects	3	916.8	7.8	0.000
Instructional mode	1	1702.8	14.7	0.000
Intellectual developmental level	2	578.3	5.0	0.009
Interaction Effects				
Instructional mode x Intellectual developmental level	2	24.4	0.2	0.811
Explained	6	520.5	4.5	0.001
Residual	91	116.2		
Total	97	141.2		

Table 15

Two-Way ANCOVA of the Effect of Instructional Mode and Intellectual Developmental Level on Achievement Scores on the "Teacher Sound" Test
N=98

Source of Variation	Degrees of Freedom	Mean Square	F Ratio	Significance of F
Main Effects	3	580.7	4.3	0.007
Instructional mode	1	412.5	3.1	0.084
Intellectual developmental level	2	702.1	5.2	0.007
Interaction Effects				
Instructional mode x Intellectual developmental level	2	6.1	0.0	0.956
Explained	6	297.4	2.2	0.050
Residual	91	135.1		
Total	97	145.2		

Table 16

Mean Scores and Standard Deviations for the Instructional Groups on the Teacher Tests

Instructional Mode	"Plant" Test	"Sound" Test
Concrete (44)		
Mean	76.5	76.1
Standard deviation	12.5	13.2
Formal (54)		
Mean	84.7	79.8
Standard deviation	9.1	10.6
Combined (98)		
Mean	80.6	78.0
Standard deviation	10.8	11.9

Note: The figures in parentheses represent the number of subjects in the various instructional groups.

group. For the "Teacher Plant" test the concrete instruction group achieved a mean of 76.5 percent while the formal instruction group achieved a mean of 84.7 percent. For the "Teacher Sound" test the means were 76.1 and 79.8, respectively.

This result is not surprising and is in agreement with a study by Talley (1973) who, in comparing concrete instruction (based on models) and formal instruction (verbal), found that on a memory test (emphasizing recall) administered following instruction the control group did better than the experimental group. Talley suggested that the reason for such a difference lay in the emphasis on memory learning in the control class, an explanation that may well apply in the present case.

Effect of Developmental Level

According to Tables 14 and 15, level of intellectual development significantly affected subjects' test scores on both tests developed by the classroom teachers. The direction of the effect is shown in Table 17. The results reported in this table indicate that formal students ($\overline{X}$ = 87.8, 84.7) achieved higher means on both subject matter tests than the transitional students ($\overline{X}$ = 80.2, 78.7) who, in turn, performed better than the concrete students ($\overline{X}$ = 78.6, 75.0). According to Tables 14 and 15, the overall trend of these differences is significant for both the "Plant" and "Sound" tests. In general, this result is similar to that obtained when the test items represented comprehension and application (investigator's tests). It appears that formal students simply achieve better regardless of the testing.

Table 17

Mean Scores and Standard Deviations for the Concrete, Transitional and Formal Students on the Teacher Tests
N=98

Intellectual Developmental Level	"Teacher Plant" Test	"Teacher Sound" Test
Concrete (46)		
Mean	78.8	75.0
Standard deviation	11.7	12.3
Transitional (33)		
Mean	80.2	78.7
Standard deviation	12.5	11.4
Formal (19)		
Mean	87.8	84.7
Standard deviation	6.7	7.2
Combined (98)		
Mean	82.3	79.5
Standard deviation	10.3	10.3

Note: The figures in parentheses represent the number of subjects in the various instructional groups.

Interaction of Instructional Mode and Developmental Level

With respect to interaction effects, the results of the present analysis are also similar to the results of the previous analysis. These results indicate that instructional mode and level of intellectual development did not interact (p = .811, .956, respectively) to significantly affect the achievement test scores on either test. Tables 18 and 19 provide the relevant mean scores. For the "Teacher Plant" test formal-operational subjects in the concrete and formal modes had a mean of 83.0 and 92.2 percent, respectively. The transitional subjects had corresponding means of 75.3 and 85.0, while for the concrete-operational subjects the means were 74.5 and 81.8. For the "Teacher Sound" test the formal-operational subjects in the concrete and formal modes had means of 81.9 and 87.3 percent, respectively. The transitional subjects had corresponding means of 76.3 and 80.9 percent, while the concrete-operational subjects had the lowest means, 73.1 and 76.3 percent, respectively.

Summary

In summary, the results of the analysis of the scores on the two knowledge level teacher-made tests indicate that instructional mode significantly affected student learning on the Plant unit. Students receiving formal instruction achieved a significantly higher mean than students receiving concrete instruction. On the other hand, instructional mode did not significantly influence learning on the Sound unit. However, students receiving formal instruction achieved a higher mean than students taught through the concrete instructional mode. There

Table 18

Mean Scores and Standard Deviations on the "Teacher Plant" Test, According to Instructional Mode and Developmental Level of Subjects
N=98

Instructional Mode	Intellectual Developmental Level of Subjects		
	Concrete	Transitional	Formal
Concrete			
Mean	74.5 (19)	75.3 (16)	83.0 (9)
Standard deviation	11.4	14.1	6.5
Formal			
Mean	81.8 (27)	85.0 (17)	92.2 (10)
Standard deviation	10.8	8.4	4.6

Note: The figures in parentheses represent the number of subjects in the various categories.

Table 19

Mean Scores and Standard Deviations on the "Teacher Sound" Test, According to Instructional Mode and Developmental Level of Subjects
N=98

Instructional Mode	Intellectual Developmental Level of Subjects		
	Concrete	Transitional	Formal
Concrete			
Mean	73.1 (19)	76.3 (16)	81.9 (9)
Standard deviation	12.6	14.3	4.9
Formal			
Mean	76.3 (27)	80.9 (17)	87.3 (10)
Standard deviation	11.5	7.0	8.4

Note: The figures in parentheses represent the number of subjects in the various categories.

was a significant difference between the performance of the developmental level groups, in a direction similar to that which was established in the previous analysis involving the tests developed as part of the study. The formal students achieved significantly higher means than the transitional students who, in turn, performed significantly better than the concrete students. Also, as for the previous analysis, there were no significant effects resulting from the interaction of intellectual developmental level and instructional mode.

Summary

Analysis of the data obtained in the present study suggests the following: In tests requiring comprehension and application of formal concepts, developmental level influences student performances, in favour of formal-operational students. However, neither instructional mode nor the interaction of instructional mode and developmental level exerted a significant influence on attainment of the concepts involved.

Similar analysis of scores on the teacher-made tests requiring only recall also suggested that achievement was dependent on intellectual development, and further, that intellectual development does not interact with instructional mode to differentially influence recall of material relating to formal concepts. However, the data do suggest the possibility that a teaching mode designed to promote understanding, rather than recall, might inhibit learning at the level of recall.

Chapter 5

SUMMARY, CONCLUSIONS, IMPLICATIONS, AND SUGGESTIONS FOR FURTHER RESEARCH

Summary

Analysis of covariance was used to evaluate three hypotheses involving the main effects of instructional mode and intellectual developmental level, and the interactive effects of these two variables, on the achievement of formal concepts. In analyzing these effects, analysis of covariance was used to adjust for unknown but potentially confounding differences between teachers. The independent variables (instructional mode and developmental level) and the dependent variable (achievement of science concepts) of the experiment will be briefly discussed in the remainder of this section.

Instructional mode involved two different methods of teaching formal science subject matter to students at different levels of intellectual development. One of the methods was referred to as concrete instruction and was based on manipulation of physical models of formal concepts while the other was referred to as formal instruction. Regular instruction was classified as formal instruction because of its reliance on the lecture approach and the formal-operational nature of the text and laboratory activities. Both approaches were used with the same subject matter.

The level of intellectual development of the 161 eighth grade students participating in the study was determined by a battery of five neo-Piagetian tasks. These were scored in a manner similar to scoring procedures used by other researchers with the same or related tasks. The categorization procedures employed in classifying students into levels of intellectual development were also based on criteria used by previous researchers. Based on this categorization scheme, the students were placed into three different levels of intellectual development, namely concrete, transitional (concrete-formal) and formal.

Four tests were used to evaluate achievement. Two tests developed by the researcher evaluated formal concepts from the corresponding subject areas involved in the study, mostly at the comprehension and application level. It was also decided to use the scores on two teacher-made tests relating to the same content to obtain some indication of how level of testing was related to instructional mode and level of intellectual development.

Conclusions

Three conclusions were formulated on the basis of the results involving scores on tests designed to evaluate <u>understanding</u> of formal-operational concepts. Firstly, concrete instruction was no more effective than formal instruction in enabling concrete-operational, transitional, and formal-operational students, respectively, to gain an understanding of formal concepts. Secondly, formal students were better able to understand formal concepts than were transitional students while transitional students were more able than concrete students to cope with these concepts. Finally, the performance of concrete-operational, transitional and formal-operational students was not differentially affected by instruction either at the concrete or formal level. A further, more tentative conclusion, derived from a post-hoc analysis of teacher-made tests representing <u>recall</u>, was that students exposed to formal instruction achieved better on knowledge level tests than students receiving concrete instruction, although this difference was statistically significant only on one of the two topics investigated.

Implications

The study has implications for practice in that it offers evidence with respect to the present controversy of how to relate instruction to the developmental level of the learner. It also has implications for further research in this respect, as well as in connection with the evidence it provides of the relationship between developmental level and achievement in science. In addition, the study has theoretical significance with respect to evidence relating to the understanding of formal concepts by students at different levels of intellectual development. However, its greatest significance may be in the area of educational practice.

With respect to classroom instruction, the study implies that students who are not functioning at the formal-operational stage of intellectual development are unable to acquire an adequate understanding of formal-operational content, even when instruction is based on concrete experiences. As such, the teaching of this level of subject matter is not as meaningful for these students. Thus, we should either refrain from teaching such content to students who are not formal-operational or we should seriously emphasize the prior development of formal reasoning through suitable classroom instruction. This latter approach seems more acceptable, particularly in light of the present incongruency between the nature of most science subject matter and the level of reasoning of the learner. In accordance with this approach, there is a need for the proper sequencing of subject matter and the development of appropriate instructional material and strategies conducive to the promotion of intellectual development. The effective and efficient fulfillment of this need requires further research. In addition, research is also needed to further investigate the use of concrete props in teaching formal subject matter.

The finding that formal-operational students perform better on tests evaluating understanding of formal-operational concepts than students functioning at a lower level of intellectual development is supportive of Piagetian theory. Also, since concrete instruction was no more effective than formal instruction in teaching concrete-operational and transitional students a meaningful understanding of formal concepts, that aspect of the theory which suggests that formal reasoning patterns must be developed before a student can develop an understanding of formal concepts is supported as well. However, it should be understood that the difference between the concrete and formal approaches was the use of concrete exemplars versus verbal description of non-perceptible exemplars of the same formal concepts. It is possible that the difference in instructional approach was not sufficient to cause a difference in achievement. It is also possible that a longer duration for the experiment, a different placement in the school year or different teachers and/or students might have resulted in different results.

In general, the study implies that formal reasoning needs to be developed in order that students might have the ability to acquire an adequate understanding of formal-operational science concepts.

Suggestions for Further Research

Further research in the area of teaching formal concepts to concrete-operational students is suggested on the basis of the present study. The replication of the experimental procedures of the study is recommended as a means of testing the conclusiveness and generalizability of the findings, especially since the study was conducted in a natural setting where experimental control was difficult to obtain. In addition to replication, a number of different instructional strategies are suggested for investigation. These involve:

(1) the employment of a different treatment of the formal concepts, i.e. a progressive development of the concepts through the ordered teaching of necessary prerequisites, as suggested by the research of Griffiths and Kass (1979).

(2) the development of the concepts through film (animation and/or real) and other audio and visual media, alone or in combination with models, etc.

(3) replication, using models similar to those employed in the study or some different treatment of the concepts, over a longer period of time.

(4) replication with other concepts.

Like many other investigations in the area, the present study was conducted under normal school conditions. Since experimental control is extremely difficult to achieve in a natural setting, these studies need extensive replication in order to establish the reliability of their results. An alternative approach in analyzing certain variables in the area of instruction would be to first investigate these variables in an artificial setting where the necessary controls are attainable, and then to apply the findings of these studies in the classroom, under natural conditions, to test their effectiveness.

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APPENDIX A

CONCRETE INSTRUCTIONAL ACTIVITIES

APPENDIX A

CONCRETE INSTRUCTIONAL ACTIVITIES

The activities included in this appendix formed the basis of the concrete instructional approach used with the experimental classes. The four activities employed to develop an understanding of the three formal "Plant" concepts included in the study are presented in the first section. The other section consists of the six activities used in a similar manner in teaching the six formal "Sound" concepts comprising the remainder of the academic content of the study. The activities from both subject areas were provided to the experimental classes with the necessary materials for their completion. Following are the activities presented in the same form as they were used with the experimental classes. The text referred to in the following activities is Exploring Science (Thurber and Kilburn, 1971).

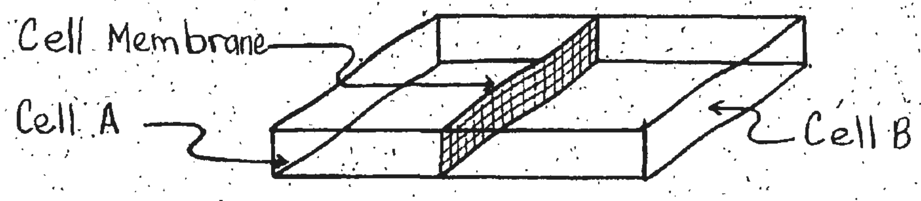
"Plant" Activities

A variety of activities have been produced by others to teach diffusion, osmosis, and digestion. Since none of these activities treated the concepts concerned in a truly concrete manner, the following activities were developed for this purpose.

DIFFUSION (Text: pp. 182-283)

Cell processes are on too small a scale to be observed directly. Therefore, activities involving these processes are carried out by use of a model.

In the model provided, the wire mesh represents a cell membrane and the two parts of the plastic container, separated by the wire mesh represent two adjacent cells OR the environment in which a plant is located and an outermost cell.



Molecules are involved in most cell processes. Because you are not able to see molecules, beads will be used to represent them.

The smallest beads (red) represent water molecules.
The medium beads (gold) represent glucose molecules.
The largest beads (orange) represent starch molecules.

Activity I

Purpose: to illustrate how water molecules move across a cell membrane.

Materials: plastic container (divided by wire mesh) and smallest beads.

Procedure:

1. Use only the smallest beads. Place them all on one side of the wire mesh. These beads represent water molecules concentrated on one side of a cell membrane.

2. Shake the container back and forth for about four or five seconds. Then hold it steady and count the number of beads on each side of the wire mesh. Record these numbers in a table similar to the one shown below.

Trial	Side A (#)	Side B (#)
1		
2		
3		
4		
5		

3. Repeat the previous procedures four times, each time recording the numbers in the proper space in your table.

4. How do the number of beads on one side of the wire mesh compare with the number on the other side after each shaking?

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The movement of beads through the wire mesh is considered similar to the movement of water molecules across a membrane. Water molecules move in the direction where there is less of a concentration of water molecules just as beads tend to move through the wire mesh to where there are no beads.

5. In light of this similarity, explain how water molecules move from one cell to another.

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Activity II

Purpose: to illustrate how glucose molecules move across a cell membrane.

Materials: plastic container (divided by wire mesh) and medium beads.

Procedure: 1. Use only medium beads. Place them on one side of the wire mesh. These beads represent glucose molecules concentrated on one side of a cell membrane.

2. Shake the container back and forth for about four or five seconds. Then hold it steady and count the number of beads on each side of the wire mesh. Record these numbers in a table similar to the one shown below.

Trial	Side A (#)	Side B (#)
1		
2		
3		
4		
5		

3. Repeat the previous procedures four times, each time recording the numbers in the proper space in your table.

4. How do the number of beads on one side of the wire mesh compare with the number on the other side after each shaking?

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5. In light of this similarity, explain how glucose molecules move from one cell to another.

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Activity III

Purpose: to illustrate why starch molecules need to be changed to glucose molecules.

Materials: plastic container (divided by wire mesh) and two size beads (medium and large).

Procedure: 1. Use the largest beads. Place them on one side of the wire mesh. These beads represent starch molecules concentrated on one side of a cell membrane.

2. Shake the container back and forth for about four or five seconds. Then hold it steady and observe the number of beads on each side of the wire mesh.

Do any of the beads move through the wire mesh? Why not?

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3. Replace some of the large beads (starch molecules) with medium size beads (glucose molecules). Again, shake the container back and forth for about four or five seconds. Do any beads move through the wire mesh? If so, which beads? Why are they able to pass through?

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4. Why do plants have to break down starch molecules into glucose molecules?

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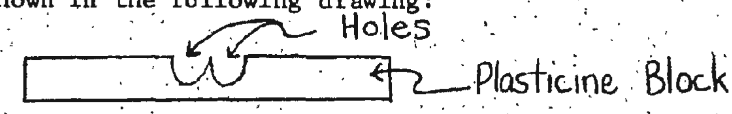
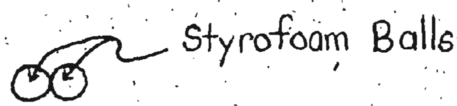
DIGESTION (Text: pp. 184-185)

Objective: to show how large starch molecules are broken down into sugar molecules by enzyme action.

Materials: a block of plasticine containing two holes lying near each other, as shown in the following drawing:



two styrofoam balls lightly cemented together. The balls are the same size as the holes in the plasticine.



Procedure:

1. Place the plasticine block on the table so that the holes are at the top. This block, with its holes, represents an enzyme of a cell.

2. Fit the cemented styrofoam balls in the holes in the plasticine block. These two balls, lightly cemented together, represents a starch molecule.

3. Force the two balls into the holes formed in the plasticine. This action represents enzyme activity. Eventually the two balls will separate. The separate balls represent sugar molecules and also the results of enzyme activity.

   As you can see, each of the two sugar molecules are smaller structures than the starch molecule and, therefore, are able to pass through smaller openings than the starch molecule.

4. Food is stored in the form of starch in some plant cells. Sometimes this stored food is needed in other cells. However, the starch molecules containing the food are too big to move through the cell membranes and, as such, the food is not able to be carried to these other cells in the form of starch. Thus, the starch molecules must be broken down (digested) into sugar molecules which are smaller and, therefore, able to move through the cell membrane. This breakdown is performed by enzymes. Use the activity involving the model to explain how

enzymes operate in the breakdown or digestion of these large starch molecules.

"Sound" Activities

Two of the "Sound" activities employed in the study were selected from a text entitled Searching for Structure by Hoyes (1973). One of the activities, "Sound Transmission," was modified while the other, "Sound Production," was used in its original form. Of the activities examined, these two were most acceptable with respect to the reliability of their performances and the level at which they dealt with the concepts concerned.

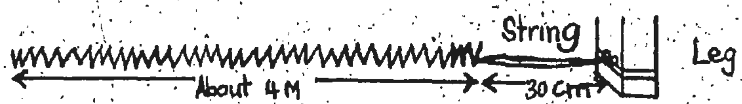
Similar to the activities available to teach the "Plant" concepts, many of the suggested activities available to instruct the concepts dealing with the nature of sound were assessed to be inadequate, not only from a treatment point of view but also from a performance standpoint. As such, it was necessary to develop activities that provided the desired level of performance and treatment.

SOUND WAVES (Test: pp. 210-213)

Purpose: to explain how a moving object affects the surrounding air.

Materials: string and slinky

Procedure: 1. Tie one end of a slinky to the leg of a desk or a chair with two pieces of string as follows:



Stretch the other end along the floor to a total length of about four meters. Move this end quickly forward and back. Observe the slinky and the string at the other end.

2. What happens to the string?

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3. Describe the changes in the coils of the slinky.

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In one rapid motion, move the slinky forward and back four or five times. Again, observe the slinky and the string at the other end.

4. What do these movements do to the string?

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5. What do these movements do to the coils of the slinky?

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6. How does the slinky transmit movements in your hand to the string?

7. How are the movements in your hand and string similar to movements in the

(a) rubber stretched across both ends of the cardboard tube:

(b) drumheads:

(c) piano or phonograph and the drum:

(d) door and window shade?

8. In terms of the behavior of the slinky, describe what happens to the air inside the

(a) cardboard tube when you snap your finger against the rubber at one end:

(b) drum when you strike one of the drumheads:

(c) drum when you play a piano or a phonograph loudly:

(d) room when you open and close a door:

9. In terms of how movements in your hand affects the slinky and thus the string at the other end, explain how movements made in each of the instances above causes other movements.

10. Assuming energy is transmitted in air in a manner similar to the transmission of movements in the slinky, explain how energy is transmitted between the door and the window shade.

SOUND TRANSMISSION (Text: [illegible]10-212)

Explanations concerning the transmission of energy inside the cardboard tube (Text: p. 210), the drum (Text: p. 211), and the room (Text: p. 212) are based on the behavior of air. The effect of the piano or the phonograph on the paper clip (Text: p. 211) is also explained in terms of the behavior of air. It seems that without air, energy transmission in each of the above instances would not occur. Let's find out whether or not air is essential for the transmission of sound energy.

IS AIR NECESSARY FOR THE TRANSMISSION OF SOUND FROM A SOURCE TO OUR EARS?

The following demonstration by your teacher will provide you with the evidence to answer this question.

The teacher, using a vacuum pump, will gradually evacuate the air from a sealed jar containing a bell that is ringing loudly. You are to observe what happens as the air is taken from the jar and then slowly let back in again.

Read the following questions beforehand and use them to guide your observations during the demonstration. After the demonstration is completed, answer the questions in the spaces provided.

1. What happens to the loudness of the sound as the bell jar is evacuated?

2. If a perfect vacuum could be created in the jar, would you hear anything? Would the bell be still functioning?

3. What happens to the loudness of the sound as air is let slowly back into the jar?

4. Is air required for the transmission of sound?

5. How is the complete removal of air from the jar similar to the removal of the slinky from between your hand and the string?

DIRECTION OF WAVE TRAVEL (Text: p. 213)

The teacher will rotate a disc so that the spiral appears to expand in a manner considered similar to the direction of wave travel from a source.

Observe what happens to the lines as the disc is being rotated. Then answer the following questions in the spaces provided.

1. What point stands for the source of the sound waves?

2. What do the lines represent?

A student will hold the slotted disc in front of the spiral disc. The teacher will continue to rotate the spiralled disc and you will view the pattern through the slot of the stationary disc.

3. What do you observe?

4. In what direction do the lines appear to move?

NOTE: The motion of the slinky and the apparent motion of the lines of the disc closely resemble the motion of sound waves when air is transmitting sound.

Imagine holding the ends of numerous slinkies that are extending outward from your hand in all directions. Movements in your hand would produce waves in the slinkies that would travel outward in a way considered similar to the transmission of sound from a source.

Sound travels outward in all directions.

SHOCK WAVES (Text: pp. 214-215)

The activities below will be performed by your teacher. For these activities, one end of a slinky will be tied to the leg of a desk or a chair and the other end will be stretched along the floor, similar to an arrangement employed in a previous activity. The end that is held by your teacher will be moved in the same direction (quickly forward and back) as you had done in an earlier activity. The difference is that in this activity the movements are much greater.

1. Do these larger movements cause greater compression and rarefaction waves in the slinky?

2. Do these large movements cause greater slackening in the string at the other end?

3. The effect of these greater movements on the slinky is considered similar to what happens to air when a loud noise is made. Your textbook suggests that loud noises (shock waves) may be produced by bursting an inflated balloon, firing a rifle, or moving an object faster than the speed of sound. In light of the similarity between the behavior of air and the coils of the slinky, explain how air is disturbed when these various sources produce a sound.

REFLECTION OF SOUND WAVES (Text: p. 217)

One end of the slinky is held in a fixed position by a student. The other is held by the teacher and the slinky is stretched along the floor. This end is quickly moved forward and back. Observe the movements in the coils of the slinky.

1. What happens to these movements when they reach the other end?

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What happens to the movements in the slinky when they reach the fixed end is considered similar to what happens to sound waves when they strike a hard, flat surface.

2. In light of this similarity, explain how sound waves are reflected.

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NOTE: Reflected sound waves travel at the SAME speed as the initial sound.

SOUND PRODUCTION (Text: pp. 218-223)

Purpose: to show that sound is produced when objects move back and forth rapidly.

Materials: tuning fork, rubber mallet (one-holed stopper on a rod), ball on a string, large container of water, elastic band, and hard thin paper.

Procedure: 1. Strike one prong of a tuning fork with a rubber mallet. (Never strike a tuning fork with a hard object.) Now perform the following tests:

(a) Touch the surface of the water with the prongs of the fork.

(b) Touch a suspended ball with the prongs of the fork.

(c) Touch your elbow with the base and then with the prongs of the fork.

What effect did the tuning fork have on the water and the ball?

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What effect did it have on your elbow?

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What do these effects tell you about the fork?

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What happened when you touched the prongs?

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2. Have your partner stretch an elastic band between his hands. Pluck the elastic so that a sound is heard. Describe the motion of the elastic band.

3. Hold two sheets of paper together between your thumbs and forefingers, about an inch from one end on both sides. Part the sheets at this end so that one will cover your upper lip and the other your lower lip. Blow. What happens to the sheets of paper when sound is produced?

4. Touch your throat while you hum. What happens to your throat as you hum?

5. Hold an object in your hand and slowly move it back and forth. Do you hear a sound? Why not?

6. State the conditions which are necessary for any object to produce a sound which can be heard.

7. What effect does an object have on the surrounding air as it produces a sound?

GRAPHING SOUND WAVES (Text: pp. 220-221)

In the simulator provided, the beads represent air particles and the movable cardboard barrier represents one of the prongs of a tuning fork.

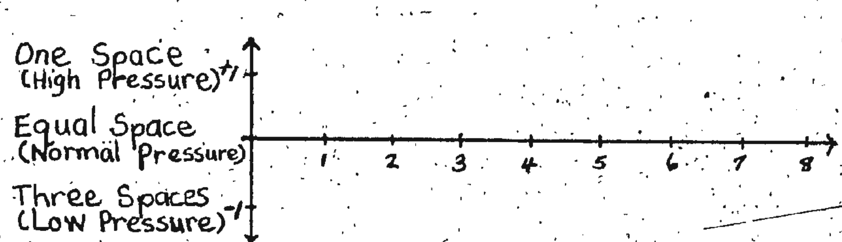
One-half of the plastic container is divided into four equal parts. These parts will be referred to as spaces. Each part represents one space.

Purpose: to illustrate how graphs of sound waves are produced.

Materials: simulator.

Procedure:

1. Place an equal number of beads on each side of the cardboard barrier. When the barrier is at mark zero (upright position), the amount of space on either side is about the same. This represents the condition that exists when the prong of the tuning fork is in the rest position. Air pressure on each side of the prong is the same. Mark the appropriate point on a graph similar to the one shown below.



2. Move the barrier to mark +1. As you move the cardboard barrier, shake the container so that the beads are constantly moving. This represents the movement of air particles in the area immediately surrounding the prong. This pushes the beads together into one space somewhat similar to the compression of air particles to the right of the prong when the prong moves towards the right.

   The movement of the cardboard barrier one space takes one unit of time. Keep this in mind as you mark the appropriate point on your graph.

3. Move the barrier to the left. Stop at mark 0. Indicate the appropriate point on your graph. Notice the empty space immediately to the right of the barrier. This represents the movement of the prong back to its upright position and the starting of a low pressure zone to the right of the prong.

4. Continue to move the cardboard barrier to the left. Stop at mark 1. Notice that the empty space immediately to the right of the barrier is now much larger. This represents the movement of the prong to the left of the upright position and the creation of a low pressure zone to the right. Again, mark the appropriate point on your graph.

5. Move the barrier back to mark 0. Notice that this movement pushes the beads together. This represents the movement of the prong back towards the right and the beginning of a high pressure zone to the right of the prong.

6. Repeat the above procedures, each time marking the appropriate point on your graph.

7. Join the points marked on your graph so that a curve is produced similar to those which appear on pp. 220-221 of your text.

In this activity, we focused our attention on the beads on the right side of the cardboard barrier and compared it to what happens to the air on one side of a moving prong. It should be kept in mind, however, that the barrier has a similar effect on the beads on the left side just as the moving prong disturbs the air on both sides.

APPENDIX B

MATERIALS AND PROCEDURES EMPLOYED IN DETERMINING LEVEL OF INTELLECTUAL DEVELOPMENT

APPENDIX B

MATERIALS AND PROCEDURES EMPLOYED IN DETERMINING LEVEL OF INTELLECTUAL DEVELOPMENT

This appendix includes the developmental test and the various procedures followed in using this test to determine the level of intellectual development of each student participating in the study. The preliminary instructions provided each class during the administration of the developmental test are reproduced in the first section. The second section contains the developmental test booklet, consisting of five neo-Piagetian tasks, in exactly the same form as it was presented in each of the various classes involved in the study. The third section presents a description of each task, the scoring scheme for each task, and the categorization scheme employed in classifying the students into levels of intellectual development.

Preliminary Instructions to Students

Each of you should now have a booklet and various materials. This constitutes what you will be working with during the remainder of this period.

The booklet consists of five different exercises or tasks. You are required to complete all five tasks.

This is not a test. I am just as interested in knowing how you arrive at your answer to each question as I am in your answer being right or wrong. So, when you are asked to explain how you figured out your answer, please do so as clearly and completely as possible.

The various materials provided are for use in particular tasks. You will know when to use them. It will be indicated in the instructions provided in the booklet.

Now, will you please turn in your booklet to task three. The diagrams on this page represent pendulums like those set up at the front of the classroom. In the diagrams in your booklet, the pendulum bobs are shown in various positions, ready to be released to start the pendulums swinging. The angles these pendulums make with the rest position are represented by numbers. For example, the size of the first angle is indicated by a 1. This tells or shows how far the pendulum bob is taken from its rest position before it is released. All the angles represented by a number 1 are the same size. The size of the other angles are indicated in a similar manner. The length of the pendulum string is in centimeters and the weight of the bob is in grams.

When you finish a task, move immediately to the next task. Do not waste time. You will probably need all of the remainder of this period in order to finish the booklet.

If you get to task two and do not have the materials for its completion, move on to the next task (task three). Come back to task two when the materials become available to do it.

Read the instructions and the questions very carefully. I would like to remind you that it is important to tell, in clear and careful writing, how you figure out your answers to the various questions included in the booklet.

Place your name and your teacher's name on the front page.

You may begin. If you have a problem during the course of your work, you will be helped individually.

Developmental Level Booklet

Student's Name: ____________________

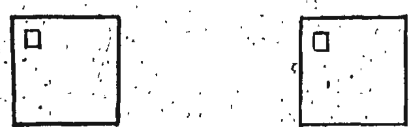
Teacher's Name: ____________________

This booklet is made up of five different tasks. Please do each task as carefully and completely as possible. **DO NOT** worry about your answers being right or wrong. **THIS IS NOT A TEST.** We are most interested in how you think as you work through each of the tasks. Therefore, it is important that you show, as clearly and completely as you can, how you arrive at each of your answers.

TASK ONE

The diagrams below represent two fields of grass that are exactly the same size.

Each field of grass is owned by a farmer; Mr. Green owns one, and Mr. Jones owns the other. Both Mr. Green and Mr. Jones built a barn on their fields. The barns are exactly the same size and are built in the location shown in the diagrams below.

Mr. Green  Mr. Jones

Is there still the same amount of grass NOT covered on each field, or does one or the other have more? Briefly explain how you arrived at your answer.

Mr. Green and Mr. Jones each built another barn of exactly the same size. Mr. Green built his second barn right next to his first barn. Mr. Jones left a space of grass between his two barns. The location of the barns is shown in the diagrams below.

Mr. Green  Mr. Jones

Is there still the same amount of uncovered grass on each field? Briefly explain how you figured out your answer.

Mr. Green and Mr. Jones each built a third barn of exactly the same size. The location of the barns is shown in the diagrams below.

Mr. Green  Mr. Jones

Is there still the same amount of uncovered grass on each field, or does one or the other have more? Carefully explain your answer.

TASK TWO

This task involves placing two metal cylinders in a tube partially filled with water. The cylinders are placed in the tube one at a time.

Read the instructions carefully. DO NOT answer any questions until you are ready, BUT once you have begun a new question DO NOT change any previous answers. Answer the questions in the order in which they appear.

1. How are the two metal cylinders alike? How are they different?

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2. Place an elastic band around the tube at the same level as the water level.

3. Very carefully lower the silver coloured cylinder into the water until it rests on the bottom. Move the elastic band to the new water level.

4. Before you place the gold coloured cylinder in the water, predict what water level you would expect if the gold coloured cylinder had been put in the water instead of the silver coloured cylinder.

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5. Explain as carefully as you can how you arrived at your answer to question 4.

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6. Carefully remove the silver coloured cylinder from the tube, and replace it with the gold coloured cylinder. Is the water level the same as you had expected? If it is not, explain why the actual water level is different from the level you expected.

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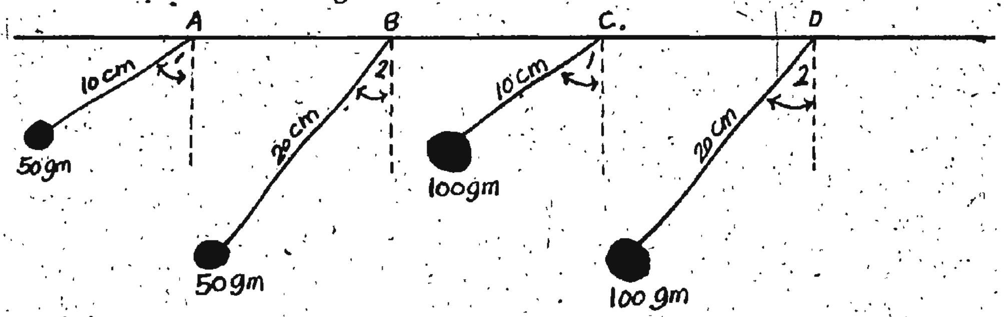
TASK THREE

Suppose you are given the following pendulums from which you could choose one or more to help you find out the factors affecting how fast or slow a pendulum swings.



Which of the following would you choose to show whether weight has any effect on how fast or slow a pendulum swings? (There may be more than one acceptable choice.)

(1) A and C

(2) A and B

(3) A and D

(4) B and D

(5) B, C, and D

(6) A, B, and C

Carefully explain why you would choose these pendulums.

TASK FOUR

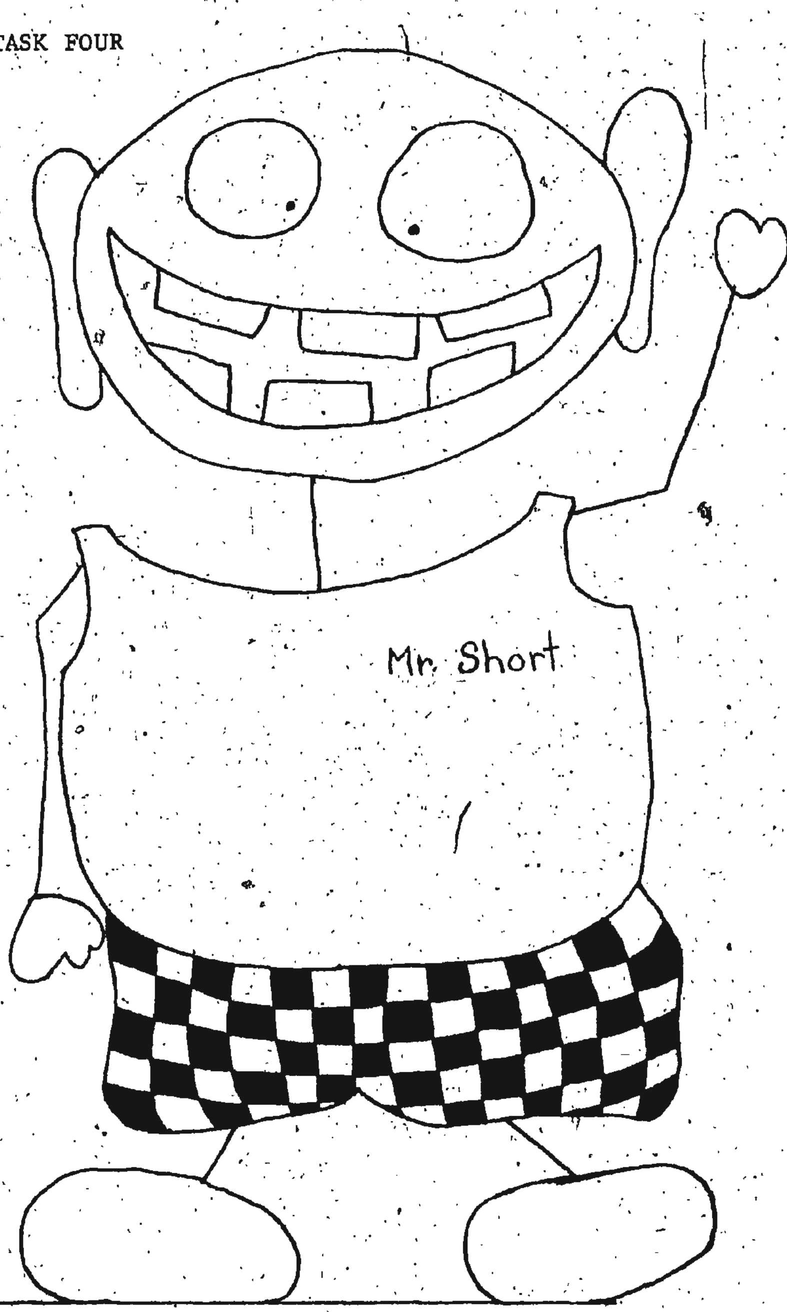
The figure at the right is called Mr. Short. We used large round buttons laid side-by-side to measure Mr. Short's height, starting from the floor between his feet and going to the top of his head. His height was four buttons. Then we took a similar figure called Mr. Tall, and measured it in the same way with the same buttons. Mr. Tall was six buttons high.

Now please do the following things:

1. Measure the height of Mr. Short using paper clips in a chain provided. The height is ________________.

2. Predict the height of Mr. Tall if he were measured with the same paper clips. ________________.

3. Explain how you figured out your prediction. (You may use diagrams, words, or calculations. Please explain your steps carefully.)



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TASK FIVE

A transitor radio  is available from your local store at sale price, but you can buy any of the following "extras" if you want to:

leather case  C

OR carrying strap  S

OR extra battery  B

OR earphone  P

Suppose you decide to buy a radio and some accessories. However, before the purchase, you decide to figure out the various combinations in which you could buy the different items listed above. Using the initials to the right of these items, write down as many different choices as you can think of.

For example, if you choose to buy the radio, a leather case, and an extra battery, you would write down R+C+B; if you choose to buy the radio and a carrying strap, you would write R+S.

Write down your choices in the space provided below.

Procedures Followed in Scoring Tasks and in Classifying Students into Levels of Intellectual Development

A group-test was used to categorize the subjects into levels of cognitive development instead of individually administered tasks, because of the problems associated with the administration of Piagetian tasks to a large number of students on an individual basis. The ease of administration thus made the group-test more desirable in this particular situation, despite claims by others (Easley, 1974; Wollman and Karplus, 1974; Philips, 1974) of its questionable validity. However, there are researchers who argue that these tests measure the same intellectual processes as a battery of tasks presented in an interview type setting (Rowell and Hoffmann, 1975; Shayer and Wharry, 1975; Tisher and Dale, 1975; Tomlinson-Keasey, 1975). Nevertheless, despite proclaimed advantages and disadvantages, group testing was used in the present study primarily for practical reasons.

The group test employed consisted of five neo-Piagetian tasks. Before presenting the guidelines followed in categorizing the subjects on the basis of their responses to these tasks, the criteria employed in scoring each will be described.

The developmental test administered required the subjects to react to the various tasks by writing their responses. These written responses were analyzed and scored according to a point system employed by Lawson, Blake and Nordland (1975) as follows:

11A	Early concrete operational:	1 point
11B	Fully concrete operational:	2 points
111A	Early formal operational:	3 points
111B	Fully formal operational:	4 points

In describing the scoring criteria used, each task will be dealt with separately, in the same order as it was included in the test of intellectual development.

TASK #1

Conservation of Area (Goldschmid, 1967)

This task tested the students' ability to conserve area. A student who indicated attainment of this ability was classified as fully concrete-operational. Therefore, the highest score obtainable on this particular task was two points.

The task consisted of four diagrams accompanied by appropriate test items. The first two diagrams and corresponding test items were included to focus the student's attention on the nature of the task. Primarily, responses to the final two diagrams were used to determine students' level of reasoning. Students were categorized on the basis of their responses to these two diagrams as follows:

IIA - The subject gives a correct answer and explanation in response to the question concerning just one of the final two diagrams; the subject gives a correct answer to both questions but is not able to explain either response (1 point).

IIB - The subject gives a correct answer and explanation in response to the question accompanying both of the final two diagrams (2 points).

TASK #2

Conservation of Volume (Karplus and Lavatelli, 1969)

This task was included to determine the students' ability to conserve volume. A student who was able to correctly complete the task was categorized as early formal-operational. Thus, the highest reasoning level displayable was the IIIA level. As previously mentioned, a student indicating this level of reasoning was assigned a total of three points.

The materials provided with the task consisted of two test tubes partly filled with water and two objects of the same volume but of noticeably different weights. That is, the difference in weight was able to be determined by lifting the objects. In the first part of the task, the student was instructed to carefully observe the two objects and then to place one of the objects (silver cylinder) into the water. An elastic band was provided to indicate the level to which the water rose. After executing the above procedures, the student was asked to predict the level to which the other object (gold cylinder) would cause the water to rise in the test tube. An explanation of this prediction was also requested. Following the completion of this part of the task, the subject was instructed to do the actual experiment and to note the results. If the observations made were at odds with the prediction developed in the initial part of the task, the subject was asked to explain the difference. The scoring, based primarily on the prediction and explanations, was conducted according to Karplus and Lavatelli (1969) as follows:

IIA - The subject makes an incorrect prediction or predicts correctly and gives the incorrect reason; cannot explain the results when he/she sees the experiment performed (1 point).

IIB - The subject makes an incorrect prediction or predicts correctly and gives the incorrect reason (as in IIA); however, when the subject sees the experiment performed he/she realizes the correct explanation (2 points).

IIIA - The subject predicts correctly and gives a correct reason (3 points).

TASK #3

Controlling Variables (Inhelder and Piaget, 1958)

This task was included to obtain some indication of the students' ability to carry out a controlled experiment. Presumably, a student who is able to correctly complete this task is able to conduct a controlled experiment. According to Inhelder and Piaget (1958), an individual who is able to conduct a controlled experiment is reasoning at a fully formal-operational level. As such, a subject who correctly completes this task is functioning at the 111B level, which is, according to Piaget, the highest reasoning level possible.

This task includes a diagram displaying four pendulums that differ with respect to at least one of the following factors: length of string, starting angle, and weight of pendulum bob. The pendulum drawings were identified by letters (A through to D), the angles were denoted by numerals (1 and 2), the length of each string was given in centimeters, and the weight of each bob was expressed in grams. Angles were indicated as equal by assigning them the same numeral.

From a list of six combinations, the student was asked to select the pendulums he/she would use to test whether weight affects the rate at which a pendulum swings. There were two acceptable choices included in the list. The subject was also instructed to explain his choice of pendulums. As indicated in the following outline, it was the subject's choice and explanation that formed the criteria used in scoring the task.

11A - The subject selects 2 and/or 3, both of which imply changing more than one variable. In choice 3 weight of bob is included in the change while in choice 2 it is not.

The task includes a diagram representing a Mr. Short. The subject is informed that Mr. Short stands four buttons tall and that a Mr. Tall, who was similarly measured with the same buttons, is six buttons high. The subject is then instructed to measure Mr. Short with the paper clips provided. Upon completing this measurement, the subject is instructed to predict the height of Mr. Tall in paper clips. The subject is also requested to explain how he/she figured out the prediction. The scoring of the task was based directly on procedures employed by Karplus, Karplus, and Wollman (1974), as follows:

IIA - intuitive computation (IC) and Scaling (S) (1 point).

IC - An explanation using the data haphazardly or in an illogical way.

S - An explanation based on a change of scale that the subject does not justify in terms of the data.

IIB - addition (A) and addition and scaling (AS) (2 points).

A - An explanation focusing on a single difference (tall—short or paper clips—buttons) uncoordinated with other differences, and solving the problem by addition.

AS - An explanation focusing on the excess height of Mr. Tall, and scaling up the two excess buttons by an unexplained factor to compensate for the size difference of buttons and small paper clips.

IIIA - Proportion, concrete (PC) and addition and proportion (AP) (3 points).

PC - An explanation using the relation that one button is about 1.5 paper clips where this relation is obtained by measuring one—fourth of Mr. Short's height with paper clips. On most of the papers there were pencil marks that indicated how Mr. Short had been divided into fourths, frequently after a trial-and-error procedure. Arithmetic errors were common.

AP - An explanation focusing on the excess height of Mr. Tall, which is expressed in terms of paper clips by a factor based on the data.

111B - Application of ratio (4 points).

R - An explanation using a proportion or deriving the scale ratio for the paper clips or heights directly from the data, and applying ratio in a proportion.

TASK #5

Combinatorial Task (Bredderman, 1974)

The purpose of Task #5 is to determine the subjects' ability to systematically combine choices so that all possible combinations are produced. A subject who satisfactorily completes this task is considered reasoning at the fully formal-operational level (111B) and is therefore given four points.

The task involved buying a transistor radio and some accessories. Essentially, the subject was instructed to record as many combinations of these accessories as he/she could produce. Since there were four accessories available for purchase, there were 16 different combinations possible.

Assessment of the subject's response was based on his/her method of combining and the number of combinations produced.

11A - Randomly combines accessories, producing less than 12 combinations (1 point).

11B - Randomly combines accessories, producing 12 or more combinations.

- Follows a partially systematic approach, producing less than 12 combinations (2 points).

111A - Follows a partially systematic approach, producing 12 or more combinations (3 points).

111B - Follows a completely systematic approach, producing 12 or more combinations (4 points).

N.B. Random Combining - the subject does not follow a scheme in combining the various accessories available. This is indicated by the lack of a pattern in the recording of the combinations produced.

Partially Systematic - the subject follows a scheme to determine some combinations but randomly combines to produce others.

Completely Systematic - all the combinations recorded are produced according to a plan. Again, this is indicated by the manner in which the combinations are presented.

In classifying subjects into developmental levels, the scores obtained on the various tasks were combined and used to place subjects into appropriate categories. The following were the procedures used in this categorization scheme:

A point system was used to create a set of continuous data. This was accomplished by combining the points obtained on each of the various tasks, thus producing scores indicating overall level of intellectual development. In order to enter level of intellectual development as a factor (as desired) in the analysis, it was necessary to group the scores. In accordance with Lawson, Nordland, and Kahle (1975), the scores were grouped so that they corresponded to three categories representing three different levels of intellectual development.

On the basis of a more thorough examination, the categorization scheme suggested by Lawson, Nordland and Kahle (1975) was considered too stringent especially in its requirements for the final two stages. As such, it was decided to decrease the upper range of the transitional category from 15 to 14. This modification would allow students who score a combination of 2, 2, 2, 4 and 4 points, or some different combination of scores totalling 14 points, on the five tasks to be classified at the formal level (early formal) instead of at the transitional level as would be the case with the original scheme. This classification level was judged more appropriate for students achieving a total of 14 points on the test. Table A explains how the three different levels of intellectual development were created.

Table A

Categorization of Subjects into Levels of Intellectual Development

Category	Range	Criteria
Concrete	5-10	A student who is reasoning at the concrete level should score no less than 1 point (for a total of 5) and no more than 2 points (for a total of 10) on each of the 5 tasks.
Transitional	11-13	A student who is reasoning at the transitional level should score at least 2 points on 4 of the tasks and 3 points on the remaining task for a total of 11 points (minimum score). As a maximum score, this particular level student should score 2 on the first task (maximum possible) and some combination of scores (2, 3 and 4) on the remaining tasks; for a total of 13 points.
Formal	14-17	A student who has attained formal reasoning ability should score 2 points on the first task (maximum) and 3 on the remaining tasks for a total of 14 points minimum. As a maximum score, a student at this level of thinking should score 2 on the first task, 3 on the second task, and 4 on the remaining tasks for a total of 17 points.

APPENDIX C

TEST ITEMS AND THEIR CLASSIFICATION ACCORDING TO BLOOM'S TAXONOMY

APPENDIX C

TEST ITEMS AND THEIR CLASSIFICATION ACCORDING TO BLOOM'S TAXONOMY

There were four different tests employed to measure student achievement in two different subject areas. Two of the tests were developed by the classroom teachers as part of their regular evaluation procedures, one to evaluate student achievement in a unit entitled "How Green Plants Make Food" and the other to determine student achievement in a unit called "The Nature of Sound." The remaining two tests were constructed by the researcher to evaluate student performance in the same two areas.

A preliminary analysis of the teacher-made test indicated that a large percentage of the test items required only simple recall and recognition for successful completion. Since application of concepts received primary emphasis in the test developed by the researcher, it was suspected that the tests written by the classroom teachers were evaluating at a different cognitive level than the tests developed as part of the study. Since the tests composed by the teachers were used as instruments to measure the dependent variable, in addition to the test produced by the researcher, it became necessary that both sets of tests be systematically and properly classified. This classification would enhance the explanation of any difference that might occur in the analyses results.

Bloom's taxonomy was followed in classifying each of the four tests. This process involved separately categorizing each item included in each test. A rationalization was also provided for the placement of each item. The overall classification of each test was determined by the proportion of items categorized at the various levels of Bloom's taxonomy.

Tests Developed by the Classroom Teachers

The tests written by the classroom teachers were the first to be classified. The initial classification involves the test evaluating achievement in the unit entitled "How Green Plants Make Food." This test consists of four parts. Each part is presented exactly as included in the test and classified as follows:

PART A: PLACE THE CORRECT ANSWER IN THE SPACE PROVIDED AT THE RIGHT.

1. All living things are made up of tiny units called ____________. (1) ________
2. When these units are organized together to do a particular job, the mass is called a ________. (2) ________
3. The outermost part of an animal cell is the ____________. (3) ________
4. The process by which plants make food is called ____________. (4) ________
5. The chemical needed by plants for food manufacture is ______. (5) ________
6. The type of conducting tissue which carries water up to the leaves is called ________. (6) ________
7. The small pores on leaves which permit transpiration are called ____________. (7) ________
8. Structures within the cell which are used for food storage are called ____________. (8) ________
9. The ____________ layer of a leaf contains most of the water to be used for food making. (9) ________
10. When leaves turn yellow in the fall, what is the name of the pigment which is showing up? ____________. (10) ________

Since each of the above items is posed in a form similar to that used in the original learning situations, the student is required to recall (1) as the referent for the term cell; (2) as the referent for the term tissue; (3) as the referent for the term membrane; (4) as the referent for the term photosynthesis; (5) as the referent for the term chlorophyll; (6) as the referent for the term xylem; (7) as the referent for the term stomates; (8) as the referent for the term plastids; (9) as the referent for the term spongy; and (10) as the referent for the term carotene.

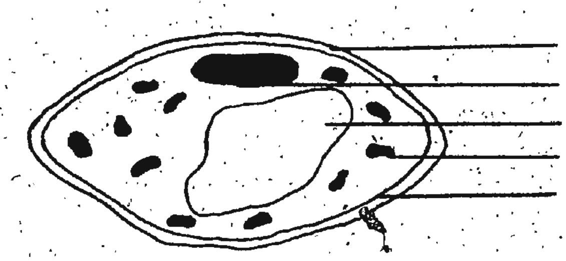
Since this part of the test emphasizes remembering through recall, it can be readily classified under knowledge.

PART B: TELL WHETHER THE FOLLOWING STATEMENTS ARE TRUE OR FALSE. IF THE STATEMENT IS FALSE, REPLACE THE UNDERLINED WORD WITH THE WORD THAT MAKES THE STATEMENT CORRECT.

	T or F	Correction
11. Osmosis is the movement of sugar molecules from regions of high concentration to regions of low concentration.	______	______________
12. The dissecting microscope is used for looking at larger items.	______	______________
13. The gas released by plants during the day is called carbon dioxide.	______	______________
14. The medium power of our microscopes magnifies the item 400 times.	______	______________
15. The living part of a cell is called protoplasm.	______	______________

The student is able to correctly complete the above items by remembering specific facts and definitions previously learned in a similar form. This remembering is accomplished by recognizing (11) as referring to diffusion and not osmosis; (12) as correct; (13) as referring to oxygen and not carbon dioxide; (14) as correct; and (15) as correct.

PART C: LABEL THE DIAGRAM BELOW:



Since the above drawing of the cell closely resembles diagrams in the text, the subject is able to successfully recognize and label its various parts. As such, Part C is clearly a test for <u>knowledge</u>.

PART D:

1. (a) Describe how you would prepare a <u>thin</u> section for examination under the microscope. Include how you would cut, etc., and get the glass slide ready.

   (b) Tell how you would properly carry a microscope.

   (c) Tell how you would properly focus a microscope. Why is it necessary to be so careful?

2. (a) Describe how guard cells protect a plant.

   (b) What are two factors which determine how much water a plant transpires?

   (c) What are vascular bundles and where are they located?

3. (a) What is meant by photosynthesis?

   (b) What are the five requirements for photosynthesis?

   (c) What often happens to the sugar which is made in the leaves?

   (d) Name a plant which stores its food as: starch
sugar
protein

Each of the above items may be correctly completed by simply recalling information previously learned. This information is provided by the text and the classroom teacher. The familiar form of each item simply requires the student to regurgitate the appropriate information according to clues included in the item. As such, Part D is written totally at the knowledge level.

The other test constructed by the classroom teachers assessed achievement in a unit called "The Nature of Sound." The classification of this test was conducted in a manner similar to the classification of the previous test.

The "Sound" test consists of two parts. As with the "Plant" test, each part was comprised of similar type items. As such, the items from each part will be classified in a similar way. The following is Part I of the test:

Put the answers to the questions in the blanks provided at the right.

1. An object which vibrates and produces sound is called a sound ________________. (1) ____________________

2. An area of high pressure is called a ________________. (2) ____________________

3. An area of low pressure is called a ____________ wave. (3) ____________________

4. If a tuning fork vibrates 256 times in one second, it produces ________________. (4) ____________________

5. If a tuning fork vibrates 512 times in one second, it produces ________________ compression waves in one second. (5) ____________________

6. What is the frequency if this graph is produced in one second? (6) ____________

7. What graph is produced by a louder sound?

(a) 

(b) 

(7) ____________

8. The highness and lowness of sound is called ________. (8) ____________

9. Stringed instruments use ________ to help amplify the sound they produce. (9) ____________

10. The method of sound amplification which uses echoes in columns of air is called ____________. (10) ____________

11. An example of an instrument which uses the kind of sound amplification in #10 is ____________. (11) ____________

12. The longer the length of the tuning fork, the (higher, lower) the pitch. (12) ____________

13. A device used to show the graphs of sound waves is a(n) (audiometer, oscilloscope, barometer)? (13) ____________

14. Which train of waves had a higher frequency?

(a) 

(b) 

(14) ____________

15. The speed of sound in air is approximately (335, 880, 1100) feet per second. (15) ____________

Because of the similarity between the student learning experiences and the form and content of the test items, the student is able to correctly complete each by remembering specific definitions and facts. He is able to adequately complete statements 1, 2, 3, 8, 9, 10 and 11 by recognizing that (1) is the definition of a sound radiator; (2) is the definition of a compression wave; (3) is the definition of a rarefaction wave; (8) is the definition of frequency; (9) is the definition of a sounding board; (10) is the definition of resonance; and (13) is the definition of an oscilloscope. He is able to successfully complete the remaining items by recalling in (4) that each time an object vibrates it produces one sound wave; (5) that each time an object vibrates it produces one compression wave; (6) the definition of frequency and the definition of vibration as it relates to the graph of a train of sound waves; (7) the relative size of graphs produced by sounds of different loudness; (11) an instrument that uses resonance as a means of sound amplification; (12) that the longer the tuning fork, the lower the pitch; (14) the relative difference between graphs of high and low frequency sounds; and (15) the speed of sound. Since all of the above items test memorization, Part I is categorized as testing knowledge.

Part II. Do this part on your own paper.

1. Give two reasons why sound is important.

2. Draw the graph produced by three vibrations of a tuning fork. Label the graph.

3. (a) What is an echo?

   (b) Give three examples where echoes are produced so they can be used.

4. (a) What is a shock wave?

(b) What is a sonic boom?

(c) Why are they dangerous?

5. What method of sound amplification does the human voice use?

Since the form and wording of the items are familiar to the students, and since the appropriate responses are provided either by the text, the teacher or both, the student can correctly complete the items by recalling the relevant information. The cues in the form and the wording of the items indicate which information needs to be recalled. Since recall is adequate for successful completion of this part of the test, the category in which it is most appropriately placed is knowledge.

Based on the above analysis, both tests developed by the teachers were classified as knowledge level tests. All of the items included in the test to determine student achievement of "Sound" concepts were classified at the knowledge level. In Part I of the test, six items were included to test knowledge of terminology while nine tested knowledge of specific facts. In Part II, which contained short answer type items, five responses required knowledge of terminology, while four required knowledge of specific facts. Again, in the test to evaluate student achievement of "Plant" concepts, only knowledge level items were used. In the objective part of this test, 19 of the 20 items tested knowledge of terminology. The remaining item tested knowledge of a specific fact. The final section of the test, comprised of short "essay" type items, contained two items examining knowledge of terminology, five items examining knowledge of specific facts and three items testing knowledge of methodology. In analyzing the various items, both the text and teacher instructional procedures were examined to determine whether the form of each item and expected response were very "different from the way in which the knowledge was originally learned" (Bloom et al, 1956). It was determined that the wording of the items was very similar to that used in the text and/or instruction and that acceptable responses were provided by the text and/or teacher either directly or as a simple step away from direct form. Clearly both tests evaluate knowledge of concepts and not understanding.

Tests Developed as Part of the Study

The procedures followed in classifying the tests developed by the researcher were similar to those utilized in the categorization of the corresponding tests written by the classroom teachers.

The following are the items comprising the "Plant" test and their classification according to Bloom's Taxonomy.

Circle the letter opposite the correct answer to each of the questions asked in the following items.

1. If there are more water molecules on the inside of a cell than there are on the outside, which of the following would be the most likely result?

   (a) The cell would expand.

   (b) The cell would shrink.

   (c) The cell would burst.

   (d) The cell would not change.

This item requires the application of the concept of osmosis in predicting that water molecules will move from the inside to the outside of the cell, causing the cell to shrink.

2. A fisherman threw a bucket of salt solution on a patch of grass growing near his wharf. About a month later, he noticed that the grass had turned a yellowish color in the area where he threw the salt solution. Which of the following could explain this event?

   (a) The grass was dying because of a lack of water.

   (b) The grass absorbed the salt solution which caused it to change color.

   (c) The grass was dying because of too much water.

   (d) The grass lost certain minerals to the soil which caused it to change color.

This item requires the application of the concept of osmosis in explaining the deterioration of the grass in the area where the salt solution was thrown.

3. There are certain plant cells that are neither involved in food production nor food storage. These cells obtain their nourishment from other cells which store food in the form of starch. What must happen in order for this stored food to be obtained by those cells which need it?

   (a) The stored food must first be diffused to where it is needed and then broken down into sugar molecules.

   (b) The stored food must first be broken down into sugar molecules and then diffused to where it is needed.

   (c) The stored food must first be broken down into water molecules and then diffused to where it is needed.

   (d) The stored food must be diffused to where it is needed and then broken down into water molecules.

The student needs to realize that starch molecules must be broken down into smaller sugar molecules (digestion) before they can diffuse to areas where the concentration of sugar molecules is low (areas where cells need food in the form of sugar particles). However, the student must translate the stem of the item in selecting B as the correct choice. As such, this item is classified at the comprehension level.

4. Two model cells containing a starch solution are placed in separate beakers of water. Enzymes are added to the starch solution contained in one of the cells. After a period of time, the contents of the cells and the water outside the cells are tested for sugar. Which of the following would be the most likely result?

   (a) The test indicates the presence of sugar in the cell containing enzymes and in the water surrounding this cell.

   (b) The test indicates the presence of sugar in the cell containing no enzymes and in the water surrounding this cell.

   (c) The test indicates the presence of sugar in the water surrounding the cell containing enzymes but does not indicate the presence of sugar in the cell itself.

   (d) The test indicates the presence of sugar in the cell containing no enzymes but does not indicate the presence of sugar in the water surrounding the cell.

In predicting the most likely results of the experiment, the student must be able to <u>apply</u> the concepts of diffusion and enzyme. The enzyme is responsible for the breakdown of starch molecules into sugar molecules. The resultant sugar molecules become more concentrated inside than outside the cell. Therefore, the sugar molecules diffuse to the outside of the cell.

9 5. A coloured substance is sometimes used to soften bathing water. A drop of this substance has a tendency to evenly spread throughout the entire volume of water in the bathtub. How do you explain the spreading out of this coloured substance?

(a) Molecules of the coloured substance have a tendency to move into areas where they are more strongly attracted to water molecules.

(b) Water molecules have a tendency to move away from the coloured substance and thus cause molecules of this substance to move away as well.

(c) The molecules of the coloured substance have a tendency to move into areas where they are less crowded.

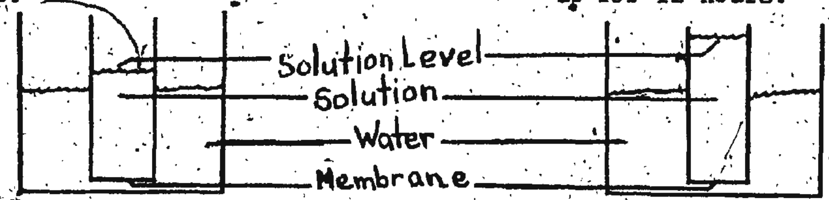
(d) Water molecules have a tendency to avoid a collision with molecules of the coloured substance and thus permit these molecules to distribute themselves evenly.

The explanation requested requires the <u>application</u> of the concept of diffusion. Molecules of the coloured substance diffuse from areas of high concentration to areas of low concentration.

6. The tube in the diagram below has a membrane for a bottom. The diagram shows what happens to the level of sugar solution in this tube when it is placed in a container of water.

Level of solution in tube immediately after apparatus set up.

Level of solution in tube after being set up for 12 hours.



Which of the following statements about the above diagram is correct?

(a) The level of solution rises in the tube because the sugar solution turns into water.

(b) Water molecules pass from the beaker to the solution in the tube and this causes the solution in the tube to rise.

(c) Sugar molecules pass from the tube to the water in the beaker and this causes the solution in the tube to rise.

(d) The level of solution rises in the tube because water evaporates from the beaker.

The explanation for the rise in solution level requires the <u>application</u> of the concept of osmosis. Water molecules are more concentrated on the outside of the test tube than they are on the inside. Therefore, according to osmosis, water molecules passes from the beaker, through the membrane, to the solution in the tube. This causes the level of solution in the tube to rise.

7. Tom is interested in growing plants, but most of his plants are in very poor condition. However, he learns that plants produce food in the form of sugar. So he decides to provide his plants with additional food by dissolving sugar in water and throwing large amounts in the soil. After a period of time he notices that his plants are in even worse condition than previously. Which of the following best accounts for this happening?

(a) Plants are unfavorably affected when they take in large amounts of water.

(b) Plants are unfavourably affected when they take in large amounts of sugar.

(c) Plants are unfavourably affected when they lose large amounts of water.

(d) Plants are unfavourably affected when they lose large amounts of sugar.

Selecting the best account from the above choices requires the <u>application</u> of the concept of osmosis. Since the concentration of water molecules is less outside the plant cells than inside, water diffuses out of the plant (osmosis), thus causing the condition of the plants to further deteriorate.

8. Suppose seeds shrivel up when placed in a liquid. What is the nature of this liquid?

   (a) The liquid contains less water molecules than the seed.
   (b) The liquid and the seed contains an equal concentration of water molecules.
   (c) The liquid contains more water molecules than the seed.
   (d) The seed does not contain any water molecules.

In determining the nature of the liquid the student must be able to apply the concept of osmosis. Since there are less water molecules in the immediate solution surrounding the seed than there are inside the seed, water molecules diffuse from within the seed to the surrounding liquid, causing the seed to shrivel.

This classification places the majority of items comprising the "Plant" test at the application level. According to Bloom's Taxonomy, this test evaluates understanding as opposed to knowledge, the category forming the major emphasis in the test constructed by the teachers.

The "Sound" test was classified in the same way as the "Plant" test. Following are the "Sound" test items and their classifications:

Circle the letter opposite the correct answer to each of the questions asked in the following items.

1. Imagine that there is no air in the earth's atmosphere. Assuming that we could live under these conditions, which of the following would be the most likely outcome?

   (a) We would not be able to hear each other speak.
   (b) We would not be properly heard unless we spoke louder than we do under normal conditions.
   (c) We would not be properly heard unless we spoke in the direction of the listener.

(d) We would not be properly heard unless we spoke slower than we do under normal conditions.

The application of the student's knowledge of sound transmission is required in predicting the correct outcome. The student must apply his/her knowledge that air is necessary as a medium of sound transmission to a functional situation.

2. Suppose that you have a very sensitive instrument for measuring air pressure. How would such an instrument respond to sound waves produced in its immediate area?

(a) The instrument would indicate a rise in pressure.

(b) The instrument would indicate no change in pressure.

(c) The instrument would indicate a fall in pressure.

(d) The instrument would indicate a rapidly rising and falling of air pressure.

In determining instrument response, the student needs to apply the concept of sound waves. He/she must realize that sound waves travel through the air as high and low pressure regions (compression and rarefaction waves respectively) and thus cause corresponding changes in the readings of the instrument.

3. Certain sounds on television sometimes cause vibration in nearby objects. How do these sounds produce such movement?

(a) The television creates a succession of high and low pressure zones in the air that are sometimes energetic enough to move nearby objects.

(b) The television creates puffs of wind in the air that are sometimes forceful enough to move nearby objects.

(c) Air particles are forced to move all the way from the television to nearby objects in sufficient numbers to produce movement in these objects.

(d) The television uses up air particles so extensively in the production of certain sounds that movements are created in nearby objects.

This item requires the application of sound waves as a rapid succession of high and low pressure zones which are sometimes so intense as to cause objects in the immediate area to vibrate.

4. Tom inflated a balloon with a certain gas so that the balloon floated between the ceiling and the floor. He claimed that the balloon could be moved across the room by making a sound. He argued that sound travels outward in the form of waves and that these waves would cause the balloon to move in their direction. However, despite the many sounds produced, the balloon did not move as expected. Why?

   (a) Air particles do not move during sound production.
   (b) Air particles vibrate back and forth during sound production.
   (c) Air particles move with the sound waves but are too small to affect the balloon.
   (d) Air particles move in the direction opposite to that in which sound waves travel.

In selecting the correct explanation, the application of the concept of sound as vibrating air particles needs to be applied. Air particles do not move very far in any one direction during the production of sound (particles vibrate back and forth) and therefore will not move the balloon across the room.

5. A good speaker is heard by everyone in his audience, even those behind him. Which of the following is the explanation for this statement.

   (a) Sound travels in two directions.
   (b) Reflection of sound from the front wall enables individuals behind the speaker to hear.
   (c) A disturbance in the air travels from the speaker to all areas of the room.
   (d) Sound travels in the same way that water travels outward from a disturbance.

In order to correctly complete this item, the student needs to comprehend the multi-directional nature of wave travel from a source.

Since sound travels outward in all directions, in more planes than that suggested in (d), choice (c) is the correct response.

6. Which of the following statements about shock waves [illegible]?

   (a) Shock waves disturb less air particles than sound waves created by a person talking.

   (b) Shock waves disturb more air particles than sound waves created by a person talking.

   (c) Shock waves disturb the air by the same amount as waves created by a person talking.

   (d) Shock waves disturb your eardrum less than sound waves created by a person talking.

This item requires the student to be able to translate his/her conception of shock waves in a way that allows comparison with the extent to which air particles are disturbed by talking.

7. A noisy jet flying close to your home may produce a rattle in the dishes on the kitchen table. Which of the following best explains such an occurrence?

   (a) The jet produces high and low pressure zones large enough to create such movements.

   (b) The jet produces a high pressure zone large enough to cause such movements.

   (c) The jet produces a low pressure zone large enough to create such movements.

   (d) The jet forces air in the direction of the earth sufficient to produce such movements.

The best explanation is determined by <u>applying</u> the concept of shock waves. Shock waves cause air disturbances intensive enough to cause easily moved objects to vibrate.

8. Bill has taken a weekend with his parents to stay in a small cabin in the country. Lighting for the cabin was provided by a small oil lamp. While playing near the lamp, Bill burst a large balloon. The lamp went out. Which of the following best explains this happening?

(a) The loud noise caused the lamp to go out.

(b) The high and low pressure zones created by the bursting of the balloon caused the lamp to go out.

(c) The movement of air particles from the lamp to the balloon caused the lamp to go out.

(d) Air particles forced in the direction of the lamp caused it to go out.

The best explanation is determined by applying the concept of shock waves. Sometimes shock waves are so intensive as to create high and low pressure zones extreme enough to cause small lights like lamps to "go out."

9. Which of the following statements about the reflection of sound is true?

(a) Reflected sound waves are larger than the original sound waves.

(b) Reflected sound waves are smaller than the original sound waves.

(c) Reflected sound waves travel faster than the original sound waves.

(d) Reflected sound waves are the same size as the original sound waves.

This item requires the student to translate his/her conception of sound reflection into a form that allows him/her to make a comparison of the magnitude of the original sound waves and the reflected sound waves.

10. Which of these statements is correct?

(a) All vibrating objects produce sound.

(b) All sounds are produced by vibrating objects.

(c) An object that moves produces sound.

(d) Sound is produced regardless of the rate of movement of some object.

The correct choice requires the <u>application</u> of the concept of sound production. The student must realize that whether or not sound is produced depends upon the frequency of vibration of an object.

11. Sea captains have sometimes used sound to determine the distance between their ship and the land during dense fog and during the night. What characteristics of sound waves do you think these captains might have used to find this distance?

   (a) Sound waves reflect from the shoreline and travel in the direction of the ship at a speed twice the rate of the original sound.

   (b) Sound waves that reflect from the shoreline produce a sound that is twice as loud as the original sound.

   (c) Sound waves reflect from the shoreline and travel outward at the same speed as the original sound.

   (d) Sound waves which reflect from the shoreline travel at a slower speed than the original sound waves.

This item requires the <u>application</u> of sound reflection to a real situation. Since reflected sound travels outward at the same speed as the original sound, the captain is able to use this information plus the speed of sound to find the distance of his ship from the nearby shore.

12. Bees produce a sound when they fly. This sound is created by the rapid movement of the bee's wings. Which of the following statements could you make on the basis of this information? An

   (a) The sound produced by the bee is high pitched.

   (b) The bee's wings vibrate faster than most tuning forks.

   (c) The vibration of the bee's wings create a rapid train of compression and rarefaction waves.

   (d) The bee's wings are too small to disturb the air.

In order to make the correct choice, sound needs to be conceived as a rapid succession of compression and rarefaction waves. The student needs to realize that if the bee's wings are creating a sound, then they must be producing a rapid train of compression and rarefaction waves. Thus, the student must be able to <u>translate</u> his knowledge of sound production in dealing with this particular item.

13. What effect does a vibrating tuning fork have on air particles when it quickly moves to the RIGHT?

(a) It causes the air particles at the RIGHT to move together.

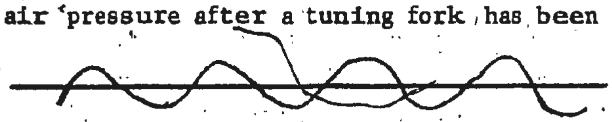
(b) It causes the air particles at the LEFT to move together.

(c) It causes the air particles at the RIGHT to move apart.

(d) It does not cause any disturbance of air particles at the LEFT.

This item requires the <u>interpretation</u> of a vibrating tuning fork with respect to its influence on surrounding air particles. As the fork moves to the right, it causes the air particles to the right to move together and the air particles at the left to move apart.

14. The following diagram is taken from your book. It represents changes in air pressure after a tuning fork has been struck.



What does this diagram tell us about the way in which sound travels from the tuning fork to the ear of the observer?

(a) Air particles move up and down as sound travels from the tuning fork to the observer.

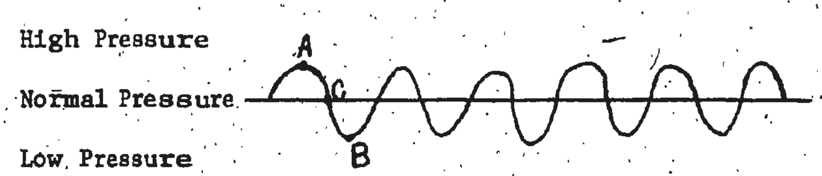
(b) Sound moves along a path similar to the above curve as it travels from the tuning fork to the observer.

(c) Sound travels from the tuning fork to the observer in the form of a succession of high and low pressure zones.

(d) Air particles travel from the tuning fork to the ear of the observer as sound travels from the tuning fork to the observer.

This item requires the interpretation of a diagram in terms of how sound travels from a source to our ears (as a series of high and low pressure sounds).

15. The graph below indicates how a vibrating object disturbs air particles.



Which of the following statements about the above graph is NOT correct?

(a) Point A is located on that part of the curve which indicates that air particles are closer together than normally is the case.

(b) Point B is located on that part of the curve which indicates that air particles are farther apart than normally is the case.

(c) Point C is located on that part of the curve which indicates that air particles are closer together than A.

(d) Point B is located on that part of the curve which indicates that air particles are farther apart than at A.

This item requires the interpretation of a graph in terms of its representation of the closeness of air particles.

16. What is the frequency of an object that makes 30 complete vibrations in ten seconds?

(a) 3 vibrations per second.

(b) 10 vibrations per second.

(c) 30 vibrations per second.

(d) 1/3 vibration per second.

The above item requires the application of the concept of frequency in determining the frequency of an object, given the appropriate information.

17. If you could change the vibration of an object, what would you do to make it produce a higher pitch?

(a) Decrease the rate of vibration.

(b) Increase the rate of vibration.

(c) Keep the rate of vibration the same.

(d) Decrease the size of vibration.

In correctly completing the above item, the student must have comprehended the concept of pitch. He/she must be aware of how the rate of vibration effects pitch.

According to the above classification, the "Sound" test consists of items written primarily at the application level. Like the "Plant" test, this test examines at a higher level than the corresponding test developed by the classroom teachers.