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THE RELATIONSHIP BETWEEN INTELLECTUAL LEVELS AND ACHIEVEMENT IN THE COMPREHENSION OF CONCEPTS CLASSIFIED ACCORDING TO A SCHEME DERIVED FROM THE PIAGETIAN MODEL

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THE RELATIONSHIP BETWEEN INTELLECTUAL LEVELS AND ACHIEVEMENT

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CHAPTER I

INTRODUCTION

Statement of the Problem

Lawson's 1973 research[1] demonstrated that formal operational students enjoyed success in the comprehension of concrete and formal concepts and concrete operational students have success only in the comprehension of concrete concepts. That research led this investigator to the conclusion that a system of classification was needed in order to enable teachers to classify the concepts that they are teaching and thereby adjust their expectations for concrete and formal students.

This investigation was designed to develop a classification system of concepts according to the type of thought, concrete operational or formal operational, required to understand them. The classification scheme was based upon the Piagetian model of cognitive development.

Motivated by Lawson's work, this investigation sought answers to the following specific questions:

[1]Anton E. Lawson, "Relationships Between Concrete and Formal Operational Science Subject Matter and the Intellectual Level of the Learner," (unpublished doctoral dissertation, University of Oklahoma, 1973).

1. What are the levels of intellectual development of students who are enrolled in chemistry and physics?

2. Which of the concepts in chemistry and physics can be classified as requiring concrete operational thought and which ones can be classified as requiring formal operational thought for understanding?

3. To what degree are concepts which are rated as concrete operational and formal operational by the classification system understood by the students at these levels?

4. What is the relationship between levels of intellectual development and achievement in the comprehension of concrete and formal concepts?

Purpose of the Study

To provide the framework for the classification system, operational criteria for formal and concrete operational thought were delineated and defined. In addition, major concepts in secondary school chemistry and physics were isolated and subjected to the criteria for evaluation and classification. The courses from which these concepts were taken are Chemical Material Education Study (CHEM Study)[2] and Project Physics.[3]

This study sought to assess understanding of concrete and formal operational concepts by students enrolled in classes in CHEM Study and Project Physics at the eleventh and twelfth grades. The levels of intellectual development of these students were determined

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[2]Robert Parry, *et al.*, *Chemistry: Experimental Foundations* (Englewood Cliffs, N. J.: Prentice-Hall, Inc., 1970), an authorized revision of the original CHEM Study course was used in this study.

[3]Project Physics Staff, *Project Physics*, (New York: Holt, Rinehart and Winston, Inc., 1970) was the text used in this course.

using three Piagetian tasks. Understanding of the concepts was assessed at the end of the first semester and at the end of the second semester using achievement tests in physics and chemistry.

Definitions

To aid in the understanding of the classification scheme and the operational criteria used, certain definitions taken from Piagetian theory were necessary. Those definitions are given here.

1. Operation - An operation is a mental action that is reversible in nature.

> An operation is an action that can be internalized, that is, it can be carried out in thought as well as executed materially . . . is a reversible action, that is, it can take place in one direction or in the opposite direction. . . . it always supposes some conservation, some invariant. . . . it is a transformation that does not transform everything at once or else there would be no possibility of reversibility. Every operation is related to a system of operations, or to a total structure as we call it.[4]

2. Structure - A structure is a group of logically related operations.

> A structure is a totality, that is, it is a system governed by laws that apply to the system as such, and not only to one another element in the system.[5]

The laws governing the system (structure) are also laws of transformation that can be carried out within the system itself; in other words, the system regulates itself.[6] Flavell defines structures as organizational properties of intelligence that are created through functioning and

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[4] Jean Piaget, Genetic Epistemology (New York: W. W. Norton and Company, Inc., 1971), pp. 21-22.

[5] Ibid., p. 22.

[6] Ibid., p. 23.

and whose existence may be deduced from an observation of the overt behavior of the individual.[7]

3. Seriation - Seriation is an operation that involves arranging non-equivalent entities A, B, C, in an order such that, for the same property, $A < B < C$. It means assembling the asymmetrical relations which express differences among individuals such that an order of succession is created.[8]

4. Transitivity - Transitivity is the operation that enables a child to see that two systems are related in terms of a specific property (like weight) although all other properties may be different. It lends to the conclusion that if A=B and B=C, then A=C, or that if $A < B$ and $B < C$, then $A < C$.[9]

5. Class Inclusion - Operations of class inclusion relate to the child's ability to manipulate part-whole relationships within a set of categories. It is possible to put together two classes to form a larger one or to take away a part from the whole. Likewise, classes can be multiplied.[10]

6. One-to-one Correspondence - This operation involves the construction of equivalence between two separate orderings, these orderings containing equal numbers of elements.[11]

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[7]John H. Flavell, The Developmental Psychology of Jean Piaget (Princeton, N. J.: D. van Nostrand Co., Inc., 1963), p. 17.

[8]Jean Piaget, Psychology of Intelligence (Totowa, N.J.: Littlefield Adams and Co., 1968), p. 44.

[9]Ibid.

[10]Barbel Inhelder and Jean Piaget, The Growth of Logical Thinking from Childhood to Adolescence (New York: Basic Books, Inc., 1958), Translator's Introduction, p. xv.

[11]Herbert Ginsburg and Sylvia Opper, Piaget's Theory of Intellectual Development (Englewood Cliffs, N. J.: Prentice-Hall, Inc., 1969), p. 138.

7. Conservation - Conservation is involved when a structure is regarded as invariant despite physical changes of some aspect. It is the ability to compensate internally for whatever external changes that may be taking place.[12]

8. Propositional Thinking - Propositional thinking involves the formulation of hypotheses and the development of deductions which, but not necessarily, culminate in experimental verification. It is a second-order operational system which operates on propositions whose truth, in turn, depend on class, relational, and numerical operations.[13]

9. Combinatorial Operations - Combinatorial operations are used when the adolescent is able to link a set of base associations or correspondences with each other in all possible ways as to draw from the relationships of implication, disjunction, exclusion.[14] Flavell calls this process of reasoning "combinatorial analysis". According to Flavell, what the adolescent does " . . . is to systematically isolate all the individual variables plus all possible combinations of these variables.[15] Using the operations of reversibility and reciprocity, the adolescent can consider all these possibilities, combine them in such a way as to enable him to decide which of a number of potential explanations, in fact, explain the situation.

10. Proportional Reasoning - Proportional reasoning is the ability

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[12]Piaget, The Psychology of Intelligence, p. 131.

[13]Inhelder and Piaget, op. cit., p. xxii.

[14]Ibid., p. 107.

[15]Flavell, Developmental Psychology of Jean Piaget, p. 205.

to combine two relations or ratios into an equivalence. It is linked to the double reversibility of reciprocals and inverses.[16] The ability to do proportional reasoning develops from a qualitative concept of proportions--the idea that two factors acting together produce the same result as the action of two other factors acting together. With this qualitative concept of proportions, the thinking is still fairly concrete. When the adolescent can generalize to all possible cases and can incorporate the notions of reversibility and reciprocity into his original thinking, then he becomes capable of proportional reasoning.

11. Separation of Variables - Separation of variables is an operation that requires the adolescent to be able to organize a complex situation by means of concrete operations and then view the sets of facts collected as a starting point for new combinations. In so doing, he can obtain a new set of operations corresponding to a structured whole.[17] Thus, through this operation, the adolescent is able to separate the variables by varying each in turn while holding all the other factors constant.

12. Exclusion - Exclusion is an operation that can be carried out after separation of variables. It involves the ability to recognize that, of the existent variables, only one actually plays a causal role. The other variables that do not have an effect must be excluded after they have been isolated.[18]

13. Reciprocal Implications - Reciprocal implications take place when the adolescent establishes concrete correspondences between two factors

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[16] Inhelder and Piaget, Growth of Logical Thinking, p. 61.

[17] Ibid.

[18] Ibid., p. 54.

and then sees that there is necessary reciprocity between the two. The reciprocity involved here is a type of reversibility in which the effect of one factor is compensated for by the effect of the other. This type of operation differs from a simple one-to-one correspondence in the sense that implications are postulated and do not result merely from empirical observations.[19]

14. Concrete Operational Concept - A concrete operational concept is a "representational scheme"[20] that requires the gathering of data from objects and the incorporation of those data into the cognitive structure before it can be understood. It is a concept that can be developed through operations based on experimental findings; its understanding can be achieved only through first-hand experience with objects.

15. Formal Operational Concept - A formal operational concept is one that can be developed by operating on concrete operations.[21] The understanding of such a concept requires the use of axiomatic thinking rather than object manipulation. It is a concept "whose meaning is derived through position within a postulatory-deductive system."[22]

Premises of the Study

The premises tested by this investigation were:

1. A system for categorizing chemistry and physics concepts in terms of concrete and formal operations can be developed.

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[19] *Ibid.*, p. 19.

[20] Hans G. Furth, *Piaget and Knowledge* (Englewood Cliffs, N. J.: Prentice-Hall, Inc., 1969), p. 52.

[21] John L. Phillips, Jr., *The Origins of the Intellect: Piaget's Theory* (San Franscisco: W. H. Freeman and Co., 1969), p. 103.

[22] Lawson, *op. cit.*, p. 5.

2. There are distinct mental operations that are needed for a complete understanding of concrete operational concepts.

3. There are distinct mental operations that are needed for a complete understanding of formal operational concepts.

Furthermore, in undertaking this investigation, the following conclusions from prior research by Lawson[23] are accepted:

1. Piagetian tasks can be used as a measure of formal and concrete operations.

2. Concrete operational concepts can be understood by students who are thinking on the level of concrete operations.

3. Concrete and formal operational concepts can be understood by students who are thinking on the level of formal operations.

Background of the Study

With the launching of Sputnik by the Russians in 1957, a wave of curricular reforms in science engulfed this country. At the forefront of this sweeping wave was a physics course designed and tested by the Physical Science Study Committee (PSSC) followed by three versions of biology designed and tested by the Biological Sciences Curriculum Study (BSCS) group. Other science programs developed for use in the junior and senior high schools include Chemical Bond Approach (CBA) to chemistry, Chemical Education Materials Study (CHEM Study), Introductory Physical Science (IPS, Physical Science II (PS II), Earth Science Curriculum Project (ESCP), and Time, Space, and Matter (TSM). For a review of

[23]Lawson, op. cit., pp. 87-92.

these programs, see Renner and Stafford[24] or Hurd[25,26].

Examination of the new science curricula led this investigator to conclude that those courses could be employed from an inquiry frame of reference and that employment would lead the student to the development of his rational powers of "recalling and imagining, classifying and generalizing, comparing and evaluating, analyzing and synthesizing, and deducing and inferring."[27] Friot, in working with junior high students, found that those students of inquiry-oriented courses showed far more significant gains in the ability to think logically than those students who took the traditional science courses.[28]

The concepts classified in this investigation are found in Project Physics, and in an authorized revision[29] of the original CHEM Study course. Both courses rely heavily on the laboratory to provide the students with opportunities to explore, to invent, and make discoveries, all of which constitute inquiry.

Parry and others[30] assert that experimentation is the vehicle for presenting chemistry as it is today. They go on to say that unifying

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[24] John W. Renner and Don G. Stafford, Teaching Science in the Secondary School (New York: Harper and Row, Publishers, 1972).

[25] Paul D. Hurd, New Directions for Teaching Secondary School Science (Chicago: Rand McNally and Company, 1969).

[26] Paul D. Hurd, New Curriculum Perspectives for Junior High School Science (Belmont, Calif.: Wadsworth Co., 1970).

[27] Educational Policies Commission, The Central Purpose of American Education (Washington, D. C.: National Education Association, 1961), p. 5.

[28] John W. Renner, et al., Research, Teaching, and Learning with the Piagetian Model (University of Oklahoma Press, In Press).

[29] Parry, et al., op. cit., p. v.

[30] Ibid.

principles developed from experimental observations allow chemistry to emerge as a science rather than as a mass of information. They assert that the cornerstone of their revision of CHEM Study is the same as the cornerstone of modern science--the development of principle from observation.

Merrill[31] discusses the role of experimentation in the development of concepts in CHEM Study.

> The experiments developed by the CHEM Study group are specific in terms of procedure but open-minded as to expected results and interpretations. The instructions include questions to help direct the student's thinking, but they are written in such a way that an experiment has to be performed and thought about to be understood. The laboratory is used as a place where students make and record observations on a system, seek patterns and regularities and then attempt to develop tentative explanations or mental models to rationalize what they have observed.

Project Physics evolved from the efforts of three men[32], a high school physics teacher, a university physicist, and a science educator. This course purports to offer a type of physics that would be within the intellectual grasp of the students in high school. The three men collaborated from 1962 to 1964 to define the main purposes and isolate the topics for inclusion in the course. They were later joined by many educators who were brought together for the express purpose of writing, editing, and testing the physics course which now goes under the name Project Physics.

Project Physics makes two assumptions about physics and the way it is to be presented: (1) Physics concepts are few in number because

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[31] Richard J. Merrill, "Chemistry: An Experimental Science." The Science Teacher Vol. 30 (April 1963), p. 26.

[32] F. James Rutherford, Gerald Holton, and Fletcher Watson, Directors of Harvard Project Physics.

the principles are interrelated, and (2) the content of physics may change by growth and structuring. Project Physics also assumes that most students are capable of learning a great deal of physics although not all of them will reach the same degree of comprehension, and that all students are capable of acquiring a qualitative, if not a quantitative, understanding of all the concepts.[33]

The chief purposes of Project Physics are:[34]

1. To design a humanistically oriented physics course.
2. To develop a course that would attract a large number of high school students to the study of introductory physics.
3. To contribute to the knowledge of the factors that influence science teaching.

Need for the Study

The need for this research grew out of the study done by Lawson in 1973 in which he demonstrated that concrete operational thinkers can not comprehend formal concepts. Lawson recommended that a careful study of specific curricula and specific students be made in order to evaluate just how much understanding is possible and just how appropriate today's new curricula are in terms of intellectual level of students.[35] To do such a study of science curricula, however, necessitated that a system based upon a theoretical framework be developed for categorizing different concepts on the basis of the kind of thinking required of the learners. This study concerned itself with the development of such a system of categorization using criteria based on the Piagetian model.

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[33] Project Physics Staff, The Project Physics Course Teachers Guide (New York: Holt, Rinehart and Winston, Inc., 1970), p. 2.

[34] *Ibid*., p. 1.

[35] Lawson, *op*. *cit*., p. 94.

Langer wrote that "there is a gap between what the developmental psychologist of cognition is talking about and what people responsible for the teaching of knowledge are doing."[36] Cronbach posed the problem in this way:[37]

> Today's curriculum maker is concerned with instruction that somehow develops mental structures and facilitates the assimilation of new and different material. Here is the objective; and here is Piaget's theory about assimilation. The two seem quite compatible; yet the pedagogical bridge is still to be found.

It is quite clear that this pedagogical bridge has not been found. This investigator believes that the development of a classification scheme based on the Piagetian model could be a first step towards bridging that gap between developmental theory and the curriculum.

Limitations

The degree to which the results of this study may be generalized has the following limitations:

1. This study was limited to two secondary science curricula: Project Physics and CHEM Study.

2. Operational criteria used in the classification scheme were chosen to be harmonious with the Piagetian theoretical framework. To validate the classification scheme, copies of the operational criteria used and examples of concepts taken from physics and chemistry that had been classified according to these criteria were sent to science educators who are knowledgeable both in the subject content and in Piagetian theory. Thus,

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[36] Jonas Langer, "Implications of Piaget's Talks for Curriculum," Journal of Research for Science Teaching Vol. 2 (1964), p. 209.

[37] Lee J. Cronbach, "Learning Research and Curriculum Development," Journal of Research for Science Teaching Vol. 2 (1964), p. 207.

the validity of this classification scheme is subject to the limitation of the analytical thought given it by this jury.

3. Results of this research are dependent upon the validity with which each item on the Project Physics and CHEM Study achievement test measures the understanding of the concept it purports to measure. Since both courses, including the achievement tests, have been field tested by many students and teachers all over the country, this investigator assumed that the content instruments had validity.

Hypotheses of the Study

Four major null hypotheses were tested against four alternative hypotheses in this study. The major null hypotheses were:

1. Ho: No significant difference exists in the population proportions of concrete and formal operational students on questions involving concrete physics concepts.

2. Ho: No significant difference exists in the population proportions of concrete and formal operational students on questions involving formal physics concepts.

3. Ho: No significant difference exists in the population proportions of concrete and formal students on questions involving concrete chemistry concepts.

4. Ho: No significant difference exists in the population proportions of concrete and formal students on questions involving formal chemistry concepts.

CHAPTER II

REVIEW OF THE LITERATURE

This literature review will be divided into two sections. The first section will deal with a summary of Piaget's cognitive developmental theory with particular emphasis on the levels of formal and concrete operations. It will also include other author's interpretations of the Piagetian model as applied to concrete and formal operational learners. The second section of this chapter will be devoted to a review of the research directly related to Piagetian theory and concept formation.

Review of Piagetian Theory of Cognitive Development

Piaget looks upon learning as being provoked rather than spontaneous. Learning is a limited process involving a single structure and can best be explained in terms of the development of knowledge. An individual learns when he actively seeks to acquire knowledge. Knowledge, to Piaget, is not a mere copy of reality. It involves setting up structures in order that what is real may be assimilated into the cognition. He says: "To know an object is to act on it."[1]

When an individual at the concrete level of thought or above acts on an object, he is performing an operation, which is the "essence of knowledge."[2] Operations may be first order mental actions such as those

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[1]Jean Piaget, "Development and Learning," Journal of Research in Science Teaching Vol. 2 (1964), p. 177.

[2]Ibid., p. 178.

of class inclusion, transitivity, seriation, one-to-one correspondence, and conservation.[3] Other operations may be second-order operations, i.e., operations performed on operations. These two types of operations cannot be understood until one knows the kinds of structures that are present and can be developed in the human mind.

In the Piagetian model, there are four stages of operations recognized. These stages are organized as follows:[4]

> After the appearance of language, or more precisely, the symbolic function that makes its acquisition possible (1½-2 years), there begins a period which lasts until mainly 4 years and sees the development of a symbolic and preconceptual thought.
>
> From about 4 to about 7 or 8 years, there is developed, as a closely linked continuation of the previous stage, an intuitive thought whose progressive articulations lead to the threshold of the operation.
>
> From 7-8 to 11-12 years, "concrete operations" are organized, i.e., operational groupings of thought concerning objects that can be manipulated or known through the senses.
>
> Finally from 11-12 years and during adolescence, formal thought is perfected and its groupings characterize the completion of reflective intelligence.

It is only during the third stage--concrete operations--that the individual becomes capable of internalizing an action that can take place in both directions. In this stage, however, such operations can take place only if objects are readily available to act upon. No formal hypothesis formation can as yet take place.

The fourth and highest level of intellectual development is that of formal operations. At the prior stage--concrete operations--the individual bases his thinking on operations that require material objects.

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[3]Robert Karplus, "Opportunities for Concrete and Formal Thinking on Science Tasks," Lecture delivered at the Third Annual Meeting of the Jean Piaget Society, May 22, 1973.

[4]Piaget, Psychology of Intelligence, p. 123.

At the formal stage, he is able to reflect on the operations which he utilized in the concrete stage. Formal operations, therefore, consist of implications and contradictions that exist between operations of class inclusion, seriation, transitivity, one-to-one correspondence, and conservation.[5]

The formation of these stages of intellectual development can be explained in terms of the set of structures inherent within each stage. The development of these sets of structures is governed by four main factors: (1) maturation, (2) experience, (3) social transmission, and (4) equilibration. The principal and most important factor is that of equilibration. Piaget says:[6]

> It is that, in the act of knowing, the object is active, and consequently, faced with an external disturbance, he will react in order to compensate and, consequently he will tend toward equilibrium. Equilibrium, defined by active compensation, leads to reversibility . . . Equilibration . . . is thus an active process. It is a process of self-regulation.

Piaget looks at the process of equilibration as one that involves balance between assimilation and accomodation in a biological sense. Assimilation takes place when an individual views the real world in his own framework. Frequently, however, something happens that he cannot quite incorporate into his cognitive structures because of the absence of a particular set of structures. He has to accommodate, that is, he has to change his view. In Duckworth's words: "He must accommodate if he wants to incorporate this new view."[7]

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[5] _Ibid._, p. 149.

[6] Piaget, "Development and Learning," p. 181.

[7] Eleanor Duckworth, "Piaget Rediscovered," _Journal of Research in Science Teaching_ Vol. 2 (1964), p. 174.

Concrete vs. Formal Thought

Piaget[8] distinguishes the concrete operational thinker from the formal operational thinker:

> Formal thought reaches its fruition during adolescence. The adolescent, unlike the child, is an individual who thinks beyond the present, and forms theories about everything, delighting especially in considerations of that which is not. The child, on the other hand, concerns himself only with action in progress and does not form theories, even though an observer notes the periodical recurrence of analogous reactions and may discern a spontaneous systematization in his ideas. This reflective thought, which is characteristic of the adolescent, exists from the stage of 11-12 years, from the time, that is, when the subject becomes capable of reasoning in a hypothetico-deductive manner, i.e., on the basis of simple assumptions which have no necessary relation to reality or to the subject's beliefs, and from the time when he relies on the necessary validity of an inference (vi formae) as opposed to agreement of the conclusions with experience.

Langer,[9] speaking from the Piagetian framework, describes the formal operational adolescent as being ready to "construct a formal logical theory of events that (a) stands independent of any particular event or instance, and (b) considers possible events in addition to actual ones." He explains that the type of thinking of which the concrete operational thinker is capable results from his ability to differentiate two types of reversible operations, those of inversion and reciprocity. Piaget defines inversion (or negation) as that which corresponds to the additions or eliminations effected in the parts of the system which comes into equilibrium. Similarly, reciprocity (or symmetry) is defined as the property which corresponds to the symmetries or compensations between these parts.[10]

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[8] Piaget, Psychology of Intelligence, p. 148.

[9] Jonas Langer, Theories of Development (New York: Holt, Rinehart and Winston, Inc., 1969), p. 145.

[10] Piaget, Growth of Logical Thinking, p. 133.

However, despite this ability to distinguish between inversion and reciprocity, the concrete thinker is unable to coordinate them. It is not until he moves into formal operations that he can relate the two in order to form a combinatorial system.

Flavell,[11] in explaining Piaget's theory, writes about the concrete child and the formal adolescent:

> . . . the child deals largely with the present, with the here and now; the adolescent extends his conceptual range to the hypothetical, the future and the spatially remote. . . There is adaptive significance in this difference. The adolescent is beginning to take up adult roles; for him the world of personally relevant future possibilities--occupational selection, marital choice, and the like --is a most important object of reflection. Similarly, the adult that he will shortly become must make intellectual contact with social collectivities much less concrete and immediate than family and friends: city, state, country, labor union, church, etc.

Maier,[12] also writing about Piaget's developmental theory, describes the formal operational thinker as having acquired the capacity to think and to reason beyond his own world of reality and his own beliefs; he can enter into a world of ideas that has no links with the real; for him, thinking is based on symbols and the use of propositions. Maier describes the concrete thinker as one who is unable to devise a systematic approach to problems and is unable to understand geometric relations and questions dealing with propositions.

Renner and Stafford[13] describe the formal operational thinker as one who is able to do an experiment, to collect data, to mentally transform and organize those data to develop a hypothesis involving "possible combinations." They go on to say that the adolescent "can

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[11]Flavell, op. cit., p. 223.

[12]Henry W. Maier, Three Theories of Child Development (New York: Harper and Row, Publishers, 1965, 1969), p. 146.

[13]Renner and Stafford, op. cit., pp. 91-93.

be thought of as a liberated thinker. He is less inhibited in his thoughts about the real world."

Gorman[14] lists concrete operations as: (1) classification and ordering, (2) decentering and coordination, (3) reversibility, (4) inductive reasoning. He says that formal operations consist of : (1) hypothetico-deductive reasoning, (2) abstract and formal thought, (3) control of variables, (4) verification of statements, (5) proportionality, and (6) an integrated system of operations and transformations.

In describing the transition from concrete to abstract cognitive functioning, Ausubel[15] writes that the adolescent becomes less dependent on objects after he has had a great deal of practice in comprehending and manipulating relationships.

> . . . the intellectually mature individual becomes capable of understanding and manipulating relationships between abstractions <u>directly</u> . . . Instead of reasoning directly from a particular set of data, he uses indirect--second order--logical operations of structuring the data; instead of merely grouping data into classes or arranging them serially in terms of a given variable, he formulates and tests hypotheses based on all possible combinations of variables.[16]

Phillips[17] summarizes the characteristics of the formal operational thinker:

> The adolescent begins where the Concrete Operations child left off --with concrete operations. He then operates on those operations by casting them into the form of propositions. These propositions then become part of a cognitive structure that owes its existence

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[14] Richard M. Gorman, <u>Discovering Piaget: A Guide for Teachers</u> (Columbus, Ohio: Charles E. Merrill Publishing Co., 1972), p. 110.

[15] David P. Ausubel, "The Transition from Concrete to Abstract Cognitive Functioning: Theoretical Issues and Implications for Education," <u>Journal of Research in Science Teaching</u> Vol. 2 (1964), p. 261.

[16] Ibid., p. 261.

[17] Phillips, <u>op</u>. <u>cit</u>., pp. 103-104.

to past experience but makes possible hypotheses that do not correspond to any particular experience. The Concrete Operations child always starts with experience and makes limited interpolations and extrapolations from the data available to his senses. The adolescent, however, begins with the possible and then checks various possibilities against memorial representations of past experience and eventually against sensory feedback from the concrete manipulations that are suggested by his hypotheses.

Related Research

Much research has been done with the Piagetian model as applied to elementary age students. In particular, several investigators have concerned themselves with conservation tasks as means of identifying the concrete operational thinker. On the other hand, an investigation of the literature does not yield much regarding research seeking to identify the formal operational thinker in senior high school. Piaget himself has been criticized for not extending his writing into the realm of adolescence and adulthood.[18] It was in response to this criticism that Piaget wrote an article[19] in which he reviewed the principal characteristics of the intellectual changes that take place during the period from 12-15 years of age and then discussed the problems that arise in evaluating the intellectual level of individuals in the next period (15-20 years). It was also in this article that Piaget stated that recent research has shown that subjects from different kinds of schools or different social environments seemed to have stayed in the concrete operational stage longer, *i.e.*, subjects 15-20 years of age were still concrete operational in their thinking.[20]

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[18] CRM Staff, Educational Psychology (Del Mar, Calif.: CRM Books, 1972), p. 88.

[19] Jean Piaget, "Intellectual Evolution from Adolescence to Adulthood," Human Development Vol. 15 (1972), pp. 1-12.

[20] Piaget's earlier prediction that formal operational structures

In 1973, Renner and Lawson reported data which support Piaget's most recent conclusions. In that report, they conclude that many students in high school (ages 15-18 years) were still concrete operational in their thinking.[21] The researchers, using the tasks of conservation of volume and exclusion of irrelevant variables[22] found that of 196 eleventh and twelfth graders tested, only ninety-seven could perform the first task and only seventy-three could do the second task. Using the conservation-of-volume task as a predictor of formal operational thinking, the Renner-Lawson report suggests that only about fifty per cent of the population from which chemistry and physics are drawn can be labeled formal thinkers.

The results of the Renner-Lawson study seem to agree with Kohlberg and Gilligan's findings on an investigation done with 265 subjects using the exclusion task. The following percentages of formal operational thinkers were found among the subjects tested.[23]

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[20]are formed in the learner at ages 12-15 was based on experiments done with secondary school students taken from the better schools of Geneva. Piaget suggested that his sample may have come from a somewhat privileged population.

[21]John W. Renner and Anton E. Lawson, "Promoting Intellectual Development Through Science Teaching," The Physics Teacher Vol. 11 (may, 1973), pp. 273-276.

[22]Conservation of volume involves the use of two cylinders of identical size and shape but different weights. Exclusion of irrelevant variables involves the use of the simple pendulum. For a complete description of these tasks, see Renner and Stafford, op. cit., p. 293-295.

[23]Lawrence Kohlberg and Carol Gilligan, "The Adolescent as a Philosopher: The Discovery of the Self in a Postconventional World," Daedelus Vol. 100 (Fall, 1971), p. 1051.

age 10-15	45%	age 21-30	65%
age 16-20	53%	age 45-50	57%

In an earlier study, Renner and co-workers,[24] reported that, in a test population of 588 students in seventh through twelfth grades, about seventy-five per cent of the subjects were still concrete operational in their thinking. Friot,[25] in working with junior high learners, obtained nearly the same results. On the other end of the spectrum, McKinnon,[26] testing a population made up of college freshmen, reported that only forty-nine per cent of the sample were operating on the level of formal operations.

Needleman[27] concluded in her study of performance of junior high learners that many of them have failed to acquire some of the concepts prerequisite to an understanding of area as well as the area concept itself. Since area is a derived quantity and its comprehension requires that the learner perform "operations on operations", the inability of the learner to acquire an understanding of this concept indicates that he is concrete operational in his thinking. The results of Needleman's study indicate agreement with Friot's findings.

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[24]Renner and Stafford, op. cit., p. 295.

[25]John W. Renner, et al., Research, Teaching, and Learning with the Piagetian model (University of Oklahoma Press, In Press).

[26]Joe W. McKinnon and John W. Renner, "Are Colleges Concerned with Intellectual Development?" American Journal of Physics (Sept., 1971), pp. 1047-1052.

[27]Joan R. Needleman, "Scalogram Analysis of Certain Area Concepts Proposed by Piaget," (unpublished doctoral dissertation, Boston University, 1970).

One other study deserves mention because its findings parallel Lawson's conclusions about what the formal operational thinker can do. Sheehan[28] tested the effects of a concrete and a formal operational procedure on students who had been classified as being either concrete or formal operational thinkers. One of his conclusions was that formal students showed greater achievement using either concrete or formal instructional procedures than concrete operational students. Lawson found that formal thought does contribute to the understanding of concrete concepts and postulated that this is possible because the formal thinker is able to elucidate a more comprehensive system of both concrete and formal content.[29] A graph comparing the performance of concrete and formal operational students on concrete and formal concepts as measured by Lawson's subject matter tests is shown in Figure 2-1.

It is evident from reviewing the findings of related research that a great percentage of the learners in secondary schools are still concrete operational in their thinking and that their intellectual levels determine the type of concepts they can comprehend. Clearly, a classification system for concepts involved in the secondary curriculum needs to be done before a meaningful compatibility between curriculum and learner can be achieved. This investigator sees this area of research as the place to put the Piagetian model to good use.

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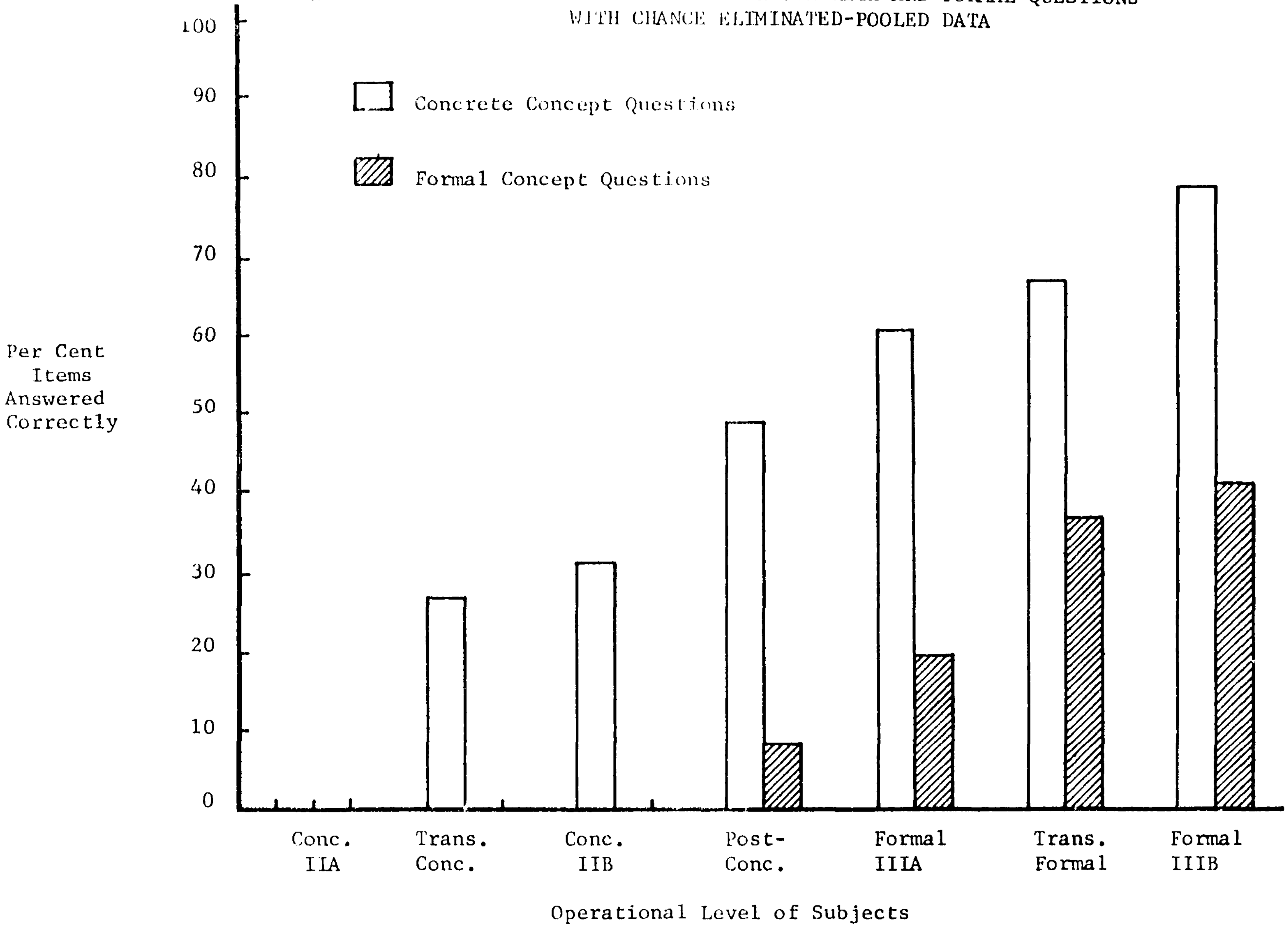
[28]Donald J. Sheehan, "The Effectiveness of Concrete and Formal Instructional Procedures with Concrete-and Formal-Operational Students," (unpublished doctoral dissertation, State University of New York at Albany, 1970).

[29]Lawson, _op. cit._, p. 90.

Figure 2-1. A COMPARISON OF SUCCESS ON CONCRETE AND FORMAL QUESTIONS WITH CHANCE ELIMINATED-POOLED DATA



SOURCE: Lawson, "Relationships Between Concrete and Formal Science Subject Matter and Intellectual Level," p. 66.

CHAPTER III

PROCEDURES OF THE STUDY

Objectives

This investigation had the following objectives: (1) to develop a classification scheme for formal and concrete operational concepts using the Piagetian model as the basis for the classification, (2) to assess the operational level of intellect of students enrolled in physics and chemistry, and (3) to determine if there is a significant difference between predicted and actual achievement of known formal and concrete operational students on physics and chemistry test questions involving formal and concrete operational concepts as placed by the classification system.

Evolution and Evaluation of Concept Classification System

A concept classification system was developed by the investigator using operational criteria based on the Piagetian model of intellect intellectual development. The operational criteria used and their definitions have been refined as a result of discussions with graduate students enrolled in a seminar on the Piagetian model of intellectual development at the University of Oklahoma in the summer of 1973. This same group of students used the operational criteria in determining which concepts in their own subject matter areas require concrete operational thought and which ones require formal operational thought for understanding.

The following is the classification system developed by this investigator. Examples of how it may be used in evaluating concepts in physics and chemistry are given. A discussion of some of the formal and concrete concepts in physics and chemistry follows to show the application of the classification system to certain concepts. Copies of this system and several examples of how it would be employed were sent to two university-level researchers, each of whom is knowledgeable in his own field of science and in Piagetian theory. Each researcher affirmed that the proposed classification system would, in his own judgement, allow formal and concrete concepts to be identified and that the system was being properly employed. The assumption was made, therefore, that face validity of the content instruments had been established.

Instruments Used in this Research

A. The Classification System

The classification of concepts according to the Piagetian model was based on different operational criteria for each stage. Concrete operational concepts are those concepts which can be understood using one or more of the mental operations of: (1) seriation, (2) transitivity, (3) class inclusion, (4) one-to-one correspondence, and (5) conservation. Formal operational concepts are those whose understanding requires the use of one or more of the mental operations of: (1) propositional thinking, (2) combinatorial operations, (3) proportional reasoning, (4) separation of variables, (5) reciprocal implications, and (6) exclusion.

	CONCRETE CONCEPTS	OPERATIONAL CRITERIA				
		Seriation	Transitivity	Class Inclusion	One-to-one Correspondence	Conservation
CHEMISTRY	Symbols and Formulas	x	x	x	x	
	Models of molecules	x	x	x	x	x
	Phase changes	x	x	x	x	x
	Factors affecting vapor pressure	x	x	x		
	Randomness	x	x	x	x	x
	Oxidation numbers	x	x	x	x	x
PHYSICS	Time	x	x	x		
	Space	x	x	x	x	x
	Vectors	x	x	x	x	x
	Weight	x	x	x		
	Superposition of waves	x	x	x	x	x
	Series circuits	x	x	x	x	x

	FORMAL CONCEPTS	OPERATIONAL CRITERIA					
		Propositional Thinking	Combinatorial Operations	Proportional Reasoning	Separation of Variables	Reciprocal Implications	Exclusion
CHEMISTRY	Energy accompanying phase changes	x	x	x		x	
	Boyle's Law	x	x	x	x	x	x
	Mole concept	x	x				
	Avogadro's Hypothesis	x	x	x	x	x	x
	Particulate nature of matter	x	x				
	Rates of reactions	x	x	x	x	x	x
	Relative weights of molecules	x	x	x			
PHYSICS	Instantaneous speed	x	x	x	x	x	x
	Acceleration	x	x	x	x	x	x
	Newton's second law: F = ma	x	x	x	x	x	x
	Momentum	x	x		x		x
	Conservation of energy	x	x				
	Universal gravitation	x	x	x	x	x	x
	Gas Laws	x	x	x	x	x	x
	Kinetic theory of gases	x	x				

Classification of Concepts--An Explanation

Energy accompanying phase changes is a formal concept. Energy is a derived quantity, not a measured one. The energy involved here is the total kinetic energy of the molecules. Mathematically, kinetic energy is one-half of the product of mass and velocity squared, that is, K.E. = $\frac{1}{2}mv^2$. Mass itself is a formal concept because there are no concrete manifestations of it. It is derivable from Newton's second law, F = ma. To understand the concept of mass, one has to perform an operation on a concrete operation, that is, set up a ratio of force to acceleration (another formal concept). Propositional thinking has to be resorted to in the comprehension of this concept because the learner has to base his thinking on what is possible and not merely on what is observable.

The variables must be, according to Flavell, subjected to a thorough combinatorial analysis to enable different values of kinetic energy to be predicted. For instance, the learner can postulate the effect of halving the mass and combining this with a doubled velocity to elicit a value of energy that is not equal to the original value but is twice as much. When two phase changes are then compared in term terms of energy differences, a proportion may result, indicating that the operation of proportional reasoning is also involved in the understanding of this concept.

Separation of variables is involved because the learner has to be able to separate the effect of mass from that of velocity. He uses this operation when he attempts to predict what will happen when mass is changed while keeping velocity constant or vice-versa.

Another formal concept is that of instantaneous speed. This concept is to be taken in the context of its definition rather than giving it the value of the reading of the speedometer of a car. Instantaneous speed is defined as the limit of the value of $\Delta d/\Delta t$ as Δt approaches zero, that is $v_{inst} = \lim_{\Delta t \to 0} \Delta d/\Delta t$. This definition clearly shows that instantaneous speed is merely a conceptual invention. Understanding of the concept requires propositional thinking because the learner has to make the assumption that amounts of time can be made so small that time intervals can approach zero. This is a proposition in itself and, on that basis, we accept the notion of instantaneous speed. In other words, the whole concept of instantaneous speed is based on this purely hypothetical approach to the time concept.

Combinatorial operations are also involved in the sense that the concept requires the learner to form distinct combinations of the propositions that he has previously cast. He reasons as follows: Granted, the time interval can be very short, then it is possible to obtain certain combinations of Δd and Δt to produce certain values of instantaneous speed. The learner needs to consider also that other possible combinations of Δd and Δt can elicit the same value of instantaneous speed.

The concepts of symbols and formulas are concrete concepts because only the operations of seriation, transitivity, class inclusion, one-to-one correspondence, and conservation are required for understanding. These concepts make use of the notion of number which would not be understood unless the learner can effectively use the operations of seriation, transitivity, and class inclusion. One-to-one correspondence is needed because the learner has to see the linkage between the element's name (or names of particular atoms) and the symbols used to represent them.

Time is another concrete concept because it can be understood by using operations of seriation (event C happens after event B which happens after event A) and class inclusion (if there are three events that are serially ordered, then time interval AC has to include time interval AB and/or time interval BC. The operation of transitivity is implied in that of seriation.

B. Piagetian Tasks

Task 1: Conservation of Volume[1]

In this task the subject was shown two identical containers partially filled with water to the same level. He was also given two metal cylinders and told that the two cylinders have the same volume or size but not the same weight. He was then asked to make a prediction on the heights to which the water levels in the two containers will rise and why the water would rise to that height when the cylinders were placed in the water. After he had made the prediction, he was asked to see if his prediction was correct or not. He was asked to explain his observation if it disagreed with his prediction.

The subject who made the successful prediction that the water levels will be the same obtained a rating of IIIA. This rating indicated that he had made his entry into the formal operational stage. His ability to separate variables and to exclude weight from volume as a non-causative factor showed that he was thinking formally.

[1] Renner and Stafford, op. cit., p. 293.

The subject who predicted that the heavier object will make the water level rise more was still clearly in the concrete operational stage and was rated IIA. If, however, when confronted with the discrepancy between his prediction and the result of the experiment, he recognized that volume was the causative factor rather than weight, he was rated IIB. This rating shows that the subject was about to leave the stage of concrete operations although he was still in need of concrete experience.

Task 2: Separation of Variables[2]

The apparatus used in this task consists of several rods of varying material, cross-sectional area and shape. These rods are clamped to the side of a shallow vessel of water so their lengths can also be varied. The subject was given a set of weights and asked to hang the weights from the ends of the rods. He was allowed to experiment with the rods and with the different weights so that he can systematically go about finding what he can do with the variables to make the hanging weight touch the water. The five variables involved in this task are: (1) length, (2) material, (3) shape, (4) cross-sectional area, and (5) weight. The most important feature that the investigator observed was how well the subject isolated one particular variable, while holding other variables constant, in order to test a particular hypothesis.

If the subject did nothing more than to classify the rods that bent the most or the least into thinner, larger, shorter, square, round, etc., he was rated IIA. If, however, he classified the rods and said

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[2]Inhelder and Piaget, op. cit., pp. 46-66.

that the thinner but shorter rod bent as much as the longer but thicker rod, he showed understanding of the compensation between two relations and was using logical multiplication, i.e., thicker x longer = thinner x shorter. Still, he was not able to test one factor at a time while keeping all the others constant. This subject was rated IIB.

The subject who compared any two rods on one property such as length while holding all other factors constant showed the ability to separate out the relevant variables and was clearly into the formal operational stage. If, however, he failed in other comparisons such as comparing two rods of unequal cross-sectional areas and different shapes, although keeping length, material and weight constant, he was considered to be IIIA.

If the subject effectively separated out all the relevant variables by the use of a combinatorial system and systematically tested for the effect of each while holding all the others constant, he was given a rating of IIIB. Such a subject was clearly into the highest stage of formal operations.

Task 3: Equilibrium in a Balance[3]

This is a task in which a simple wooden beam supported on a fulcrum is used. The beam had 30 holes drilled in one inch intervals along its length and weights could be hung from these holes. The weights used were referred to as 2-unit, 5-unit, and 10-unit weights.

The investigator first showed the beam to be in balance when there were no weights hanging from it. Then a 10-unit weight was hung 7-unit distances from the fulcrum and the subject was asked

[3] Ibid., pp. 164-181.

to hang another 10-unit weight on the other side to obtain the same state of equilibrium as before.

One of the 10-unit weights was removed and the subject was given two 5-unit weights which he was asked to hang on the other arm of the beam so that the same state of balance could be achieved. Then one of the 5-unit weights was removed and the subject was asked to predict the location of the remaining 5-unit weight on the beam to achieve equilibrium. After indicating the location, the subject was asked to explain his choice. If the subject could not give the correct location for the 5-unit weight, much less offer an explanation, he was given a rating of IIA. If the subject chose the correct location for the 5-unit weight but used the difference between 10 and 5 units instead of the ratio of 10 to 5 units to explain his choice, he was clearly showing a lack of understanding of the systematic coordination between weight and distance. This subject was given a rating of IIB. If the subject made the correct choice <u>and</u> explained that an inverse proportion between weight and distance is involved, he was given a rating of IIIA.

The final step in this task was to determine whether or not the subject could be rated as completely formal operational--class IIIB. This was done by placing a 10-unit weight 7-unit distances from the fulcrum and asking the subject where he could hang a 7-unit weight in order to achieve equilibrium. If he made the correct prediction and the correct explanation, he clearly indicated the ability to use proportional reasoning--an integral part of formal thinking. He was rated IIIB.

C. Achievement Tests

Achievement tests for each unit of study have been constructed for both the CHEM Study and Project Physics materials. Each test is reportedly designed to evaluate the student's ability to apply the principles he has learned in the laboratory and classroom and consists of twenty-five multiple-choice questions.

Treatment of the Data

The data obtained from the administration of the Piagetian tasks to the physics and chemistry students were analyzed separately and subjects were placed in two main groups, concrete and formal. Subgroupings of the concrete subjects into concrete operational IIB, and post concrete operational and of the formal subjects into formal operational IIIA, transitional formal, and formal IIIB (following Lawson's groupings) were made. The percentages of subjects belonging to each group was also determined.

Reliabilities of the achievement tests were determined using Kuder-Richardson technique.[4] The Kuder-Richardson formula 20 is:

$$r_{xx} = \frac{n}{n-1}\left(\frac{s_x^2 - \sum_{i=1}^{n} p_i q_i}{s_x^2}\right)$$

where n = number of test items

p_i = proportion of individuals passing item i

q_i = proportion of individuals failing item i

s_x^2 = variance of scores on test defined as $\sum (X - \bar{X})^2/N$

and r_{xx} = reliability coefficient of the test.

[4] George A. Ferguson, Statistical Analysis in Psychology and Education (New York: McGraw Hill Book Company, 1959), p. 379.

What was actually being tested in this study was the classification system designed by this investigator. The examination questions were labeled concrete or formal according to the criteria established by the classification scheme. The proportion of concrete students responding correctly to each concrete question was compared with the proportion of formal students responding correctly to the same question. To find out if the difference between these two proportions is significant and not due to sampling error, a z-test[5] of significance between two independent proportions was done for each concrete item on the written examinations. The same statistical test was applied to the proportions of concrete and formal students responding correctly to the formal items on the examinations.

The idea was adopted that if it turns out that is no significant difference between the proportions of formal and concrete students responding correctly to questions that have been labeled as requiring formal operational thought, then the labels must be incorrect; the classification system is faulty. If, on the other hand, the difference is significant, then the classification scheme must be useful in evaluating concepts in physics and chemistry. As far as questions that have been labeled as requiring concrete operational thought are concerned, the expectation here is that there will be no significant difference between the proportions of formal and concrete students responding correctly to those items. If no such difference is found in the majority of the concrete items of the written tests, then the instruments that was used in evaluating them must be a valid one.

[5]the value z may be interpreted as a deviate of the unit normal curve.

CHAPTER IV

PRESENTATION OF THE DATA, VALIDITY AND RELIABILITY OF TEST INSTRUMENTS

Presentation of the Data

The data collected consists of (1) scores obtained by ninety-five physics and chemistry students on three Piagetian tasks, and (2) scores obtained by these students on the concrete and formal questions found in the achievement tests. Those test scores, and the sex and chronological age designation for each student are given in Tables 4-1 and 4-2.

Operational Levels of Students

Lawson[1] classified the subjects in his study into one of seven categories on the basis of scores obtained during the administration of the Piagetian tasks. The categories he used were: concrete operational IIA, transitional concrete, concrete operational IIB, post concrete operational, formal operational IIIA, transitional formal, and formal operational IIIB.

The intermediate categories were necessary according to Lawson because the classification of the responses to the tasks for a single subject sometimes varied widely with classes II and III. For example, a subject's response may have been classified IIB both on the conservation-of-volume task and the equilibrium-in-the balance task but may have

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Lawson, *op. cit.*, pp. 61-62 .

been rated IIIA on the separation-of-variables task. Lawson placed such a subject in the post-concrete group. He found many such instances where the classification of the subject into one of two categories, concrete operational and formal operational, was not clear-cut.

This investigator found a similar situation prevailing in the course of the interview conducted for this study and decided to use Lawson's method for evaluating subjects. Since none of the subjects tested rated a IIA classification on any of the tasks, only five categories were used in the grouping of subjects. These were (1) concrete operational IIB, (2) post-concrete operational, (3) formal operational IIIA, (4) transitional formal, and (5) formal operational IIIB. Each of the ratings in the three tasks was awarded a certain number of points. A IIA rating was equivalent to one point, a IIB rating to two points, a IIIA rating to three points, and a IIIB rating to four points. The following is the scale used in placing the subjects in the afore-mentioned categories.

Concrete IIB = 6 points
Post-concrete = 7-8 points
Formal IIIA = 9 points
Transitional formal = 10 points
Formal IIIB = 11 points

Tables 4-3 and 4-4 show the number, sex, grade level, and percentage of subjects in each of the five categories.

TABLE 4-1

RAW DATA FOR PHYSICS SAMPLE

Subject No.	Sex	Age in Months	Con. Vol.	Sep. Var.	Equil. Balance	First Semester Conc. Ques.	First Semester Formal Ques.	Second Semester Conc. Ques.	Second Semester Formal Ques.
1	M	197	3	3	3	10	8	7	11
2	M	199	3	3	3	9	10	7	11
3	M	192	3	4	2	10	8	8	14
4	M	196	3	3	3	9	10	8	10
5	M	198	2	2	2	10	4	6	1
6	M	192	3	3	3	10	8	7	10
7	M	206	3	3	3	12	8	8	10
8	M	201	3	4	3	9	10	9	12
9	M	199	3	3	3	10	8	8	10
10	M	207	2	2	2	9	2	9	3
11	M	202	3	3	3	11	7	10	9
12	M	198	3	3	3	12	7	9	9
13	M	192	3	2	2	5	5	8	6
14	M	206	3	4	3	10	9	9	11
15	M	199	3	3	2	9	1	5	4
16	M	191	3	3	3	10	7	10	7
17	F	193	3	3	3	9	6	10	7
18	F	203	3	2	3	9	3	6	5
19	M	213	3	4	4	12	10	9	8
20	M	207	3	4	4	12	12	10	13
21	M	207	3	3	4	11	7	9	10
22	M	209	3	2	2	12	2	7	5
23	M	216	3	3	3	12	6	10	8
24	M	215	3	4	3	12	9	9	10
25	M	213	3	4	3	11	8	8	10
26	M	206	3	3	3	11	6	10	9
27	M	199	3	4	4	10	11	9	8
28	M	221	3	3	3	11	7	9	8
29	F	209	3	3	2	9	5	6	6
30	F	208	3	4	3	12	10	8	12
31	F	213	3	4	3	11	9	6	9
32	F	214	3	3	3	10	9	8	10
33	F	197	3	3	3	11	7	10	6
34	F	205	3	3	2	4	11	7	7

TABLE 4-2

RAW DATA FOR CHEMISTRY SAMPLE

Subject No.	Sex	Age in Months	PIAGETIAN TASKS			ACHIEVEMENT TESTS			
						First Semester		Second Semester	
			Con. Vol.	Sep. Var.	Bal-ance	Conc. Ques.	Form. Ques.	Conc. Ques.	Form. Ques.
1	M	216	3	3	4	10	10	6	17
2	M	209	3	4	3	10	11	7	16
3	M	208	3	3	3	10	8	7	13
4	M	214	3	3	3	10	9	7	13
5	M	211	3	3	3	9	11	7	14
6	M	207	3	2	2	8	2	6	7
7	M	215	3	2	4	9	12	7	12
8	M	217	3	4	4	9	12	7	15
9	M	206	3	4	3	10	10	7	16
10	M	210	3	3	3	10	10	7	11
11	M	211	3	4	3	8	13	7	16
12	M	209	3	2	3	10	2	5	5
13	M	199	3	2	2	8	7	6	9
14	M	219	3	4	4	10	13	7	14
15	M	209	3	3	3	10	8	7	14
16	M	213	3	4	4	10	13	7	16
17	M	216	3	4	3	9	11	7	15
18	M	211	3	4	4	10	13	7	15
19	M	220	3	4	4	10	11	7	14
20	M	206	3	3	3	9	8	7	13
21	M	219	3	4	4	10	15	7	15
22	M	207	3	3	3	10	8	7	13
23	M	211	3	3	3	9	7	7	13
24	M	215	3	4	4	10	14	7	17
25	M	209	3	3	3	10	9	7	14
26	M	213	3	4	3	10	9	7	16
27	M	209	3	3	3	10	9	7	14
28	M	216	3	3	3	10	9	7	15
29	M	219	3	4	4	10	14	7	14
30	M	221	3	4	4	9	12	7	18
31	M	206	3	4	3	9	10	7	16

TABLE 4-2-Continued

Subject No.	Sex	Age in Months	PIAGETIAN TASKS Con. Vol.	Sep. Var.	Bal-ance	ACHIEVEMENT TESTS First Semester Conc. Ques.	Form. Ques.	Second Semester Conc. Ques.	Form. Ques.
32	M	209	3	3	3	10	7	7	14
33	M	215	3	4	4	10	12	7	16
34	M	219	3	4	4	10	14	7	17
35	M	209	3	3	3	10	7	7	13
36	F	215	3	4	3	10	8	7	14
37	F	212	3	2	2	10	1	7	6
38	F	217	3	3	4	10	10	5	15
39	F	209	3	3	3	9	6	7	12
40	F	218	3	4	4	10	14	7	14
41	F	211	3	3	3	8	8	6	12
42	F	213	3	4	3	9	11	7	14
43	F	209	3	3	3	9	6	5	10
44	M	202	3	3	3	9	9	5	11
45	M	199	3	2	2	10	6	7	8
46	M	196	3	2	2	8	3	7	7
47	M	193	3	2	2	10	4	6	7
48	M	197	2	3	3	8	9	7	8
49	M	204	3	3	3	9	9	4	14
50	M	199	2	2	2	8	3	7	1
51	M	198	3	4	4	10	15	6	15
52	M	209	3	4	3	9	11	7	15
53	M	205	3	4	3	10	9	6	14
54	M	201	3	3	3	10	8	5	10
55	F	201	2	2	2	9	4	5	3
56	F	206	3	4	4	10	14	7	16
57	F	206	3	2	2	9	4	7	4
58	F	211	3	4	3	9	8	6	14
59	F	197	3	2	2	9	5	5	6
60	F	198	3	3	3	8	9	5	12
61	F	201	3	4	2	8	5	6	4

TABLE 4-3

OPERATIONAL LEVELS OF PHYSICS STUDENTS

CATEGORIES	11th Grade			12th Grade			TOTAL N	PER CENT
	M	F	Total	M	F	Total		
Concrete IIB	2	0	2	0	0	0	2	5.9
Post-Concrete	2	1	3	1	2	3	6	17.6
Formal IIIA	10	1	11	3	2	5	16	47.1
Transitional Formal	2	0	2	3	2	5	7	20.6
Formal IIIB	0	0	0	3	0	3	3	8.8
TOTAL	16	2	18	10	6	16	34	100.0

TABLE 4-4

OPERATIONAL LEVELS OF CHEMISTRY STUDENTS

CATEGORIES	11th Grade			12th Grade			TOTAL N	PER CENT
	M	F	Total	M	F	Total		
Concrete IIB	1	1	2	0	0	0	2	3.3
Post-Concrete	4	3	7	3	1	4	11	18.0
Formal IIIA	3	1	4	14	3	17	21	34.4
Transitional Formal	2	1	3	7	3	10	13	21.3
Formal IIIB	1	1	2	11	1	12	14	23.0
TOTAL	11	7	18	35	8	43	61	100.0

Evaluation of Concepts in Achievement Tests

Achievement tests designed by the curriculum developers of CHEM Study were given to the subjects at the end of each of the two semesters of study. An item analysis of each test was done to identify the concept whose understanding is being measured and then each concept was subjected to the operational criteria delineated for the classification scheme. Each concept, therefore, was evaluated as requiring either concrete or formal operational thought for understanding. Achievement tests prepared for use with Project Physics by its developers and administered to the subjects making up the physics sample at the end of the first and second semesters were also subjected to the same procedure of concept evaluation. Tables 4-5 through 4-8 show the concept involved in each test item and the evaluation of each concept according to the operational criteria. Classification of the concept depended on the manner in which the questions were asked. For instance, although an understanding of the second law of thermodynamics requires the use of formal operations, item 8 in Table 4-7 was labeled concrete because the question invoked only a statement of the law and not an application of it.

Difficulty Level of Questions

The percentages of students responding correctly to each test item are given in Tables 4-9 through 4-12. An examination of these tables will show that the percentages of correct responses to the concrete items is nearly always greater than the same percentages in the formal items. Table 4-13 gives the number of subjects in each sample,

TABLE 4-5

EVALUATION OF CONCEPTS BASED ON OPERATIONAL CRITERIA
PHYSICS ACHIEVEMENT TEST-FIRST SEMESTER

Ques. No.	CONCEPTS	Operational Criteria											Evaluation
		S	T	CI	OC	C	PT	CO	PR	SV	RI	E	
1	Vectors	x	x	x	x	x							Concrete
2	Potential _vs._ kinetic energy						x	x	x	x	x	x	Formal
3	Frictionless systems						x	x		x	x		Formal
4	Transverse waves			x	x	x							Concrete
5	Elastic collisions-definition		x	x	x								Concrete
6	Newtonian mechanics						x	x		x	x		Formal
7	Normal distribution						x	x		x	x	x	Formal
8	2nd law of thermodynamics	x	x	x	x								Concrete
9	Projectile motion						x	x		x	x	x	Formal
10	_Vis viva_ (mv^2)			x	x	x							Concrete
11	Potential _vs._ kinetic energy						x	x		x	x	x	Formal
12	Diffraction of waves			x	x	x							Concrete
13	Interference of light			x	x	x							Concrete
14	Conservation of momentum						x	x	x	x	x	x	Formal
15	Inelastic collisions						x	x	x	x	x	x	Formal
16	Total energy						x	x		x		x	Formal
17	Propagation of waves			x	x	x							Concrete
18	Unit of momentum	x	x	x	x								Concrete
19	Maxwell and thermodynamics			x	x								Concrete
20	Kinetic energy						x	x		x	x	x	Formal
21	Velocity						x	x	x	x	x	x	Formal
22	Work		x	x	x								Concrete
23	Kinetic energy						x	x	x	x	x	x	Formal
24	Superposition	x	x	x	x	x							Concrete
25	Sound waves		x	x	x								Concrete

Explanation of symbols used:

S = seriation
T = transitivity
CI = class inclusion
OC = one-to-one correspondence
C = conservation

PT = propositional thinking
CO = combinatorial operations
PR = proportional reasoning
SV = separation of variables
RI = reciprocal implications
E = exclusion

TABLE 4-6

EVALUATION OF CONCEPTS BASED ON OPERATIONAL CRITERIA
PHYSICS ACHIEVEMENT TEST-SECOND SEMESTER

Ques. No.	CONCEPTS	Operational Criteria											Evaluation
		S	T	CI	OC	C	PT	CO	PR	SV	RI	E	
1	Series circuits	x	x	x	x	x							Concrete
2	Newton's second law						x	x	x	x	x	x	Formal
3	Projectile motion						x	x	x	x	x	x	Formal
4	Centripetal acceleration						x	x	x	x	x	x	Formal
5	Linear acceleration						x	x	x	x	x	x	Formal
6	Definition of work		x	x	x	x							Concrete
7	Coulomb's law						x	x	x	x	x	x	Formal
8	Elastic collision		x	x	x	x							Concrete
9	Power						x	x	x	x	x	x	Formal
10	Period _vs_. frequency						x	x	x		x		Formal
11	Frequency of light						x	x	x	x	x	x	Formal
12	Kilowatt-hour	x	x	x	x								Concrete
13	Electrical resistance						x	x	x	x	x	x	Formal
14	Vectors	x	x	x	x	x							Concrete
15	Electrical energy						x	x	x	x	x	x	Formal
16	Coulomb's law						x	x	x	x	x	x	Formal
17	Mass number	x	x	x	x	x							Concrete
18	Binding energy						x	x		x		x	Formal
19	Cloud chamber						x	x		x		x	Formal
20	Nuclear reactions	x	x	x	x	x							Concrete
21	Nuclear reactions	x	x	x	x	x							Concrete
22	Nuclear fission						x	x		x		x	Formal
23	Refraction		x	x	x								Concrete
24	Conservation of energy-name		x	x	x								Concrete
25	Instantaneous speed						x	x	x		x		Formal

TABLE 4-7

EVALUATION OF CONCEPTS BASED ON OPERATIONAL CRITERIA
CHEMISTRY ACHIEVEMENT TEST-FIRST SEMESTER

Ques. No.	CONCEPTS	Operational Criteria											Evaluation
		S	T	CI	OC	C	PT	CO	PR	SV	RI	E	
1	Relative weight of gases						x	x	x	x	x	x	Formal
2	Molecular weight						x	x	x		x		Formal
3	Molecular formula	x	x	x	x	x							Concrete
4	Significant figures	x	x	x	x	x							Concrete
5	Cooling curve						x	x		x		x	Formal
6	Freezing point	x	x	x	x	x							Concrete
7	Solid and liquid phases						x	x		x		x	Formal
8	Avogadro's number						x	x	x	x	x	x	Formal
9	Balancing equations						x	x	x	x	x	x	Formal
10	Stoichoimetry						x	x	x	x	x	x	Formal
11	Conservation of mass	x	x	x	x	x							Concrete
12	Chemical families	x	x	x	x	x							Concrete
13	Metallic properties	x	x	x	x	x							Concrete
14	Chemical prediction						x	x		x		x	Formal
15	Alkali metals	x	x	x	x								Concrete
16	Moles						x	x	x	x	x	x	Formal
17	Partial pressure						x	x	x	x	x	x	Formal
18	^{o}K to ^{o}C	x	x	x	x	x							Concrete
19	Activation energy						x	x		x		x	Formal
20	Molecular weight	x	x	x	x	x							Concrete
21	Counting atoms	x	x	x	x	x							Concrete
22	Avogadro's principle						x	x	x	x	x	x	Formal
23	Endothermic reaction						x	x		x		x	Formal
24	Conservation of matter						x	x		x		x	Formal
25	Use of periodic table						x	x		x		x	Formal

TABLE 4-8

EVALUATION OF CONCEPTS BASED ON OPERATIONAL CRITERIA
CHEMISTRY ACHIEVEMENT TEST-SECOND SEMESTER

Ques. No.	CONCEPTS	Operational Criteria											Evaluation
		S	T	CI	OC	C	PT	CO	PR	SV	RI	E	
1	Periodicity						x	x		x		x	Formal
2	Orbital representation						x	x		x		x	Formal
3	Formulas and periodicity						x	x		x		x	Formal
4	Conductivity						x	x		x		x	Formal
5	Ionization energy	x	x	x	x	x							Concrete
6	Metallic bonding		x	x	x								Concrete
7	Chemical families	x	x	x	x	x							Concrete
8	Properties of atoms						x	x		x		x	Formal
9	Properties of metals						x	x		x	x	x	Formal
10	Equilibrium and concentration						x	x	x	x	x	x	Formal
11	Equilibrium and pressure						x	x		x		x	Formal
12	Counting moles	x	x	x	x	x							Concrete
13	K_{eq} *vs.* concentration						x	x	x	x	x	x	Formal
14	Acid-base equilibrium						x	x		x		x	Formal
15	Acidity *vs.* pH and $[H_3O^+]$						x	x		x		x	Formal
16	K_a *vs.* strong acids	x	x	x	x	x							Concrete
17	Law of Multiple Proportions						x	x		x		x	Formal
18	Electron dot representation	x	x	x	x	x							Concrete
19	Molecular dipoles						x	x		x		x	Formal
20	Solubility-Identification						x	x		x		x	Formal
21	Solubility-Identification						x	x		x		x	Formal
22	Flame test	x	x	x	x	x							Concrete
23	Gas formation						x	x		x		x	Formal
24	Solubility						x	x	x	x	x	x	Formal
25	Use of K_{sp}												

TABLE 4-9

GROUP PERCENTAGES ON CONCRETE AND FORMAL QUESTIONS
PHYSICS ACHIEVEMENT TEST-FIRST SEMESTER

Question Number	Concept Evaluation	Concrete Group Per Cent	Formal Group Per Cent	Both Groups Per Cent
1	Concrete	63	85	79
2	Formal	13	73	59
3	Formal	25	69	59
4	Concrete	88	89	88
5	Concrete	38	92	79
6	Formal	38	77	68
7	Formal	63	89	82
8	Concrete	88	85	85
9	Formal	13	62	50
10	Concrete	88	89	88
11	Formal	13	35	29
12	Concrete	75	92	88
13	Concrete	100	100	100
14	Formal	13	65	53
15	Formal	50	77	71
16	Formal	0	38	29
17	Concrete	87	89	88
18	Concrete	88	96	94
19	Concrete	63	77	74
20	Formal	13	35	32
21	Formal	13	42	35
22	Concrete	63	92	85
23	Formal	25	81	68
24	Concrete	88	92	91
25	Formal	38	73	65

TABLE 4-10

GROUP PERCENTAGES ON CONCRETE AND FORMAL QUESTIONS
PHYSICS ACHIEVEMENT TEST-SECOND SEMESTER

Question Number	Concept Evaluation	Concrete Group Per Cent	Formal Group Per Cent	Both Groups Per Cent
1	Concrete	75	92	88
2	Formal	12	54	44
3	Formal	63	65	65
4	Formal	13	50	41
5	Formal	13	46	38
6	Concrete	100	100	100
7	Formal	25	73	62
8	Concrete	50	85	77
9	Formal	25	81	68
10	Formal	50	81	74
11	Formal	13	85	68
12	Concrete	88	92	91
13	Formal	13	65	53
14	Concrete	88	92	91
15	Formal	13	54	44
16	Formal	25	61	53
17	Concrete	63	73	70
18	Formal	25	54	47
19	Formal	38	73	65
20	Concrete	88	85	85
21	Concrete	75	88	82
22	Formal	25	69	59
23	Concrete	100	92	94
24	Concrete	100	81	85
25	Formal	13	50	41

TABLE 4-11

GROUP PERCENTAGES ON CONCRETE AND FORMAL QUESTIONS
CHEMISTRY ACHIEVEMENT TEST-FIRST SEMESTER

Question Number	Concept Evaluation	Concrete Group Per Cent	Formal Group Per Cent	Both Groups Per Cent
1	Formal	8	69	56
2	Formal	31	67	56
3	Concrete	100	96	97
4	Concrete	77	90	87
5	Formal	23	75	64
6	Concrete	85	96	93
7	Formal	15	88	72
8	Formal	23	71	61
9	Formal	23	48	43
10	Formal	23	85	72
11	Concrete	77	92	85
12	Concrete	85	94	92
13	Concrete	92	96	95
14	Formal	38	67	61
15	Concrete	85	98	95
16	Formal	15	67	56
17	Formal	15	83	69
18	Concrete	85	96	93
19	Formal	54	58	55
20	Concrete	92	100	98
21	Concrete	100	96	97
22	Formal	8	63	51
23	Formal	85	88	87
24	Formal	23	63	54
25	Formal	23	48	43

TABLE 4-12

GROUP PERCENTAGES ON CONCRETE AND FORMAL QUESTIONS
CHEMISTRY ACHIEVEMENT TEST-SECOND SEMESTER

Question Number	Concept Evaluation	Concrete Group Per Cent	Formal Group Per Cent	Both Groups Per Cent
1	Formal	15	88	72
2	Formal	23	69	59
3	Formal	46	88	78
4	Formal	23	63	54
5	Concrete	92	96	95
6	Concrete	77	88	84
7	Concrete	92	94	93
8	Formal	23	58	51
9	Formal	31	79	69
10	Formal	46	92	82
11	Formal	7	75	61
12	Concrete	92	98	97
13	Formal	23	75	64
14	Formal	38	85	75
15	Formal	46	85	77
16	Concrete	92	94	93
17	Formal	23	85	72
18	Concrete	92	92	92
19	Formal	8	67	54
20	Formal	0	31	25
21	Formal	54	94	85
22	Concrete	92	98	96
23	Formal	69	100	93
24	Concrete	38	90	79
25	Formal	69	94	88

TABLE 4-13

MEANS AND STANDARD DEVIATIONS
CONCRETE AND FORMAL QUESTIONS

Achievement Test	Number of Subjects	Mean Concrete	S. D. Concrete	Mean Formal	S. D. Formal
Physics-First Semester	34	86.6	12.6	54.3	14.7
Physics-Second Semester	34	86.3	11.4	54.8	12.8
Chemistry-First Semester	61	93.8	3.03	60.0	11.3
Chemistry-Second Semester	61	92.9	9.95	68.8	15.9

means and standard deviations for the concrete and formal sections of each achievement test. Note that the means for the formal questions are much lower than the means for the concrete questions.

Validity of Test Instruments

The test instruments used in this research were: (1) achievement tests in chemistry and physics, and (2) Piagetian tasks.

The achievement test items designed by the CHEM Study and Project Physics personnel have been tested and validated using populations made up of students who participated in the pilot testing of these two courses in many parts of the country. Each test was designed to measure the student's ability to apply the principles he has learned in the classroom and in the laboratory. This investigator therefore assumed that the achievement tests had content validity.

The Piagetian tasks have previously been validated by Lawson and Renner using the technique of Principal components analysis.[3] These tasks have been designed by Piaget to measure formal operational thought and, when analyzed statistically, should correlate highly with only one principal component. Data collected in the Lawson-Renner study with 134 students and subjected to principal components analysis yielded the following results:[4]

Task	Correlation with First Principal Component
1. Conservation of Volume	0.84
2. Separation of Variables	0.85
3. Equilibrium in the Balance	0.80

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[3]For a complete discussion of this technique, see Maurice M. Tatsouka, Multivariate Analysis: Techniques for Educational and Psychological Research (New York: John Wiley and Sons, 1971).

[4]Anton E. Lawson and John W. Renner, "A Quantitative Analysis of Responses to Piagetian Tasks and Its Implications for Curriculum," Science Education Vol. 58, No. 3, In Press.

These results demonstrate that all three of the Piagetian tasks correlate highly with one principal component[5] indicating that the tasks measure the same thing which, the investigators inferred, was formal operational thought.

Reliability of Test Instruments

The reliability of each achievement test used in this investigation was determined using the Kuder-Richardson formula 20. For a discussion of this technique, see Chapter III. The reliability coefficients are given in Table 4-14.

TABLE 4-14

RELIABILITY COEFFICIENTS OF ACHIEVEMENT TESTS

Achievement Test	Reliability Coefficient
Physics-First Semester	0.654
Physics-Second Semester	0.647
Chemistry-First Semester	0.792
Chemistry-Second Semester	0.826

Most methods used in measuring the reliability of a test (the one used in this study is no exception) make the assumption that all items of the test are of equal difficulty, i.e., the same proportion of subjects, although not necessarily the same persons, solve each item correctly.[6] This assumption, however, can not be made with the tests used in this study. The expectation here is that some items would be more difficult than others (formal vs. concrete questions) for one group

[5]This principal component accounted for 62.2 per cent of the variance.

[6]Henry E. Garrett, Statistics in Psychology and Education (New York: Longmans, Green and Co., 1956), p. 351.

of students--the concrete operational group. Therefore, it is not surprising that coefficients such as those shown in Table 4-14 were obtained. Guilford has the following to say about reliabilities of test instruments used in research.[7]

> As to how high reliability coefficients should be, no hard and fast rules can be stated. For research purposes, one can tolerate reliabilities than one can for practical purposes of diagnosis and prediction. We are frequently faced with the choice of making the best of what reliability we can get, even though it may be of the order of only 0.50, or of going without the use of the test at all.

In this light, this investigator accepted the reliabilities of the written tests as sufficient for the purposes of this study.

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[7] J. P. Guilford, Psychometric Methods (New York: McGraw-Hill Book Company, 1954), pp. 388-389.

CHAPTER V

ANALYSES OF DATA

The data presented in Tables 4-9 through 4-12 clearly show differences in the proportions of formal subjects and concrete subjects responding correctly to the formal and concrete portions of the examinations. These differences will be examined in this chapter to see if the general questions asked in Chapter I have been answered. In other words, the data are examined here to see if the difference between performances on achievement tests by formal and concrete operational students is significant.

There are really two trends expected in this study. The expectation was that the proportion of formal students responding correctly to concrete items should not be significantly different from the proportion of concrete students responding correctly to the same items. Thus, in this portion of the study, an acceptance of the null hypothesis is expected. On the other hand, a significant difference was assumed to exist between the proportion of formal subjects responding correctly to formal questions and the proportion of concrete students responding correctly to the same questions. Here, rejection of the null hypothesis was expected.

Statistical Treatment of the Data

To study these differences, a test of the significance of the .ference between two independent proportions was performed on each item of the four achievement tests. To perform this statistical test of significance, the z-test of significance between two proportions which are independent was used. The find the z-value, which may be interpreted as a deviate of the unit normal curve, the following formula was used:[1]

$$z = \frac{p_1 - p_2}{\sqrt{pq\left[\frac{1}{N_1} + \frac{1}{N_2}\right]}}$$

where p = proportion of correct responses by both groups[2]

q = $1 - p$ = proportion of incorrect responses by both groups

N_1 = number of subjects in formal group

N_2 = number of subjects in concrete group

p_1 = proportion of correct responses by formal group

p_2 = proportion of correct responses by concrete group.

Error Types[3]

There are two types of error that may be committed in reaching a decision whether to accept the null hypothesis or to reject it. The first, Type I error, is committed with the rejection of the null hypothesis, Ho, when in fact it is true. The second, Type II error, is made when the null hypothesis, Ho, is accepted when in fact it is false. The level of significance α, is the probability of making a type I error.

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[1]Ferguson, op. cit., p. 177.

[2]Ferguson suggests that combining the data from the two samples to obtain a single estimate of p is justified in that all cases where the difference between two proportions is tested, the null hypothesis is assumed. This hypothesis states that there is no difference between the two proportions. Because this is assumed to be the case, an estimate of p based on the combined data for the two samples can properly be used.

[3]Ferguson, op. cit., pp. 163-164.

In making a decision as to the level of significance demanded in the test for the difference between the proportions of correct responses made by formal and concrete students to formal items of the achievement test (Ho 2 and Ho 4), this investigator was guided by the belief that, indeed, there should be a significant difference. If too strict a level of significance is chosen, this action might result in the failure to reject the null hypothesis. To ensure that the expected rejection of null hypothesis 2 and 4 takes place, the level of significance can be raised. However, in so doing, the probability of making a Type I error (rejecting Ho when it is true) is increased. The consequences of a Type I error are that the classification system might then be adopted when actually it is not a valid instrument. However, the use of an invalid instrument does not really impede the learning process; neither does it entail added cost to the school. In other words, the consequences of making a Type I error here are not serious.

On the other hand, suppose a Type II error is made. That would mean accepting the null hypothesis--no significant difference exists in the proportions of concrete and formal operational students responding correctly to formal items when, in fact, such a difference probably exists. An instrument such as the classification system designed would not be adopted when in fact it is valid.

In the light of possible consequences of making either of the two types of error, this investigator decided to reduce the possibility of making a Type II error. Thus, a level of significance of .10 for testing null hypotheses 2 and 4 was chosen.

In testing null hypotheses Ho 1 and Ho 3, the situation is reversed. This investigator believes that if the concrete items have been labeled correctly, then concrete and formal students should enjoy success in the same proportion; the null hypotheses should be accepted for all concrete items in the physics and chemistry tests. Making a Type I error in these cases will result in rejecting the null hypothesis when it is actually true. This rejection will in fact mean the non-acceptance of the classification system as a valid instrument. Conversely, suppose a Type II error is made. This means the null hypothesis is accepted when it is actually false. The consequences of making this type of error for hypotheses 1 and 3 are that the classification instrument might then be adopted when in fact it is a faulty instrument. Again, this action does not have serious consequences; the use of an invalid instrument does not do much harm to the students. Thus, in testing hypotheses Ho 1 and Ho 3, the possibility of making a Type I error was to be minimized and a more strict level of significance was needed. So for these two hypotheses, the decision was to adopt a 0.01 level of significance.

Analyses of Results

Tables 5-1, 5-3, 5-5, and 5-7 give z-values obtained for the concrete questions of the achievement tests. The .01 level of significance was chosen for these groups of test items. The null hypotheses being tested in these cases are similar, that is, Ho 1 and Ho 3 state: No significant difference exists between the proportion of correct responses from concrete and formal operational subjects on concrete items. The null hypotheses are different only in that Ho 1 applies to the physics tests and Ho 3 applies to the chemistry tests.

Table 5-1 shows that a significant difference between the proportions of correct responses by concrete and formal subjects was obtained in only one out of twelve concrete items on the test. The null hypothesis Ho 1, which states that no significant difference exists between the two proportions on concrete items of the physics-first semester test was accepted for all cases except one.

Tables 5-3, 5-5, and 5-7 show that the null hypothesis was accepted in all cases. These results clearly show that there is no difference in the performance of formal and concrete operational students on concrete items of the achievement examinations as predicted by the Lawson study. Therefore, the concrete items must have been properly evaluated by the classification system.

In regard to the formal questions on the examinations, the null hypothesis, Ho, was expected to be rejected in favor of the alternative hypothesis which states that formal operational students should show a greater proportion of correct responses than concrete students. For the thirteen formal items on the physics first-semester test (see Table 5-2) a significant difference between the proportion of correct responses was obtained in each of the items. Thus, the null hypothesis was rejected in all of the cases.

Tables 5-4, 5-6, and 5-8 show item analyses for the formal items of the other examinations. In all those items, rejection of the null hypothesis was expected. Table 5-4 shows rejection of Ho in fourteen out of fifteen cases. Table 5-6 indicates rejection of Ho in thirteen out of fifteen cases. Table 5-8 shows even better results, with the null hypothesis being rejected in all of the eighteen cases. All these clearly indicate that there is a significant difference in the performance of formal and concrete operational students on formal items of the achievement examinations as predicted by the Lawson study. Thus, the conclusion is made that the formal questions must have been properly evaluated by the classification scheme.

Summary

The data from this study show the following results:

1. The majority of the concepts involved in physics and chemistry were categorized as requiring formal operational thought for understanding.

2. Achievement test items that have been labeled as requiring formal operational thought by the classification scheme designed in this study invoked a greater measure of success among formal operational students than among concrete operational students.

3. Achievement test items that have been labeled as requiring concrete operational thought by the classification system invoked succesful performance on the part of both the formal operational and the concrete operational group.

4. On the items labeled as requiring formal thought by the classification system, a comparison of the performances of known formal and concrete operational students showed significance was obtained in fif fifty-seven out of sixty-one cases tested, indicating rejection of the null hypothesis in these cases. The findings thus made show that in ninety-three per cent of the items, the classification system was effective in evaluating the concepts.

5. On the items labeled as requiring concrete operational thought, significance was obtained at the level chosen in thirty-eight out of thirty-nine cases, indicating acceptance of the null hypothesis in those test items. In so far as concrete items are concerned, this investigator concluded that ninety-seven per cent of the time, the classification system was applied with validity.

6. Pooling the results obtained from the tests of significance applied to all the items on the four achievement tests, the conclusion was made that the classification procedure worked ninety-five per cent of the time.

TABLE 5-1

z-VALUES AND INDICATION OF SIGNIFICANCE AT .01 LEVEL
FOR FORMAL AND CONCRETE STUDENTS ON CONCRETE ITEMS
PHYSICS ACHIEVEMENT TEST-FIRST SEMESTER

Item Number	z-Value Obtained	Critical Value of z from Table	Indication of Significance	Decision
1	1.35	2.326	Not significant	Accept Ho
4	0.12	2.326	Not significant	Accept Ho
5	3.28	2.326	Significant	Reject Ho
8	0.17	2.326	Not significant	Accept Ho
10	0.10	2.326	Not significant	Accept Ho
12	1.36	2.326	Not significant	Accept Ho
13	0.00	2.326	Not significant	Accept Ho
17	0.12	2.326	Not significant	Accept Ho
18	0.89	2.326	Not significant	Accept Ho
19	0.82	2.326	Not significant	Accept Ho
22	2.05	2.326	Not significant	Accept Ho
24	0.39	2.326	Not significant	Accept Ho

TABLE 5-2

z-VALUES AND INDICATION OF SIGNIFICANCE AT .10 LEVEL
FOR FORMAL AND CONCRETE STUDENTS ON FORMAL ITEMS
PHYSICS ACHIEVEMENT TEST-FIRST SEMESTER

Item Number	z-Value Obtained	Critical Value of z from Table	Indication of Significance	Decision
2	3.025	1.282	Significant	Reject Ho
3	2.200	1.282	Significant	Reject Ho
6	2.090	1.282	Significant	Reject Ho
7	1.760	1.282	Significant	Reject Ho
9	2.450	1.282	Significant	Reject Ho
11	1.220	1.282	Not significant	Accept Ho
14	2.100	1.282	Significant	Reject Ho
15	1.471	1.282	Significant	Reject Ho
16	2.072	1.282	Significant	Reject Ho
20	1.354	1 282	Significant	Reject Ho
21	1.531	1.282	Significant	Reject Ho
23	3.044	1.281	Significant	Reject Ho
25	2.360	1.282	Significant	Reject Ho

TABLE 5-3

z-VALUES AND INDICATION OF SIGNIFICANCE AT .01 LEVEL
FOR CONCRETE AND FORMAL STUDENTS ON CONCRETE ITEMS
PHYSICS ACHIEVEMENT TEST-SECOND SEMESTER

Item Number	z-Value Obtained	Critical Value of z from Table	Indication of Significance	Decision
1	1.290	2.326	Not significant	Accept Ho
6	0.000	2.326	Not significant	Accept Ho
8	2.051	2.326	Not significant	Accept Ho
12	0.388	2.326	Not significant	Accept Ho
14	0.388	2.326	Not significant	Accept Ho
17	0.574	2.326	Not significant	Accept Ho
20	0.174	2.326	Not significant	Accept Ho
21	0.833	2.326	Not significant	Accept Ho
23	0.833	2.326	Not significant	Accept Ho
24	1.320	2.326	Not significant	Accept Ho

TABLE 5-4

z-VALUES AND INDICATION OF SIGNIFICANCE AT .10 LEVEL
FOR CONCRETE AND FORMAL STUDENTS ON FORMAL ITEMS
PHYSICS ACHIEVEMENT TEST-SECOND SEMESTER

Item Number	z-Value Obtained	Critical Value of z from Table	Indication of Significance	Decision
2	2.091	1.282	Significant	Reject Ho
3	0.134	1.282	Not significant	Accept Ho
4	1.881	1.282	Significant	Reject Ho
5	1.913	1.282	Significant	Reject Ho
7	2.423	1.282	Significant	Reject Ho
9	2.963	1.282	Significant	Reject Ho
10	1.742	1.282	Significant	Reject Ho
11	3.310	1.282	Significant	Reject Ho
13	2.600	1.282	Significant	Reject Ho
15	2.074	1.282	Significant	Reject Ho
16	1.782	1.282	Significant	Reject Ho
18	1.430	1.282	Significant	Reject Ho
19	1.843	1.282	Significant	Reject Ho
22	2.211	1.282	Significant	Reject Ho
25	1.880	1.282	Significant	Reject Ho

TABLE 5-5

z-VALUES AND INDICATION OF SIGNIFICANCE AT .01 LEVEL
FOR CONCRETE AND FORMAL STUDENTS ON CONCRETE ITEMS
CHEMISTRY ACHIEVEMENT TEST-FIRST SEMESTER

Item Number	z-Value Obtained	Critical Value of z from Table	Indication of Significance	Decision
3	0.749	2.326	Not significant	Accept Ho
4	1.235	2.326	Not significant	Accept Ho
6	1.370	2.326	Not significant	Accept Ho
11	1.530	2.326	Not significant	Accept Ho
12	1.060	2.326	Not significant	Accept Ho
13	0.587	2.326	Not significant	Accept Ho
15	2.202	2.326	Not significant	Accept Ho
18	1.370	2.326	Not significant	Accept Ho
20	1.830	2.326	Not significant	Accept Ho
21	0.749	2.326	Not significant	Accept Ho

TABLE 5-6

z-VALUES AND INDICATION OF SIGNIFICANCE AT .10 LEVEL
FOR CONCRETE AND FORMAL STUDENTS ON FORMAL ITEMS
CHEMISTRY ACHIEVEMENT TEST-FIRST SEMESTER

Item Number	z-Value Obtained	Critical Value of z from Table	Indication of Significance	Decision
1	3.961	1.282	Significant	Reject Ho
2	2.321	1.282	Significant	Reject Ho
5	3.471	1.282	Significant	Reject Ho
7	5.173	1.282	Significant	Reject Ho
8	3.150	1.282	Significant	Reject Ho
9	1.612	1.282	Significant	Reject Ho
10	4.420	1.282	Significant	Reject Ho
14	1.910	1.282	Significant	Reject Ho
16	3.352	1.282	Significant	Reject Ho
17	4.700	1.282	Significant	Reject Ho
19	0.281	1.282	Not significant	Accept Ho
22	3.510	1.282	Significant	Reject Ho
23	0.237	1.282	Not significant	Accept Ho
24	2.530	1.282	Significant	Reject Ho
25	1.614	1.282	Significant	Reject Ho

TABLE 5-7

z-VALUES AND INDICATION OF SIGNIFICANCE AT .01 LEVEL
FOR FORMAL AND CONCRETE STUDENTS ON CONCRETE ITEMS
CHEMISTRY ACHIEVEMENT TEST-SECOND SEMESTER

Item Number	z-Value Obtained	Critical Value of z from Table	Indication of Significance	Decision
5	0.5873	2.326	Not significant	Accept Ho
6	0.9565	2.326	Not significant	Accept Ho
7	0.2506	2.326	Not significant	Accept Ho
12	1.1240	2.326	Not significant	Accept Ho
16	0.2506	2.326	Not significant	Accept Ho
18	0.0000	2.326	Not significant	Accept Ho
22	0.9788	2.326	Not significant	Accept Ho

TABLE 5-8

z-VALUES AND INDICATION OF SIGNIFICANCE AT .10 LEVEL
FOR FORMAL AND CONCRETE STUDENTS ON FORMAL ITEMS
CHEMISTRY ACHIEVEMENT TEST-SECOND SEMESTER

Item Number	z-Value Obtained	Critical Value of z from Table	Indication of Significance	Decision
1	5.195	1.282	Significant	Reject Ho
2	2.987	1.282	Significant	Reject Ho
3	3.326	1.282	Significant	Reject Ho
4	2.561	1.282	Significant	Reject Ho
8	2.240	1.282	Significant	Reject Ho
9	3.323	1.282	Significant	Reject Ho
10	3.830	1.282	Significant	Reject Ho
11	4.700	1.282	Significant	Reject Ho
13	3.476	1.282	Significant	Reject Ho
14	3.476	1.282	Significant	Reject Ho
15	2.971	1.282	Significant	Reject Ho
17	4.484	1.282	Significant	Reject Ho
19	1.880	1.282	Significant	Reject Ho
20	2.291	1.282	Significant	Reject Ho
21	3.572	1.282	Significant	Reject Ho
23	3.881	1.282	Significant	Reject Ho
24	4.083	1.282	Significant	Reject Ho
25	2.461	1.282	Significant	Reject Ho

CHAPTER VI

CONCLUSIONS, EDUCATIONAL IMPLICATIONS, AND SUGGESTIONS FOR FURTHER STUDY

Conclusions

The data from this investigation and the results of the statistical treatments to which these data were subjected led this investigator to the conclusion that the concept classification system based on the Piagetian model is a valid instrument that can be utilized in the design of science curricula and in the teaching of that discipline.

This investigator has had many years of experience in teaching chemistry and physics and believes these findings reveal a reason for the small enrollments in secondary school chemistry and physics. The belief of this investigator is that students are selecting themselves and disqualifying themselves from courses that are as structured and abstract or, in the language of Piaget, as formal as these disciplines presently are.

Educational Implications

The data from the Lawson study show that concrete operational students cannot comprehend formal concepts. Data from this investigation corroborate Lawson's findings and clearly indicate that, among the physics and chemistry students involved in this investigation, those who were evaluated as being concrete operational in their thinking were the ones who demonstrated an inability to comprehend formal concepts.

Since physics and chemistry students who are eleventh and twelfth graders evince a lack of understanding of formal concepts, discovering that a good number of biology students (mostly tenth graders) are unable to work with formal concepts is not surprising. And yet a cursory look at the materials used in teaching biology, for example, the Biological Sciences Curriculum Study group textbooks--Blue, Yellow and Green Versions--reveals such concepts as DNA, osmotic pressure, metabolism, enzyme action, photosynthesis, and cell function, all of which can be classified as requiring formal operational thought to be understood. All of these are beyond the comprehension of most of the learners inasmuch as 64.8 per cent of tenth grade biology students have been found to be concrete operational in their thinking by the Lawson study.[1]

In view of the kind of student population in biology, physics , and chemistry and the kind of content that is currently being attempted in those disciplines, clearly the high school biological science curriculum is by far the most serious problem area in all of science. Kohlberg and Gilligan[2] are justified in saying that curriculum developers have assumed formal operational thought on the part of the learners when various curricula were designed and schools have made the same assumption when implementing those curricula. Such an assumption is turning out to be unwarranted and unjustified in the light of recent research identifying the intellectual levels of secondary school students.[3]

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[1]Lawson, "Relationships Between Subject Matter and Intellectual Levels," p. 63.

[2]Kohlberg and Gilligan, _op_. _cit_., p.1052.

[3]Renner, _et_ _al_., _Research, Teaching, Learning--Piagetian Model_.

Clearly, what needs to be done is to identify the intellectual levels of the learners first and then develop the curriculum for their use. It is in the development of these new curricula that the classification system designed in this study could be put to good use.

Recommendations

The findings of this study lead this investigator to make the following recommendations:

1. This same study should be replicated in other disciplines such as mathematics, social science, language arts, as well as the remainder of the sciences in order to identify major concepts in these disciplines which can then be examined for compatibility with the learners in regard to their intellectual levels.

2. Piaget has suggested that, in the movement from concrete to formal operational thought, learners develop such operational structures as identity , negation, reciprocity, and correlation (the INRC group). If the relationship between the INRC group and the operational criteria used in this investigation is known, then this knowledge would allow for a more definitive scheme in the analysis of concepts. In this manner, not only the thought required for understanding is identified but the particular operation is as well. This investigator, therefore, recommends that a study be done to see in what manner the operational criteria delineated in this investigation may be linked with the INRC group of Piaget.

3. Data from this investigation suggest that the concrete operational subjects did not move from concrete operations. If they did, then the tests of significance for the test items on the second semester would have yielded different results from those obtained. This investigator

hypothesizes that concrete learners cannot use formal content such as is found in physics and move to formal operations. This study should be replicated in such a way that levels of intellectual development among the concrete subjects could be measured at several points during the year to determine if they could use formal content and move to formal operations.

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