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RELATIONSHIPS BETWEEN CONCRETE AND FORMAL

OPERATIONAL SCIENCE SUBJECT MATTER

AND

THE INTELLECTUAL LEVEL OF THE LEARNER

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CHAPTER I

INTRODUCTION

Statement of the Problem

The primary objective of this investigation was to assess understanding of concrete and formal operational concepts by concrete and formal operational students in secondary school biology, chemistry, and physics classes.

To accomplish this objective, the percentage of concrete and formal operational students in selected biology, chemistry, and physics classes was determined, and individual subjects were identified as concrete or formal operational thinkers. Six Piagetian styled tasks were used to assess levels of thinking.

The major concepts taught during the year in each science class were classified as concrete or formal operational, and a written test involving those concepts was constructed and administered.

This study, then, sought answers to the following questions. What is the level of intellectual development of selected students in biology, chemistry, and physics classes as determined by Piagetian tasks? What are the major concrete and formal operational concepts taught in those classes? What are the relationships between students' scores on the Piagetian tasks and written test scores on concrete and formal operational concepts, i.e.; are concrete operational students able to understand only concrete concepts while formal operational students are able to understand both concrete and formal operational concepts?

Definitions

The following definitions are taken from Piagetian theory:

1. Mental Structures - Mental structures are hypothesized electrical or chemical patterns which exist in the brain. At this point in the study of human mental functioning the determination of their exact physiological and structural nature is not possible. They are assumed to exist and to function in organizing the environment so that the person can function effectively. Basically then, mental structures represent more or less tightly organized mental systems to guide behavior.

2. Mental Operations -

> An operation is a type of action; it can be carried out either directly, in the manipulation of objects, or internally, when it is categories or (in the case of formal logic) propositions which are manipulated. Roughly, an operation is a means for mentally transforming data about the real world so they can be organized and used selectively in the solution of problems. An operation differs from simple action or goal directed behavior in that it is internalized and reversible.[1]

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

Mental structures serve to guide these operations.

3. Concrete Operational Thinking - Concrete operational thinking is thinking based upon the use of what Piaget calls concrete operations. According to the theory, concrete operations develop between seven and eleven years of age. These mental operations are termed concrete because they operate on objects and not yet on verbally expressed hypotheses.[2] As stated previously, these operations depend upon the use of mental structures. Concrete mental structures depend on the logic of classes (class-inclusion operations) and the logic of relations (serial-ordering).[3] They represent a means for structuring immediately present reality.[4]

4. Formal Operational Thinking - The most important features of formal operational thinking are the development of the ability to use hypothetical reasoning based on the logic of all possible combinations and to perform controlled experimentation.[5] This type of thinking begins to develop, according to the theory, at about age eleven or twelve. The mental structures upon which this type of thinking depends are called the "lattice" and the "group." These structures are integrated

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[2]Jean Piaget, "Development and Learning," Journal of Research in Science Teaching, 1964, No. 3, p. 177.

[3]Inhelder and Piaget, The Growth of Logical Thinking, p. xiv.

[4]Ibid., p. xvii.

[5]Ibid., p. xiii.

into what Piaget refers to as the "structured whole."[6]

Aside from the structural differences between concrete and formal operational thought, the most fundamental property of formal thought is the reversal of direction between reality and possibility.[7]

> The adolescent differs from the child above all in that he thinks beyond the present. The adolescent is the individual who commits himself to possibilities - although we certainly do not mean to deny that his commitment begins in real-life situations. In other words, the adolescent is the individual who begins to build 'systems' or 'theories,' in the largest sense of the term.
>
> The child does not build systems . . . . In other words, the child has no powers of reflection - i.e., no second-order thoughts which deal critically with his own thinking. No theory can be built without such reflection.[8]

One further point should be mentioned concerning the nature of the formal operations. Formal operations "consist essentially of 'implications' (in the narrow sense of the word) and 'contradictions' established between propositions which themselves express classifications, seriations, etc."[9]

5. Concrete Operational Concepts - Concrete operational concepts are concepts whose meaning can be developed from first-hand experience with objects or events. These concepts

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[6]For a detailed explanation of these structures, see Inhelder and Piaget, The Growth of Logical Thinking, pp. 272-333.

[7]Ibid., p. 255.

[8]Ibid., pp. 339-340.

[9]Jean Piaget, The Psychology of Intelligence, (Paterson, N. J.: Littlefield, Adams, 1963), p. 149.

may arise through intuition in which the entire meaning of the concept is given through the senses such as the color "blue." Concrete concepts may also arise by postulation, however, if so, part of the meaning of the concept must be sensed or immediately apprehended. Examples are common objects such as tables, chairs, and other persons.

6. Formal Operational Concepts - Formal operational concepts are concepts whose meaning is derived through position within a postulatory-deductive system. Meaning is given to these concepts not through senses but through imagination or through their logical relationships within the system. To fully comprehend the meaning of a formal concept one must be able to operate formally or logically in a hypothetico-deductive manner since a formal concept is one the meaning of which in whole or part is designated by postulates of the deductive theory in which it occurs. In other words the concept's meaning is developed by virtue of the properties or relations assigned to it by the postulate or set of postulates within which it is a member term.

Some formal concepts can be imagined using concrete models. The solid particle model of atoms is an example of this type of concept. The light model which borrows the pattern of waves on water is another example. (Note: Since concepts such as these can be modeled using concrete objects, events, or symbols, concrete operational individuals can develop the ability to verbalize about such things. However, they are denied a full comprehension of the concepts until development of formal operations which allow construction of the postulatory-deductive system within which the concept derives its full meaning.

In evaluating comprehension of such concepts it is imperative to avoid an evaluation based solely upon comprehension of concrete models. This type of evaluation fails to test for understanding of a concept's implications.)

7. Understanding - The classification scheme developed in Taxonomy of Educational Objectives: The Classification of Educational Goals edited by Benjamin S. Bloom was used to categorize examination questions to assess concept understanding. That scheme classifys educational goals into six levels: (1) Knowledge, (2) Comprehension, (3) Application, (4) Analysis, (5) Synthesis, and (6) Evaluation. Since level (1) questions require only recall and levels (4), (5), and (6) test for mental operations other than concept understanding, it was decided that questions developed here must be constructed using only levels (2) and (3).

Understanding, then, is operationally defined as the ability to select the correct or best response from among those given on multiple choice questions involving items classified on the comprehension or application level of the above mentioned taxonomy.

The following summary has been taken from Bloom's taxonomy of the cognitive domain. It represents sub-classification of questions in levels (2) and (3).

2.00 COMPREHENSION

This represents the lowest level of understanding. It refers to a type of understanding or apprehension such that the individual knows what is being communicated and can make use of the material or idea being communicated without necessarily relating it to other material or seeing its fullest implications.

2.10 TRANSLATION

Comprehension as evidenced by the care and accuracy with which the communication is paraphrased or rendered from one language or form of communication to another. Translation is judged on the basis of faithfulness and accuracy, that is, on the extent to which the material in the original communication is preserved although the form of the communication has been altered.

2.20 INTERPRETATION

The explanation or summarization of a communication. Whereas translation involves an objective part-for-part rendering of a communication, interpretation involves a reordering, rearrangement, or a new view of the material.

2.30 EXTRAPOLATION

The extension of trends or tendencies beyond the given data to determine implications, consequences, corollaries, effects, etc., which are in accordance with the conditions described in the original communication.

3.00 APPLICATION

The use of abstractions in particular and concrete situations. The abstractions may be in the form of general ideas, rules of procedures, or generalized methods. The abstractions may also be technical principles, ideas, and theories which must be remembered and applied.[10]

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[10]Benjamin S. Bloom, editor, Taxonomy of Educational Objectives: The Classification of Educational Goals, Handbook 1, Cognitive Domain, (New York: David McKay, 1956), pp. 204-205.

Premises of the Study

The premises tested by this investigation were:

1. Concrete operational thinking students are able to understand concrete operational concepts.
2. Concrete operational thinking students are unable to understand formal operational concepts.
3. Formal operational thinking students are able to understand both concrete and formal operational concepts.
4. One ability, namely, development of the "structure whole," determines the subject's success on Piagetian tasks.

Background of the Study

A number of new secondary school science programs have been developed in recent years which not only update the content of science teaching, but emphasize the laboratory as a means to student inquiry, for reviews see Hurd, 1969,[11] 1970.[12] These new programs further attempt to accurately reflect the structure of the particular discipline, be it chemistry, physics, or biology. For example, the Biological Science Curriculum Study has three versions of inquiry-oriented biology textbooks available for school use. Each textbook emphasizes one

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[11]P. Dehart Hurd, New Directions in Teaching Secondary School Science, (Chicago: Rand McNally and Co., 1969).

[12]P. Dehart Hurd, New Curriculum Perspectives for Junior High School Science, (Belmont, California: Wadsworth Co., 1970).

selected area in biology-ecology, cell biology, or molecular biology. Although each text emphasizes different areas of biology, nine basic unifying themes pervade each text:

1. Change of living things through time: evolution
2. Diversity of type and unity of pattern in living things
3. The genetic continuity of life
4. The complementarity of organism and environment
5. The biological roots of behavior
6. The complementarity of structure and function
7. Regulation and homeostasis: preservation of life in the face of change
8. The history of biological conceptions
9. Science as inquiry[13]

Project Physics, which originated at Harvard University in 1962, includes in its program, a textbook, student guides for each unit, a laboratory guide, laboratory equipment, audio-visual material, teacher's guides, and an evaluation program. The units of the text reflect the program's adherence to the fundamental concepts of the discipline. The units are: (1) Concepts in Motion; (2) Motion in the Heavens; (3) Energy; (4) Waves and Fields; (5) Models of the Atom: and (6) The Nucleus.[14]

In the field of chemistry, new programs are also in evidence. One such program is the CHEM Study program which evolved out of a committee established in 1959 by the American Chemical Society. CHEM Study materials include the text, laboratory manual, teacher's guides, instruction pamphlets, achievement tests, related monographs, and films.[15] The content and structure of the textbook include:

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[13]Hurd, New Directions in Teaching Secondary School Science, p. 154.

[14]Ibid., pp. 193-196.

[15]Ibid., pp. 177-178.

1. presentation of the experimental evidence upon which the main concepts and principles of modern chemistry are based, and discussion of how such evidence is obtained;
2. discussion of the major concepts and principles that have grown out of the evidence;
3. application of the concepts and principles in a variety of areas of chemistry; and
4. inclusion of tabular data useful in applying concepts and principles in the solution of problems.[16]

During the period of time these new science programs were being constructed, the works of Jean Piaget, a Swiss epistemologist and psychologist, were receiving greater and greater attention. Piaget, in his numerous works dealing with cognitive development of children, has formulated a theory of intellectual growth which is opening up new avenues of investigation and providing new insights. Many educators are seeing rather striking implications of Piaget's theory for both classroom procedures and curriculum development. For example, a number of recent books have appeared not only explaining Piaget's theory but providing possible applications of his ideas in education.[17,18,19,20,21] Piaget, himself, has expressed an interest

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[16]Richard J. Merrill, David W. Ridgeway, The CHEM Study Story, (San Francisco: W. H. Freeman and Co., 1969), p. 27.

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

[18]Richard Gorman, Discovering Piaget: A Guide for Teachers, (Columbus: C. E. Merrill Co., 1972).

[19]John L. Phillips, Jr., The Origins of Intellect: Piaget's Theory, (San Francisco: Freeman and Co., 1969).

[20]John G. Flavell, The Developmental Psychology of Jean Piaget, (Princeton, N. J.: D. Van Nostrand Co., Inc., 1963).

[21]John W. Renner, Robert F. Bibens, Gene D. Shepherd, Guiding Learning in the Secondary School, (New York: Harper and Row Publishers, 1972), Chapter 4.

in education in his Science of Education and the Psychology of the Child.[22]

According to Piaget, a child passes through three preliminary stages of intellectual development to reach the fourth and final stage, adult thinking patterns. The first stage, from birth to about two years old, is labeled sensory-motor. The child's major objective is to learn about objects and their spatial relationships. Stage two, from age two to age seven, is called pre-operational. The primary achievement during this stage is the development of an understanding of symbolic meaning. The third stage, concrete operational, is characterized by the child's ability to perform what Piaget calls operations. Operations consist of mental manipulations based on the understanding of classes, relations, and quantities. Of primary concern to the educator is the restriction that these mental operations must always originate with concrete objects or experiences. In the fourth and final stage, beginning (according to Piaget) around age twelve, the child develops the use of propositional thinking. These operations based on propositional logic, which Piaget terms formal operations, enable the child to see implications and develop an understanding of abstract concepts. In short, the child is no longer tied to concrete experience but can think also in the realm of the possible.

Piaget has summarized the principal differences between

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[22]Jean Piaget, Science of Education and the Psychology of the Child, (New York: Viking Press, 1971).

concrete and formal operational thinking from a structural standpoint.

> 1. The child develops concrete operations and carries them out on classes, relations, or numbers. But their structure never goes beyond the level of elementary logical 'groupings' or additive and multiplicative numerical groups. . . . In contrast, the adolescent superimposes propositional logic on the logic of classes and relations. Thus, he gradually structures a formal mechanism (reaching an equilibrium point at about 14-15 years) which is based on both the lattice structure and the group of four transformations. This new integration allows him to bring inversion and reciprocity together into a single whole. As a result, he comes to control not only hypothetico-deductive reasoning and experimental proof based on the variation of a single factor with the others held constant (all other things being equal) but also a number of operational schemata which he will use repeatedly in experimental and logico-mathematical thinking.[23]

Piaget goes on to indicate that there is more to thinking than logic.

> 2. . . . the adolescent differs from the child above all in that he thinks beyond the present. The adolescent is the individual who commits himself to possibilities although we certainly do not mean to deny that his commitment begins in real life situations. In other words, the adolescent is the individual who begins to build 'systems' or 'theories,' in the largest sense of the term.[24]
>
> 3. The adolescent's theory-construction shows that he has become capable of reflective thinking and that his thought makes it possible for him to escape the concrete present toward the realm of the abstract and the possible.[25]

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[23] Inhelder and Piaget, The Growth of Logical Thinking, p. 335.

[24] Ibid., pp. 339-340.

[25] Ibid., pp. 342.

Piaget further provides examples of the types of concepts which can be understood only by the formal operational thinker.

> First, we are struck by the fact that feelings about ideals are practically nonexistent in the child. A study of the concept of nationality and the associated social attitudes has shown us that the child is sensitive to his family, to his place of residence, to his native language, to certain customs, etc., but that he preserves both an astonishing degree of ignorance and a striking insensitivity not only to his own designation or that of his associates as Swiss, French, etc., but toward his own country as a collective reality. . . . The notions of humanity, social justice (in contrast to interindividual justice which is deeply experienced at the concrete level), freedom of conscience, civic or intellectual courage, and so forth, like the idea of nationality, are ideals which profoundly influence the adolescent's life; but with the child's mentality, except for certain individual glimpses, they can neither be understood nor felt.[26]

Piaget's stages provide a possible tool for the evaluation of school curricula in terms of the intellectual ability of students. First, Piaget has provided tests for the assessment of levels of thinking, and second, he has detailed the types of understandings and thought processes available to individuals in each level. School curricula can now be analyzed in terms of the concrete or formal nature of the major concepts taught to determine whether students for which those curricula were designed are capable of achieving the desired understanding.

Piaget's theory clearly predicts that concrete operational students (as operationally defined by performance on

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[26] Ibid., pp. 348-349.

selected tasks) will not be able to develop understanding of abstract concepts i.e., concepts which require the building of theories and departures from concrete reality. Also, it is implied that formal operational students (as operationally defined by performance on selected tasks) will be able to develop understanding of both concrete and abstract concepts.

This work of Piaget, as mentioned, offers an excellent tool for analyzing the appropriateness of school curricula in terms of the intellectual levels of the students. Once the intellectual levels of students are known, programs can be constructed to fit that level and promote progress to higher levels.

Need for the Study

The number of recent research studies dealing with Piagetian ideas is indeed large.

In general, research is confirming Piaget's developmental scheme. Brainerd, 1971,[27] in attempting to validate cross sectionally Piaget's claims concerning proportionality reasoning, stated that the sequence and timing of development for the concepts of volume and density were acquired as Piaget predicted. Mecke and Mecke, 1971,[28] statistically confirmed

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[27] C. J. Brainerd, "The Development of Proportionality Scheme in Children and Adolescents," Developmental Psychology, 1971, 5, pp. 469-476.

[28] G. Mecke and V. Mecke, "The Development of Formal Thought as Shown by Explanations of the Oscillations of a Pendulum: A Replication Study." Adolescence, 1971, 6, pp. 219-228.

a gradual age-dependent increase in children's ability to perform formal operations as determined by the Piagetian task dealing with oscillations of a pendulum. This represents statistical support for a previously not quantified aspect of Piaget's theory.

Karplus and Karplus, 1970,[29] testing children and adults with an Islands Puzzle to assess abstract reasoning ability, were able to identify preoperational, concrete, and formal operational levels of thought within the sample. Karplus and Peterson, 1971,[30] demonstrated these same Piagetian levels of reasoning as determined by responses on a ratio problem requiring a change in the unit of length measurement.

Of particular interest in the two previous studies is that although the existence of stages of development is supported, the stages are occurring at older ages than expected. In fact, in some instances the stage of formal operations may not be reached at all.

Kohlberg and Gilligan[31] report that in a study of the ability of 265 persons to perform on the Piagetian pendulum

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[29] R. Karplus and E. Karplus, "Intellectual Development Beyond Elementary School I: Deductive Logic." School Science and Mathematics, May, 1970, pp. 398-406.

[30] R. Karplus and R. W. Peterson, "Intellectual Development Beyond Elementary School II: Ratio, A Survey." School Science and Mathematics, Dec., 1970, pp. 813-820.

[31] Lawrence Kohlberg and Carol Gilligan, "The Adolescent as a Philosopher: The Discovery of the Self in a Postconventional World," Daedlus, Fall, 1971, 100, pp. 1051-1084.

task these results were obtained:

age ten to fifteen:	45 per cent formal
age sixteen to twenty:	53 per cent formal
age twenty-one to thirty:	65 per cent formal
age forty-five to fifty:	57 per cent formal

These results, as those of Karplus and Karplus, 1970, and Karplus and Peterson, 1970, indicate a large portion of the adolescent and adult populations has not reached the level of abstract formal thinking.

The Science Education Center, University of Oklahoma, has gathered data which indicate that a large percentage of high school students are still concrete operational (75.3 per cent of a sample of 588 students in grades 7-12).[32] This has serious implications for the above mentioned secondary school science programs in that each subject - biology, chemistry, and physics - deals largely with abstract concepts. The understanding of these abstract concepts is probably not possible for concrete operational learners. The combination of concrete operational students and predominately formal operational curricula could be a reason for much of the student difficulty and frustration with high school science courses.

In light of these previously mentioned studies, clearly what is needed is a careful look at specific curricula and specific students in an attempt to determine just how much understanding is possible and just how appropriate today's

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[32]John W. Renner and Don G. Stafford, Teaching Science in the Secondary School, (New York: Harper and Row Publishers, 1972), pp. 291-296.

new curricula are in terms of the intellectual level of the students. If Piagetian theory is correct and if indeed a large portion of secondary school students are concrete operational, then the major portion of today's science curricula is beyond the student's level of understanding and, therefore, unappropriate. The conclusion Kohlberg and Gilligan came to when they stated, "Clearly these new curricula assumed formal operational thought rather than attempting to develop it,"[33] certainly deserves a careful analysis.

Procedures

Although a description of the procedures used in this study will be detailed in Chapter III, a short discussion of those procedures is included below to facilitate clarity.

Subjects from a single high school were selected from classes in biology, chemistry, and physics. They were taught their science courses by the regular classroom teacher. During the last month of instruction in the 1972-73 academic year, the investigator administered six Piagetian tasks to each subject. The subjects responses were scored as preoperational (I), concrete operational (IIa or IIb), or formal operational (IIIa or IIIb). Subject matter tests were then administered to the subjects in their respective disciplines. These tests basically consisted of two parts: (1) evaluation of understanding

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[33]Lawrence Kohlberg and Carol Gilligan, "The Adolescent as a Philosopher," p. 1082.

of concrete operational concepts, and (2) evaluation of understanding of formal operational concepts. Numerical scores were obtained for each subject on both parts of the test. Pearson product-moment correlations of Piagetian task scores and subject matter test scores were calculated and significance levels obtained. Multiple correlation coefficients,[34] were obtained and tested for significance using F-tests.

The data were further analyzed using step-wise semi-partial regression techniques to determine which Piagetian task best predicted subject success on concrete and formal operational concepts.[35] Principal components analysis was also used to determine the number of cognitive parameters underlying success on the six Piagetian tasks.[36]

Limitations

The limitations of this study can be viewed as follows: (1) generalization, (2) construction and validation of subject matter tests, (3) standardization of scoring of Piagetian tasks, (4) cause and effect assumption.

In order to determine the degree to which the data could be generalized, the calculated multiple correlation

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[34]Maurice M. Tatsuoka, Multivariate Analysis: Techniques for Educational and Psychological Research, (New York: John Wiley and Sons, Inc., 1971), pp. 26-38.

[35]Richard B. Darlington, "Multiple Regression in Psychological Research and Practice," Psychological Bulletin, 1968, 69, p. 178.

[36]Maurice M. Tatsuoka, Multivariate Analysis, pp. 44-48.

coefficients obtained between the Piagetian tasks and the content examinations were cross-validated assuming the random variable model.[37] Using this procedure the cross-validated multiple correlation coefficients represent the generalizability of the results.

In order to validate the content of the subject matter tests, copies of the tests were sent to five selected science educators who were asked to judge the suitability of each test item. The persons chosen to examine the subject matter tests were science educators who had demonstrated, through their investigations and publications, a good understanding of both Piagetian theory and the disciplines of biology, physics, and chemistry. The critical factors were in assuring, (1) that the test items truly tested the understanding of concepts and not memorization of correct responses, and (2) that the selected concepts had been classified correctly into concrete and formal operational categories.

Content validity was assured by having each classroom instructor read the examinations prior to administration. Any question which did not refer to material taught during the year was replaced by an appropriate item.

All Piagetian tasks were administered by the investigator. This was to eliminate as much experimenter variance as possible. The consistency of scoring was determined by

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[37]C. Stein, "Multiple Regression," in I. Olkin, et al., editors, Contributions to Probability and Statistics, (Stanford: Stanford University Press, 1960) p. 427.

comparing average subject scores obtained during each day of the interviewing using the statistical technique of one-factor analysis of variance.

This study involved correlations of Piagetian task scores with student test scores. The assumption that success on Piagetian tasks caused success on the subject matter test of formal operational concepts was not made. However, Piagetian theory states that success on the Piagetian tasks indicates the development of certain mental structures and these mental structures enable the subject to develop understanding of the formal operational concepts. That prediction then became the working hypothesis of this study and it does involve a causal relationship.

Major Hypotheses of the Study

Sixteen major null hypotheses were tested against sixteen alternative hypotheses in this study. The major null hypotheses were:

1. Ho: No significant multiple correlation exists between Piagetian task scores and success on questions involving concrete biology concepts.

2. Ho: No significant multiple correlation exists between Piagetian task scores and success on questions involving formal biology concepts.

3-6. The same null hypotheses were tested for chemistry and physics samples.

7. Ho: No significant difference exists in mean scores of concrete and formal operational students on concrete concepts.

8. Ho: No significant difference exists in mean scores of concrete and formal operational students on formal concepts.

9. Ho: Additional Piagetian task scores do not add significantly in the prediction of concrete biology concept scores over the best single predictor task.

10. Ho: Additional Piagetian task scores do not add significantly in the prediction of formal biology concept scores over the best single predictor task.

11-16. The same null hypotheses were tested for chemistry and physics samples.

CHAPTER II

REVIEW OF LITERATURE

This investigation deals with concrete and formal operational levels of thinking in adolescents enrolled in secondary school science programs, and student ability to develop understanding of major concepts of those programs. Although no study has been conducted which addresses itself to the question of student understanding of concrete and formal operational science concepts, a number of studies related to this topic have been carried out and require mention. To facilitate review the literature will be divided into three sections: (1) levels of intellectual development in adolescents, (2) levels of intellectual development in relation to concept learning, and (3) validation of Piagetian formal operational tasks.

Levels of Intellectual Development in Adolescents

A number of studies in recent years have revealed that a relatively large percentage of high school students have failed to reach the formal operational stage of thinking.

Friot[1] measured intellectual development of 210 seventh, eighth, and ninth grade students in an Oklahoma junior high school using five Piagetian tasks. The tasks administered were Conservation of Volume, Reciprocal Implications, Elimination of Contradictions, Separation of Variables, and Exclusion. The findings revealed 82 per cent of the subjects concrete operational. In a cross-sectional study of preadolescent girls, college coeds, and middle age women, Keasey[2] showed that the majority of the adolescent girls were performing at the concrete operational level while the majority of the coeds were performing at the formal operational level. The women as a group scored between the coeds and the girls. Piagetian tasks used in this study were: Exclusion, Separation of Variables, and Equilibrium in the Balance.

McKinnon and Renner[3] report responses of 131 members of the freshman class at a college in Oklahoma in which students were evaluated on tasks of Conservation of Volume, Reciprocal Implication, Elimination of Contraditions, Separation of Variables, and Exclusion. On the basis of these tasks

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[1]Faith E. Friot, The Relationship Between an Inquiry Teaching Approach and Intellectual Development, Unpublished Doctoral Dissertation, University of Oklahoma, 1970.

[2]Carol T. Keasey, The Nature of Formal Operations in Preadolescence, and Middle Age, Unpublished Doctoral Dissertation, University of California, Berkeley, 1970.

[3]Joe W. McKinnon and John W. Renner, "Are Colleges Concerned With Intellectual Development?" American Journal of Physics, 1971, 39, pp. 1047-1052.

it was concluded that 50 per cent of the entering college freshmen were operating completely at the concrete level and another 25 per cent had not fully attained the established criteria for formal thought.

Higgins-Trenk and Gaite[4] studying 162 adolescents between the ages of 13.4 and 17.7 years from a Wisconsin high school used the Conservation of Volume task to measure formal operational thinking. Their results indicated only 43 per cent of the subjects operated at a formal level. In summarizing the study, the authors stated: "Indeed, it would seem that the normal adolescent is unlikely to reach the level of formal thought until his late teens or early twenties if he reaches it at all . . ."[5]

A similar conclusion was reached by Lovell[6] in testing 200 British subjects between the ages of eight and eighteen. Each subject was tested on four of the Piagetian tasks in an attempt to confirm Piaget's stage theory of intellectual development. The main stages in development were confirmed, but the author raises a number of points in disagreement with Piaget. One such point was that the transition to formal operational thinking in the British sample was occurring at

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[4]A. Higgins-Trenk and A. J. H. Gaite, "Elusiveness of Formal Operational Thought," Proceedings, 79th Annual Convention, American Psychological Association, 1971, pp. 201-202.

[5]Ibid., p. 202.

[6]K. Lovell, "A Follow-Up Study of Inhelder and Piaget's The Growth of Logical Thinking," British Journal of Psychology, 1961, 52, pp. 143-153.

an older age than in Piaget's Geneva subjects. Melborne subjects were tested on Piaget's Combination of Colorless Chemicals task by Dale.[7] Only 10 per cent of his sample of 200, ages eleven to twelve, completely solved the problem and only 25 per cent were completely successful at age fifteen. Dale concurs with Lovell's statement that the sample of Geneva children tested by Piaget must have consisted only of "able children."

Karplus and Karplus,[8] using an Islands Puzzle which required propositional reasoning for correct solution, sampled responses of 449 subjects ranging from fifth graders to physics teachers. They were able to identify categories of responses which were similar to Piagetian stages. A gradual transition in the group median for each age group 5-6 up to the physics teachers was observed, however, the stages in intellectual development achieved by each age group was disappointingly low.[9]

The results of the study by Kohlberg and Gilligan cited earlier indicated approximately 50 per cent of the adolescents tested were concrete operational. The Exclusion task was used as the measure.

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[7]L. G. Dale, "The Growth of Systematic Thinking: Replication and Analysis of Piaget's First Chemical Experiment," Australian Journal of Psychology, 1970, 20, No. 3, pp. 277-285.

[8]Karplus and Karplus," Intellectual Development Beyond Elementary School I: Deductive Logic," pp. 398-406.

[9]*Ibid.*, p. 403.

Levels of Thinking in Relation to Concept Learning

The number of studies which address themselves to questions concerning the relationship between Piagetian levels of intellectual development and concept development outside the Geneva school is indeed small. Wallace, in his book Concept Growth and Education of the Child (1965) reviewing British, French, and American literature on concept learning concluded after 198 pages: "It is a sad commentary on the effectiveness of our methods of enquiry that after some eighty years of psychological investigation and a discontinuous history of forty years of laboratory experiments, our fund of accepted knowledge on the subject of conceptualization comprises so little of consequence that it is hardly worth compiling."[10]

Belanger, in reviewing concept learning studies in science education, concluded: "In the nearly total absence of a theoretical framework for the study of science concepts, studies attempting to pit ad hoc hypotheses against each other will probably continue only to demonstrate the obvious or to add to the already confusing list of findings from 'method X vs. method Y' investigations.[11] There appears to this date

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[10]J. G. Wallace, Concept Growth and the Education of the Child, (The Mere, England: National Foundation for Educational Research in England and Wales), 1965, p. 198.

[11]Maurice Belanger, "Learning Studies in Science Education," Review of Educational Research, 1969, 39, No. 4, p. 381.

to be a distinct lack of studies incorporating a theoretical framework which Berlinger referred.

Bridgham[12] investigated the usefulness of Piagetian tests as predictors of students' understanding of electrostatics. His sample consisted of 50 second grade students in a Boston suburb. He reported moderate correlations (0.31-0.66) between Piagetian tests of seriation, additive classifications, and multiplicative classification, with electrostatics scores. Electrostatics learning was presumed to involve class and series concepts as important components.

Palmer[13] studied the development of selected concepts by students in BSCS biology. Although not directly involved with Piagetian styled research, he reported that concept formation occurred primarily by interrelating small amounts of factual material through the ability to think and to reason effectively, and conceptualization depended more on the ability to think critically and reason effectively than any other factors.

One additional study, although not concerned with

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[12]Robert G. Bridgham, An Investigation of Piagetian Tests as Predictors of Students Understanding of Electrostatics, Unpublished Doctoral Dissertation, Harvard University, 1967.

[13]Ray A. Palmer, The Development of Selected Concepts by Students in BSCS Biology, Unpublished Doctoral Dissertation, George Peabody College, Nashville, Tennessee, 1969.

science conceptualizations, warrents mention. Adelson,[14] in studying modes of discourse about political perspectives in English, German, and American youth found a shift during adolescence from concrete to abstract modes of discourse paralleling a shift from concrete to formal operations. In reference to types of concepts attained he concludes: "What is of greater moment is that the idea of government itself is an achievement only slowly won. The concept of government, or indeed of any collectivity, is too abstract for our younger subjects to manage. They recognize only dimly, if at all, the existence of a social order. Hence, such terms as 'society,' 'government' and 'community' are essentially empty of meaning for them.[15]

Validity of Piagetian Formal Operational Tasks

This investigation involved the use of six Piagetian styled tasks to assess levels of intellectual development. Four of the tasks were administered in personal interviews while two were pencil and paper tasks administered to groups of students. The literature reports few attempts to validate Piagetian formal interviews or written tasks. The reports which do occur in the literature are somewhat contradictory.

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[14]Joseph Adelson, "Adolescent Perspectives on Law and Government," Paper presented at the annual meetings of the American Psychological Association, San Francisco, August, 1968. U. S. Department of Health, Education, and Welfare, Document No. CG003107.

[15]*Ibid.*, p. 6.

Hughes[16] tested 40 subjects in early adolescence with four Piagetian tasks including the Equilibrium in the Balance task. With principal components analysis all the tasks were found to have high correlations (0.57-.81) with the first principal component.

Lovell and Butterworth[17] tested 60 subjects with the Equilibrium in the Balance and Projection of Shadows tasks. Again using principal components analysis, both tasks loaded substantially on the first principal component.

Neimark,[18] using two Piagetian formal tasks, Chemical Combinations and Correlations tasks, tested 61 fourth, fifth, and sixth grade students. The two tasks did not show significant positive intercorrelations indicating that the tasks were measuring different psychological factors.

Bart,[19] attempting to validate four Piagetian formal operational tasks, tested 90 subjects from Chicago area schools ranging from 13 through 19 years of age. The tasks administered

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[16]M. M. Hughes, A Four Year Longitudinal Study of Growth of Logical Thinking in a Group of Secondary Modern School Students. Unpublished M. Ed. Thesis, University of Leeds, 1965.

[17]K. A. Lovell and I. B. Butterworth, "Abilities Underlying the Understanding of Proportionality," Mathematics Teaching, 1966, 37, pp. 5-9.

[18]Edith D. Neimark, "A Preliminary Search for Formal Operations Structures," Journal of Genetic Psychology, 1970, 116, pp. 223-232.

[19]William M. Bart, "A Construction and Validation of Formal Operational Reasoning Instruments," Paper presented at the annual meeting of the American Educational Research Association, Minneapolis, March, 1970.

were, Exclusion, Projection of Shadows, Equilibrium in the Balance, and Conservation of Motion. Three written tests were produced to test formal reasoning abilities in biology, literature, and history. The written examinations, although in specific subject areas, did not test concept understanding. The examinations consisted of absurd situations which compelled the subject to follow the form of arguments with no concrete references. Moderate intercorrelations were found among the four Piagetian tasks (0.448-0.731). Correlations ranging between 0.269 and 0.536 were obtained among the Piagetian measures and the written examinations.

Using written examinations this investigation has as its primary objective the assessment of concept understanding by secondary science students from a Piagetian frame of reference. By providing data concerning the intellectual levels of secondary school science students, relative levels of concept understanding, and validity of the Piagetian measures of thought processes, this study hopes to become a significant step in the direction of theoretically based science education.

CHAPTER III

PROCEDURES OF THE STUDY

Overview

This investigation was designed with three objectives. These were: (1) to determine the operational level of students in biology, chemistry, and physics classes in a selected high school as determined by Piagetian styled tasks; (2) to correlate students' operational level with success on tests of concrete and formal operational concepts taught during the year; (3) to isolate the best single predictor task of student ability to comprehend formal operational concepts. This study also represents tests of two implications of Piagetian theory. It directly tests one of its major implications, i.e., success on tasks is significantly correlated with understanding of formal concepts and it provides an opportunity to determine, using principal components analysis, the number of factors underlying the subjects' success on the six tasks. Piagetian theory predicts the presence of only one factor, i.e., propositional logic based on the "structured whole."

Selection of the Subjects

Subjects for this study were selected from Norman High

School, Norman, Oklahoma, a school of over 2000 students, which offers classes in biology, chemistry, and physics.

Sample sizes were determined to comply with the statiistical techniques used. Although no strict rules exist, when multiple correlation coefficients are calculated,approximately ten subjects are suggested for each independent variable. In this study, five formal operational Piagetian tasks were used, therefore, 51 subjects were representatively selected from biology classes and 50 subjects were similarly selected from chemistry classes. All 33 subjects were selected from the only physics class. Sex and chronological age were recorded for each student.

Instruments

Six tasks patterned after Piaget and Inhelder were administered to each subject to determine intellectual development: one concrete operational task, the Conservation of Weight, and five formal operational tasks. The tasks used were: (1) Conservation of Weight;[1] (2) Conservation of Volume;[2] (3) Separation of Variables;[3] (4) Equilibrium in the Balance;[4]

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[1]Renner and Stafford, Teaching Science in the Secondary School, pp. 89-90.

[2]The Developmental Theory of Piaget: Conservation, (San Francisco, John Davidson Film Producers, 1969).

[3]Inhelder and Piaget, Growth of Logical Thinking, pp. 46-66.

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

(5) Ratio;[5] and (6) Islands Puzzle.[6] Subjects were scored separately on each task. Responses were categorized as follows:

1. I, Preoperational
2. IIa, Transition to concrete operational
3. IIb, Concrete operational
4. IIIa, Transition to formal operational
5. IIIb, Formal operational

Numerical scores were awarded on a one to five scale contingent upon the category into which the subjects responses were classified.

Description of the Piagetian Tasks

1. The Conservation of Weight

The subject was given two balls of clay and allowed to work with them until he believed their weights were the same. The examiner then distorted one of the balls. He then asked the subject to tell him (without picking up the clay) which portion of clay weighed more or if they weighed the same. A correct response placed the subject in Class IIb. An incorrect response was classified as IIa.

2. Conservation of Volume Using Two Identically Shaped Cylinders of Different Weights

In this task the subject was given two metal cylinders

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[5] Robert Karplus, Elizabeth F. Karplus, and Warren Wollman, "Intellectual Development Beyond Elementary School IV: Ratio, The Influence of Cognitive Style," Unpublished manuscript.

[6] Karplus and Karplus, "Intellectual Development Beyond Elementary School I: Deductive Logic," pp. 398-399.

of exactly the same size but with a very obvious difference in their weights. All the foregoing properties of the cylinders were pointed out to the subject. He was next presented two identical cylinders partially filled with water and allowed to adjust the levels until he was convinced that each tube contained exactly the same amount of water. The subject was then asked if the heavy cylinder would push the water level up more, if the lighter cylinder would push the level up more, or if the cylinders would push the levels up the same. Successful completion of the task placed the subject in Class IIIa. If he predicted incorrectly and then explained the event after he saw it, he was classified as IIb. An unsuccessful prediction and no explanation was classified as IIa.

3. <u>Separation of Variables</u>

The subject was shown the apparatus which consisted of six flexible metal rods of varying length, diameter, shape, and material. The rods were attached to a stationary block of wood with adjustable clamps. Weights of 100 and 200 grams were placed on the ends to demonstrate the flexible nature of the rods. The subject was also shown how to adjust the length of the rods using the adjustable clamps. The subject was then asked to experiment with the apparatus until he could determine which of the rods bent the most and which bent the least.

After the exploration, the subject was asked to explain why some rods bent more than others, and to name the factors which determined how much the rods would bend. Following the naming of the factors, the subject was asked to prove the role of each of the factors mentioned.

The subject that simply classified the rods that bent the most and/or least into thicker, thinner, longer, shorter, square, or round was classified as IIa.

The subject who classified but compared two rods using logical multiplication was categorized as IIb. Logical multiplication can be thought of as (thicker) x (longer) = (thinner) x (shorter), this subject used compensation to explain what he saw. The distinguishing factor of a student in either Class IIIa or IIIb was his ability to demonstrate proof by utilizing the "all things being equal concept."

The subject who demonstrated that he could prove that one rod would not bend as much as another by holding, say material, length and weight (or any combination) constant and experimenting with the diameter was classified as IIIa. This subject would try to hold other variables constant and manipulate still others but to fail in some cases.

The subject who identified all the variables (weight, length, material, shape, and diameter) and systematically set about holding all but one constant and testing that one until all were tested was classified as IIIb and was completely formal operational.

4. Equilibrium in the Balance

The subject was shown the apparatus which consisted of a balance arm with 30 holes drilled in one inch intervals along its length. Weights of 10 units, 5 units and 2 units, which could be hung in the holes, were also pointed out. The interviewer hung one 10 unit weight 7 units of length from the fulcrum and asked the subject to hang another 10 unit weight on the opposite arm to achieve a balance.

Following completion of this, the subject was given two 5 unit weights to replace one of the 10 unit weights and asked to place them on the arm to achieve a balance. While the subject determined the proper location for the 5 unit weights, the interviewer held the arms of the balance parallel to the table surface. After the subject hung the weights, the interviewer released the arm to see if a balance had been achieved.

Next the subject removed his weig[illegible] was given one 5 unit weight, and asked to hang it to again balance the 10 unit weight. Again the examiner held the end of the balance arm. After the subject had selected the location, he was asked to explain his selection. Correct position selection and explanation placed the subject in Category IIIa. Following the explanation, the examiner let go of the balance arm to again see if balance had been achieved. If the subject reasoned that the 5 unit weight was 5 less than the 10 unit weight, therefore, it must be placed 5 units farther out, he has used the difference between 10 and 5 for his comparison, not the ratio of 10 and 5. This response is concrete and is categorized as IIb. No systematic explanation or a response which indicates the subject does not understand the law "heavier $\rightleftharpoons$ nearer," placed the subject in Category IIa.

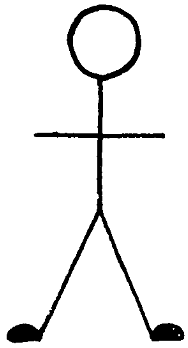
In a final task to differentiate IIIa from IIIb responses, the subject was given a 7 unit weight and asked to make it balance a 10 unit weight placed 7 units from the center. Correct prediction and explanation of this more difficult proportion problem placed the subject in Category IIIb.

5. Ratio

This task was administered to groups of subjects. Responses were written rather than oral. The subjects were given answer pages as shown in Figure 3-1 and a chain of No. 1 "gem" paper clips containing 8 clips. The subjects were then told that there was a figure called Mr. Tall, similar to the Mr. Short on their papers but larger, at the experimenter's (E) office. The

FIGURE 3-1

Mr. Short



(actual height - 7 7/8")

1. How tall is Mr. Short measured with the paper clips?

   Answer________________________

2. Predict the height of Mr. Tall measured with the paper clips.

   Answer________________________

3. Explain how you figured out your prediction.

experimenter explained: "I measured Mr. Short's height with large buttons, one on top of the other, starting with the floor between Mr. Short's feet and going to the top of his head." Four buttons reached to the top of his head. (At this point, E wrote 'Mr. Short: 4 buttons' on the board.) "Then I measured Mr. Tall with the same buttons and found that he was six buttons high." ('Mr. Tall: 6 buttons' was written on the board.)

"Now you do three things. First, you measure Mr. Short using your small paper clips. Then you predict the height of Mr. Tall if you could measure him with the paper clips. Then please explain how you figured out your prediction. Explain as best as you can how you figured out the number of paper clips in your prediction."

Subjects with questions or requests for more information were referred to the data on the chalkboard and were encouraged to use their own ideas for answering the questions. E briefly scanned the papers when they were turned in and asked individuals with incomplete explanations to clarify their reasoning.

Subject responses were categorized using the procedures outlined by Karplus, Karplus, and Wollman.[7] Categories IC and S were considered equivalent to Category IIa. Categories A and AS were labeled IIb while Categories PC and AP were considered IIIa responses. Subcategory R was equivalent to IIIb responses.

6. Islands Puzzle

This task was administered to groups of subjects. Responses were written rather than oral. Each subject was given a written copy of the puzzle. The examiner explained that it was a puzzle to determine the various types of problem solving methods used by persons their age. The diagram of the islands was pointed out and the introduction was presented. The subjects were also read the first two clues and the first question. They were asked to respond with one of the three choices and explain their choice. The islands are shown in Figure 3-2 followed by the problem format.

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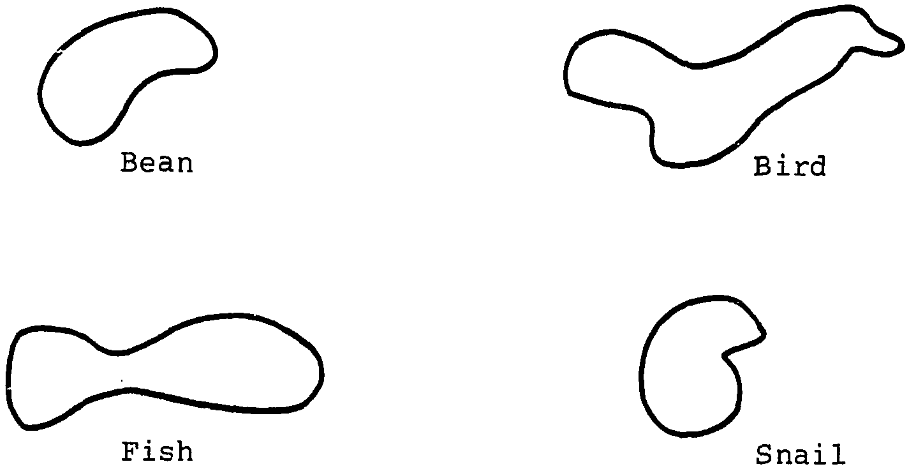
[7]Karplus, Karplus, and Wollman, "Ratio, The Influence of Cognitive Style," pp. 2-3. The acronyms represent the following: IC-intuitive computation, S-scaling, A-addition, AS-addition and scaling, PC-proportion concrete, AP-addition and proportion, R-application of ratio.

FIGURE 3-2



Introduction: The puzzle is about four islands in the ocean. People have been traveling among these islands by boat for many years, but recently an airline started in business. Listen carefully to the clues I give you about possible plane trips. The trips may be direct or they may include stops on one of the islands. When I say a trip is possible, it can be made in both directions between the islands.

This is a map with the four islands, called Bean Island, Bird Island, Fish Island, and Snail Island. You may make notes or marks on your map to help you remember the clues. Raise your hand if you have questions about the clues.

First clue: People can go by plane between Bean and Fish Islands.

Second clue: People cannot go by plane between Bird and Snail Islands.

Use these two clues to answer Question 1.

Question 1: Can people go by plane between Bean and Bird Islands? Yes?____ No?____ Can't tell from the two clues.____ Explain your answer.

Third Clue: People can go by plane between Bean and Bird Islands.

Use all three clues to answer Questions 2 and 3. Don't change your answer to Question 1.

Question 2: Can people go by plane between Fish and Bird Islands? Yes?____ No?____ Can't tell from the three clues.____ Explain your answer.

Question 3: Can people go by plane between Fish and Snail Islands? Yes?____ No?____ Can't tell from the three clues.____ Explain your answer.[8]

The written responses were classified into the five Piagetian categories following the procedures detailed by Karplus and Karplus.[9]

Subject Matter Tests

Subject matter examinations were constructed for physics, biology, and chemistry classes. These examinations tested concepts taught during the school year by the classroom instructors. Each examination consisted of two major sections. One section comprised of questions which tested the students' understanding of concrete operational concepts. The other section tested students' understanding of formal operational concepts. Two factors were of utmost importance in test construction: (1) the concepts must be classified correctly into concrete or formal operational categories; and (2) the test items involving these concepts must test understanding and not memorization. To help insure these points the examinations were mailed to the following science educators: Dr. Robert Karplus, Dr. Robert Knott, Dr. Glenn Berkheimer, Dr. Chester Lawson, and Dr. Warren Wollman. These persons were asked to

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[8]Karplus and Karplus, "Intellectual Development Beyond Elementary School I: Deductive Logic," pp. 398.

[9]*Ibid*., pp. 400-401.

evaluate the examinations on these two points. A substantial amount of agreement was obtained from the evaluators, however, on points of disagreement, the investigator served as the final judge of a task item's suitability.

The examination questions were designed to test for understanding of concrete and formal concepts. In order to do this it was necessary to define precisely the meaning of "concrete concepts" and "formal concepts" as well as "understanding."

The definitions of those terms given in Chapter I served to guide the construction of the examinations. Appendix I includes the three examinations, the concepts evaluated and their classification in the Piagetian model and in Bloom's Taxonomy. Appendix II includes definition of the concepts evaluated. The concept definitions are necessary because most terms have more than one level of meaning or sophistication. This means a term may be concrete or formal depending how it is defined or used in the students' text. An example is the biological term "niche." Taken to mean, an organism's profession, the term is a concrete concept. If, however, niche means, an organism's trophic level, its spatial habitat, and its multidimensional hypervolume of environmental conditions of existence, it is clearly a formal concept.

Treatment of Data

When possible analyses of data were performed in two ways. The data from biology, chemistry, and physics classes were first analyzed separately, then pooled and reanalyzed using the same techniques. The proportions of concrete, transitional and formal thinkers in each sample were determined.

Means and standard deviations were calculated for each Piagetian task. This indicated the difficulty levels of tasks. Pearson product-moment correlations were used to obtain an intercorrelation matrix of the six Piagetian task scores, concrete operational concept test scores, and formal operational concept test scores. This matrix provided an initial indication of strength of relationships between the respective variables.

Principal components analysis was used to determine factor loadings for each Piagetian task. This technique was used to determine the number of basic abilities or attributes underlying the set of independent variables and to factorially validate the six tasks. For a discussion of this technique see Appendix III. According to Piagetian theory, the same factor, propositional reasoning ability, should determine the subject's success on each of the six tasks. Therefore, each task should correlate highly with the first principal component. If not one, but several abilities determine success on the Piagetian tasks, then high correlations will be found on the second and perhaps the third principal component.

Since only one person administered the Piagetian tasks, the problem of experimenter differences was minimized. To check the consistency of scoring, the mean scores obtained each day during the interviewing were analyzed for significant differences using the statistical technique of one-factor analysis of variance. This procedure was followed for each separate sample, biology, chemistry, and physics.

Reliabilities of the subject matter examinations were determined using the Spearman-Brown split-half correlation technique.[10] The number of items answered correctly on each half of the examination by each subject was correlated using Pearson product-moment correlations. These correlations were then substituted into the Spearman-Brown formula to obtain test reliabilities. The formula is as follows:

$$r_{tt} = \frac{2r_{hh}}{1 + r_{hh}}$$

where r_{tt} = test reliability
r_{hh} = correlation of correctly answered test items on first and second half of test.

Each subject matter examination was submitted to an item analysis.[11] Each analysis consisted of four parts. First,

[10] J. P. Guilford, Fundamental Statistics in Psychology and Education, (New York: McGraw Hill, Company, 1965), 2nd ed., p. 457.

[11] Ibid., pp. 493-506.

the difficulty level of each item was determined by calculating the proportion of correct responses. Second, the proportion of correct responses made by concrete and formal operational subjects on the concrete and formal operational questions were calculated and corrected for chance success by using the formula [12]

$$cp = \frac{kp - 1}{k - 1}$$

where cp = the corrected proportion of correct answers
p = the obtained proportion
k = the number of alternative answers to each item.

Third, subject scores on each test item were correlated using point-biserial correlations with their total Piagetian interview task scores. And fourth, these same test-item scores were correlated with each Piagetian task score individually. The correlations of test item scores with Piagetian scores are particularly significant in that they provide a means of determining the "concreteness" or "formalness" of each test item.

Multiple regression analysis was used to obtain a multiple correlation coefficient between the Piagetian tasks and the concrete operational concept test scores. This multiple R was then tested for significance using an F-test at the 0.05 confidence level. A multiple correlation coefficient was also

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[12] J. P. Guilford, "The Determination of Item Difficulty When Chance Success if a Factor," Psychometrika, 1936, 1, pp. 259-264.

calculated for the Piagetian tasks and the formal operational concept test scores and similarly tested for significance.

Null hypotheses 1-8 (see Page 20) were tested at the 0.05 significance level. This level has been selected after a consideration of the types of possible decision errors and their consequences.

TABLE 3-1

ERROR TYPES[13]

(Ho - null hypothesis, H_1 = alternate hypothesis)

		State of Nature	
		Ho is true	H_1 is true
Decision	Reject Ho	Type I error	Correct decision
	Reject H_1	Correct decision	Type II error

Null hypotheses 1, 3, and 5 test the correlation between the Piagetian task scores and the concrete operational concept test scores. The concrete operational subjects, as well as formal operational subjects were expected to be able to comprehend concrete concepts, therefore, a non-significant correlation should be obtained. In effect the null hypothesis should be accepted. Committing a Type I error represents a rejection of the null hypothesis when it is true. In other words, success on Piagetian tasks was not significantly correlated with the

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[13]Gene V. Glass and Julian C. Stanley, Statistical Methods in Education and Psychology, (New Jersey: Prentice-Hall Inc., 1970), p. 284.

concrete operational test scores, however, it was incorrectly decided there was a significant correlation. A Type II error represents accepting the null hypothesis when it is false. In this context, this means that there was significant correlation and it was decided there was not. Involved here is a test of implications of Piagetian theory. In terms of that theory, clearly the Type I error is the most detrimental. This would falsely lead to a rejection of part of the theory, and its consequences for curriculum design.

Null hypotheses 2, 4, and 6 test the correlation between the Piagetian task scores and the formal operational concept test scores. Since success on Piagetian tasks and success on the formal operational concept test both presumably require "formal operational thinking," a high positive and significant correlation should be obtained. Here the null hypothesis should be rejected; committing a Type I error means that no significant correlation existed between Piagetian tasks and test scores on formal operational concepts, however, it was concluded that there was a significant correlation. A Type II error means that a significant correlation did exist but it was concluded not to be significant. In terms of Piagetian theory a Type II error is deterimental while a Type I error represents false support. For both sets of null hypotheses the same independent variables were used. Since a Type I error is more serious in one case while a Type II error is more serious in the other, the hypotheses were tested at the same significance level. An alpha of 0.05 was chosen as an initial significance level although in reporting results all correlations are given as well as respective levels of significance.

The calculated multiple correlation coefficients were cross-validated assuming the random variable model following Stein, 1960.[14] The cross-validated coefficients represent correlations that could be expected if the obtained sample beta weights were applied to other samples, hence, the cross-validated coefficients indicate generalizability of the results.

On the basis of obtained scores on the Piagetian tasks, subjects were classified into two major groups: concrete operational or formal operational. Mean concrete and formal concept examination scores were calculated for both groups. These group means were then tested for significant differences at the 0.05 leveı using two sample t-tests. The appropriate test statistic[15] is:

$$t = \frac{\overline{X}_1 - \overline{X}_2}{\frac{(n_1-1)S_1^2 + (n_2-1)S_2^2}{n_1 + n_2 - 2}\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}$$

where $\overline{X}$ and $\overline{X}_2$ are group means, S_1^2 and S_2^2 are the group variances, and n_1 and n_2 are the sample sizes.

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[14]Stein, "Multiple Regression," p. 427.

[15]Glass and Stanley, Statistical Methods, p. 295.

Step-wise semi-partial multiple correlation coefficients were calculated for the Piagetian tasks and the concrete and formal operational concept scores. This indicated the unique contribution of each Piagetian task in predicting success on the concrete and formal operational concepts. The possibility existed that perhaps only one or two of the Piagetian tasks account for a large percentage of the variance of the written test. If so, these tasks could be used as simple and efficient predictors of student understanding in science classes.

CHAPTER IV

PRESENTATION OF THE DATA, VALIDITY AND RELIABILITY OF TEST INSTRUMENTS

The data collected in this investigation is of two types, (1) scores obtained by 134 subjects enrolled in high school biology, chemistry, and physics classes on six tasks to determine levels of intellectual development, and (2) scores obtained by these subjects on concrete and formal portions of subject matter examinations. These initial data, the sex, and chronological age of the subjects appear in Table 4-1, Table 4-2, and Table 4-3.

Validation of Piagetian Tasks

The statistical technique of principal components analysis was used to determine the factorial validity of the six Piagetian styled tasks administered in this study. For a discussion of this technique and its use in validation of psychological measures, see Appendix III.

The scores on the Piagetian tasks from the three samples, biology, chemistry, and physics were pooled and analyzed twice by principal components analysis using program FACTOR.[1]

[1]Donald J. Veldman, Fortran Programming for the Behavioral Sciences, (New York: Holt, Rinehart and Winston, 1967), pp. 219-236.

TABLE 4-1

RAW DATA FOR BIOLOGY SAMPLE

Subject No.	Sex	Age Months	Con. Weight	Con. Vol.	Sep. Var.	Bal-ance	Ratio	Island	Conc. Ques.	Form. Ques.
120	M	177	3	3	4	3	5	4	11	3
122	F	176	3	2	4	4	3	4	10	4
123	M	176	3	3	4	4	3	4	13	3
124	M	177	3	4	3	4	5	4	14	6
125	F	210	3	2	3	4	3	3	13	3
126	M	202	3	4	3	3	5	3	14	4
127	F	186	3	4	4	4	3	3	9	6
128	F	199	2	3	2	3	3	1	5	3
129	M	179	3	4	4	4	4	3	11	2
130	F	197	3	3	3	3	3	2	9	1
131	M	196	3	4	4	4	3	2	11	7
132	F	194	3	3	2	3	2	2	7	2
133	F	201	2	2	2	2	1	1	4	0
134	F	176	3	3	3	3	3	3	16	2
135	F	209	2	3	4	3	3	4	8	4
136	M	178	2	3	3	3	4	3	10	3
137	M	184	3	4	3	4	4	4	14	3
138	M	181	3	4	4	4	4	4	9	4
139	M	175	3	3	3	3	3	3	4	2
140	F	178	3	4	4	4	5	4	17	8
141	F	178	2	2	2	3	3	2	12	3
142	F	185	3	4	4	4	4	4	14	8
143	M	178	3	4	4	4	3	3	12	4
144	F	178	3	3	3	4	3	3	6	2
145	F	175	3	3	3	3	3	2	10	1
146	M	183	2	4	4	4	4	3	11	1
147	F	179	3	4	4	4	5	3	14	7
148	M	190	3	4	4	4	5	4	10	2
149	M	181	2	3	4	4	4	2	11	6
150	F	177	3	4	3	3	5	4	13	5
151	F	198	3	4	4	3	3	3	9	2
152	M	187	3	3	4	4	5	3	12	4
153	F	180	3	4	4	4	4	3	9	5
154	F	196	2	2	2	2	3	2	4	1
155	F	180	3	3	3	3	3	2	8	1
156	F	186	3	3	2	4	2	1	8	2
157	M	188	3	4	5	4	5	5	13	7
158	M	190	3	4	4	3	3	3	4	4
159	F	177	2	3	3	3	3	3	9	2
160	M	178	3	3	3	3	3	3	10	1
161	F	179	3	4	3	4	5	4	14	8
162	M	193	3	3	3	4	5	2	11	2
163	F	198	3	3	4	3	4	3	11	7
164	M	188	3	4	4	4	5	4	16	6
165	F	176	3	2	3	3	5	3	9	0
166	M	186	3	4	4	4	4	4	13	4
167	M	183	3	3	4	4	4	4	*-	-
168	M	177	3	3	4	4	4	2	-	-
169	M	188	3	3	4	4	4	2	-	-
170	F	191	3	4	4	4	5	1	-	-
171	F	179	2	2	2	2	2	1	-	-

*Indicates subject absent on day of examination.

TABLE 4-2

RAW DATA FOR CHEMISTRY SAMPLE

Subject No.	Sex	Age Months	Con. Weight	Con. Vol.	Sep. Var.	Bal-ance	Ratio	Island	Conc. Ques.	Form. Ques.
50	M	190	3	4	4	4	5	4	9	8
51	M	190	3	4	4	4	5	4	10	11
52	F	188	3	4	5	4	5	4	11	14
53	M	193	3	4	4	5	5	4	9	7
54	M	196	3	4	4	4	5	4	9	8
55	M	200	3	4	4	5	5	4	9	8
56	M	177	3	4	4	4	5	2	7	4
57	M	198	3	4	4	4	5	4	8	7
58	M	203	3	4	5	4	5	4	9	7
59	M	199	3	3	3	4	4	4	5	3
60	M	193	3	4	4	5	5	4	11	9
61	F	207	3	4	4	4	5	4	4	3
62	M	199	3	3	3	3	4	4	4	1
63	M	191	3	4	4	4	5	5	9	3
64	F	207	3	4	4	3	3	4	10	7
65	F	207	3	4	4	4	4	3	9	6
66	F	201	3	3	3	3	5	3	7	2
67	M	189	3	4	4	4	5	3	11	11
68	M	197	3	4	5	4	5	4	9	8
69	M	188	3	2	4	4	5	4	9	9
70	M	190	3	4	4	4	5	4	8	10
71	M	203	3	3	3	4	3	3	7	4
72	M	196	3	4	4	4	5	3	9	8
73	F	191	3	4	4	4	5	4	7	6
74	M	192	3	4	4	3	5	4	11	6
75	M	190	3	4	4	4	4	4	8	8
76	M	187	3	4	4	3	5	4	9	9
77	F	208	3	4	4	4	4	4	10	10
78	F	218	3	2	3	3	3	3	7	5
79	M	195	3	4	4	4	5	5	11	9
80	M	196	3	4	4	4	5	3	10	10
81	M	192	3	4	4	4	5	4	6	7
82	M	195	3	4	4	4	5	5	8	6
83	M	188	3	4	4	4	5	4	4	6
84	M	208	3	4	4	4	5	3	8	3
85	M	189	3	4	5	5	4	4	9	7
86	M	192	3	4	4	4	4	4	9	10
87	M	201	3	4	4	5	5	4	9	8
88	M	194	3	4	4	4	5	4	9	8
89	M	187	3	4	5	5	5	4	10	9
90	F	203	3	4	4	4	4	2	6	3
91	F	195	3	4	4	4	5	4	10	8
92	M	200	3	4	4	4	5	3	7	8
93	M	196	3	3	4	4	5	4	7	8
94	M	190	2	3	4	5	5	1	11	10
95	M	196	3	4	4	5	5	4	8	9
96	M	203	2	3	4	3	5	3	9	8
97	M	198	3	4	4	5	5	4	9	9
98	M	189	3	4	5	4	5	4	11	9
99	M	196	3	4	5	4	5	4	8	6

TABLE 4-3

RAW DATA FOR PHYSICS SAMPLE

Subject No.	Sex	Age Months	Con. Weight	Con. Vol.	Sep. Var.	Bal-ance	Ratio	Island	Conc. Ques.	Form. Ques.
1	M	210	3	4	5	5	5	5	13	9
2	M	218	3	4	4	4	5	4	13	7
3	M	223	3	4	3	4	4	4	10	4
4	M	212	3	3	3	4	5	3	10	8
5	F	220	3	3	4	3	5	3	11	7
6	M	221	3	3	4	4	5	2	12	9
7	M	220	3	4	3	3	5	4	13	9
8	F	215	3	4	4	4	5	4	11	4
9	M	222	3	4	5	4	5	1	13	8
10	M	213	3	4	4	4	5	1	11	8
11	M	198	3	4	4	5	5	4	11	9
12	M	200	3	4	5	4	4	5	11	11
13	M	210	3	4	4	5	5	3	11	8
14	M	212	3	4	4	4	5	4	12	6
15	M	201	3	4	5	5	5	4	12	11
16	M	214	2	4	4	3	5	3	10	7
17	M	210	3	4	4	3	5	1	9	3
18	M	219	3	4	4	4	5	4	11	10
19	M	213	3	3	3	4	5	1	9	9
20	M	210	3	4	4	4	5	3	9	5
21	M	221	3	4	5	5	5	4	12	12
22	F	213	3	4	4	3	5	4	8	6
23	M	210	3	3	4	4	4	4	9	9
24	M	212	3	4	4	4	5	4	11	5
25	M	210	2	2	3	3	2	2	9	5
26	M	223	3	4	4	4	4	2	12	5
27	M	221	3	4	5	4	5	5	12	10
28	M	212	3	4	4	5	5	3	13	9
29	M	226	3	4	3	3	4	4	10	6
30	M	219	3	4	5	5	5	4	13	10
31	M	221	3	4	4	4	4	4	13	8
32	M	212	3	4	5	4	5	3	11	9
33	M	214	3	4	4	5	5	5	12	5

Pooling of the samples was appropriate since all six tasks were identical for each sample.

First, all components or roots were extracted, and second, the program extracted only those components corresponding to eigenvalues[2] of the correlation matrix that were greater than unity. This procedure of extracting components with roots greater than one is a widely used procedure and was first proposed by Kaiser[3] (1960). Table 4-4 shows the results after a variance-maximizing rotation of the axes has been carried out and only roots with values greater than one have been extracted. It can be seen that only one principal component was extracted and that this component accounts for 62.2 per cent of the variance of the sample scores. That percentage represents a relatively large or respectable portion of the variance.[4]

When all roots are extracted and a Scree Test[5] as shown in Figure 4-1 is used, a change in slope occurs between

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[2]The term "eigenvalue" is essentially synonymous with the terms root, latent root, or characteristic root commonly used in a branch of matrix algebra. Eigenvalues represent variances of the principal components.

[3]H. F. Kaiser, "The Application of Electronic Computers to Factor Analysis," Educational and Psychological Measurement, 1960, 20, pp. 141-151.

[4]For discussion of statistical techniques used to determine significant components and variances, see: Maurice M. Tatsuoka, Multivariate Analysis: Techniques for Educational and Psychological Research, (New York: John Wiley and Sons, 1971), pp. 146-147.

[5]R. B. Cattell, "The Scree Test for the Number of Factors," Multivariate Behavioral Research, 1966, 1, pp. 245-276.

the first eigenvalue and the last five. This further indicates that only one factor represents a significant component of the six Piagetian tasks.

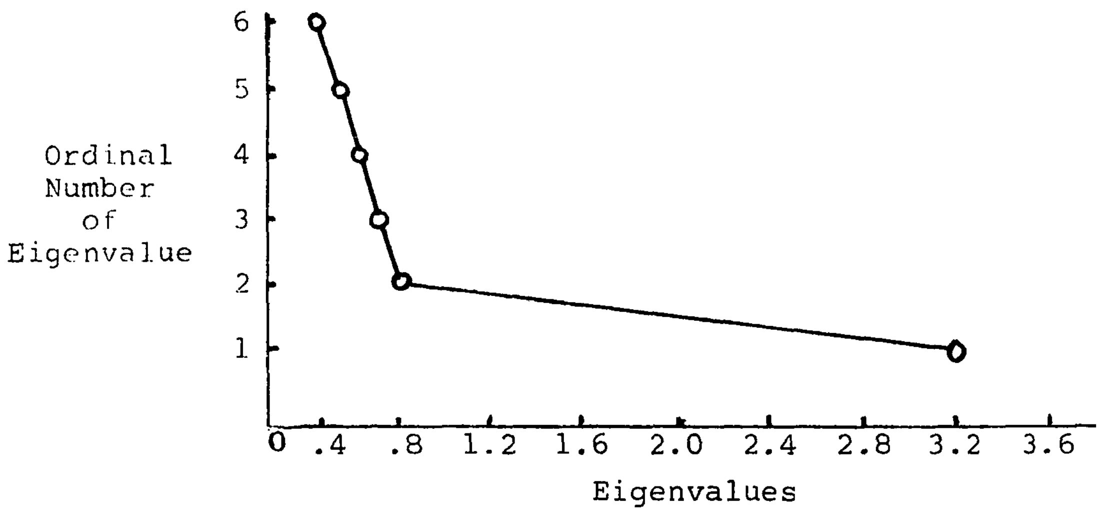
TABLE 4-4

PRINCIPAL COMPONENTS ANALYSIS, N = 134
VARIANCE MAXIMIZING ROTATION

Task	First Component Loading, 62.2 Per Cent of Variance	Per Cent Communality
1. Conservation of Weight	0.74	55.49
2. Conservation of Volume	0.84	70.40
3. Separation of Variables	0.85	72.13
4. Equilibrium in the Balance	0.80	63.56
5. Ratio	0.80	63.71
6. Islands Puzzle	0.69	47.97

FIGURE 4-1

SCREE TEST FOR THE NUMBER OF FACTORS



In reference once again to Table 4-4, note that tasks 2, 3, 4, and 5 all correlate highly (0.84, 0.85, 0.80, and 0.80 respectively) with the first principal component. Tasks 1 and 6, the Conservation of Weight and the Islands Puzzle also load substantially (0.74 and 0.69 respectively) on this component. The Conservation of Weight task accounts for 55.49 per cent of its communality or common factor variance and the Island Puzzle accounts for 47.97 of its communality. Although these numbers are substantial they are less then those for the other tasks which range between 63.56 and 72.13 per cent.

These results indicate that all the tasks, with the possible exception of the Conservation of Weight and the Islands Puzzle are measuring the same thing, namely "formal operational thinking." Recall the construct of "formal operational thinking" and its regulation by what Piaget terms the "structured whole" represents a cornerstone of Piagetian theory. These results then support the Piagetian constructs and factorially validate the formal operational tasks.

Since the Conservation of Weight task was designed to measure concrete rather than formal thinking, its high correlation (0.74) with the first principal component was unexpected. A possible explanation is that only 10.4 per cent of the pooled sample was categorized IIa and scored 2 points while 89.6 per cent was categorized IIb and awarded 3 points. Because of this, a very narrow range of highly skewed scores resulted and the statistical analysis was not sensitive enough to extract this trend. To support this possible explanation, consider the biology sample where 19.6 per cent of the subjects were categorized IIa. The conservation of weight task correlated less (0.59) in that group. Also, only 35.7 per cent of its communality was accounted for. This result indicates that the task may be measuring something other than formal thought. See Table 4-5.

TABLE 4-5

PRINCIPAL COMPONENTS ANALYSIS BIOLOGY SAMPLE, VARIANCE MAXIMIXING ROTATION, N = 51

Task	First Component Loading, 55.5 Per Cent of Variance	Per Cent Communality
1. Conservation of Weight	0.59	35.77
2. Conservation of Volume	0.76	58.16
3. Separation of Variables	0.81	66.84
4. Equilibrium in the Balance	0.74	55.91
5. Ratio	0.72	52.27
6. Islands Puzzle	0.80	64.22

Consistency of Interview Scoring

As mentioned in Chapter I, all interviews were conducted and scored by the investigator. Since the interviews did not consist of a rigid protocol and often required a certain degree of improvisation, the consistency of scoring on subsequent days of interviewing was checked.

Means scores were obtained for each group of subjects interviewed each day. These means were subjected to a one-factor analysis of variance to determine if significant differences existed. The hypothesis that no significant difference existed was tested at the 0.25 level of significance. This level of significance was chosen to decrease the probability of accepting the null hypothesis and thereby making the test more stringent. In each case the assumption was made that the samples were randomly drawn from normal populations.

Biology subjects were interviewed on five separate days. The analysis of variance for these groups yielded an F-ratio of 0.945. This value was not significant. Chemistry subjects were interviewed on three separate days. The analysis of variance for these groups yielded an F-ratio of 0.929, also not significant. Physics subjects were interviewed on five separate days. A similar analysis yielded an F-ratio of 0.286 which again was not significant.

The conclusion was drawn that the interview scoring was entirely consistent. For group sizes, means, and one-factor analysis of variance tables, see Appendix IV.

Analysis of the Subject Matter Tests

Test Reliabilities

The reliability of each subject matter examination was determined using the Spearman-Brown split-half correlation technique. For discussion of the technique refer to Page 44.

The reliabilities were as follows: biology examination $r_{tt} = 0.765$, chemistry examination $r_{tt} = 0.709$, physics examination $r_{tt} = 0.591$. In light of these results, it was concluded that the tests were reliable instruments.

Difficulty Level of Questions

The per cent of students responding correctly to each test question is given in Appendix I. A summary of those data is given in Table 4-6 below, which gives percentages of correctly answered questions, means, and standard deviations for the concrete and formal sections of each examination. Notice in each sample the mean value for the formal concept questions was much lower than for concrete questions.

TABLE 4-6

MEANS AND STANDARD DEVIATIONS, CONCEPT QUESTIONS

Examination	n	Mean Concrete	S. D. Concrete	Mean Formal	S. D. Formal
1. Biology	46	61.00	16.24	31.30	18.76
2. Chemistry	48	76.79	16.41	51.12	18.73
3. Physics	33	78.84	10.91	48.51	14.28

Correlations of Exam Questions With Piagetian Scores

Biserial correlation coefficients between each examination question and total Piagetian scores for the four interview tasks were calculated. These correlation coefficients were then used to obtain an indication of "concreteness" or "formalness" of each test item. The higher a subject's Piagetian score the more formal operational he was presumed to be. A correct test item response obtained a score of 1 while an incorrect response obtained a score of 0. Therefore, if an item required formal thought, a moderate positive correlation was expected, and if an item did not require formal thought a near zero correlation was expected.

Appendix I, Pages 100-123 show the obtained correlations for each test item and whether the item was originally classified concrete or formal.

CHAPTER V

OPERATIONAL LEVELS OF SAMPLES, SUBJECTS, AND THEIR RELATIONSHIPS WITH CONCRETE AND FORMAL CONCEPT EXAMINATION SCORES

Operational Levels of Samples

In order to determine relative levels of intellectual development for the biology, chemistry, and physics classes each subject was classified into one of seven categories on the basis of scores obtained during the individual interviews. The categories 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 considered appropriate and necessary because subject responses often were classified into different operational levels on different tasks. For example, responses of subject number 120 from the biology sample were classified concrete operational IIb on the Conservation of Weight, Conservation of Volume and Equilibrium in the Balance tasks. However, on the Separation of Variables task, he demonstrated some beginning formal operational thought and here his response was classified IIIa. To accurately classify this subject, a category designated as post-concrete operational was created. Similar situations prompted the creation of other intermediate categories.

Figure 5-1 shows a comparison of means of the six tasks. Recall the Conservation of Weight and Conservation of Volume tasks had maximum scores of 3 and 4 respectively. The Separation of Variables and Equilibrium in the Balance tasks show very consistent means. This indicates, as does comparison of individual raw scores, the tasks are of approximately equal difficulty. However, the Ratio task's mean score is considerably higher while the Islands Puzzle's mean is considerably lower. For this reason scores on the written tasks were determined to be unreliable determiners of formal thought and were not included in this portion of the study.

FIGURE 5-1

COMPARISON OF MEANS FOR EACH PIAGETIAN MEASURE

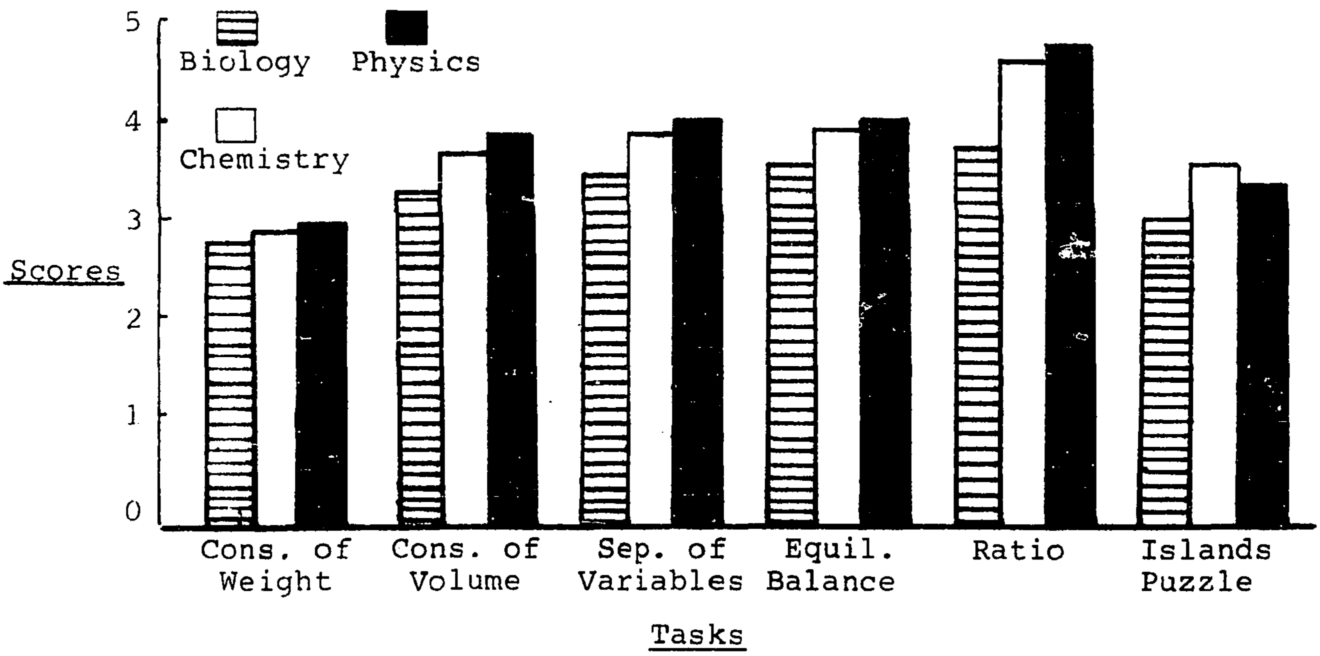


Table 5-1 shows the number and percentage of subjects in each of the seven categories as classified on the basis of the four interview scores.

Table 5-1 shows that 29.5 per cent of the biology sample was determined to be fully concrete operational, while an additional 35.3 per cent was post-concrete operational. In effect, 64.8 per cent of the sample was categorized as concrete operational or partially concrete operational. Notice only one subject was categorized as transitional formal and no subjects were determined to be fully formal.

The chemistry sample shows a majority of subjects somewhere in the transition between concrete, IIb, and formal, IIIb, thinking; 92 per cent of the sample was categorized as post-concrete, formal operational IIIa, or transitional formal.

The physics sample also shows a majority of its subjects between concrete IIb and formal IIIb, however, the per cent of fully formal subjects, 12.1 per cent, is over three times that of the chemistry sample. Still a substantial portion of the sample, 36.3 per cent, exhibited some concrete operational characteristics (post-concrete or lower).

These samples are not necessarily representative of all biology, chemistry, and physics classes, therefore, generalization must be made with reservations. It should be mentioned, however, that these results appear consistent with those reported in the literature cited earlier. The conclusion reached by other investigators that a substantial portion of the high school

TABLE 5-1

OPERATIONAL LEVELS OF BIOLOGY, CHEMISTRY, AND PHYSICS SAMPLES

Subject		Concrete IIa	Transition Concrete	Concrete IIb	Post Concrete	Formal IIIa	Transition Formal	Formal IIIb
Biology	number	3	6	6	18	17	1	
	per cent	5.9	11.8	11.8	35.3	33.3	1.9	
Chemistry	number		1	1	9	27	10	2
	per cent		2.0	2.0	18.0	54.0	20.0	4.0
Physics	number		1		11	9	8	4
	per cent		3.0		33.3	27.3	24.3	12.1

population is operating on a concrete level has been supported. As expected, differences between biology, chemistry, and physics classes were obtained. A vast majority of the biology students were sophomores. Chemistry enrolls juniors and a few seniors, while physics enrolls seniors and a very few juniors. This, plus the fact that physics and chemistry are electives and attract to a large extent only the educationally successful, explains the differences in the numbers of formal and concrete thinkers found in these classes.

Relationships With Concrete and Formal Concept Scores

The element of chance success on examination questions can be eliminated by the formula shown on Page 45. Using this formula, the adjusted percentage of correct responses for each of the seven operational level categories was calculated. A comparison of success on concrete and formal concept questions with the element of chance eliminated is shown in Figure 5-2 for pooled data from the biology, chemistry, and physics samples. Data from each discipline are graphed separately in Figures 5-3, 5-4, and 5-5.

In reference to the pooled data, notice that the concrete IIa level subjects demonstrated no success on concrete or formal concepts. Also no subject in the transitional concrete and concrete IIb level demonstrated success above the chance level on formal concepts. This result supports the premise that concrete operational subjects are unable to develop

FIGURE 5-2

A COMPARISON OF SUCCESS ON CONCRETE AND FORMAL CONCEPTS
WITH CHANCE ELIMINATED-POOLED DATA

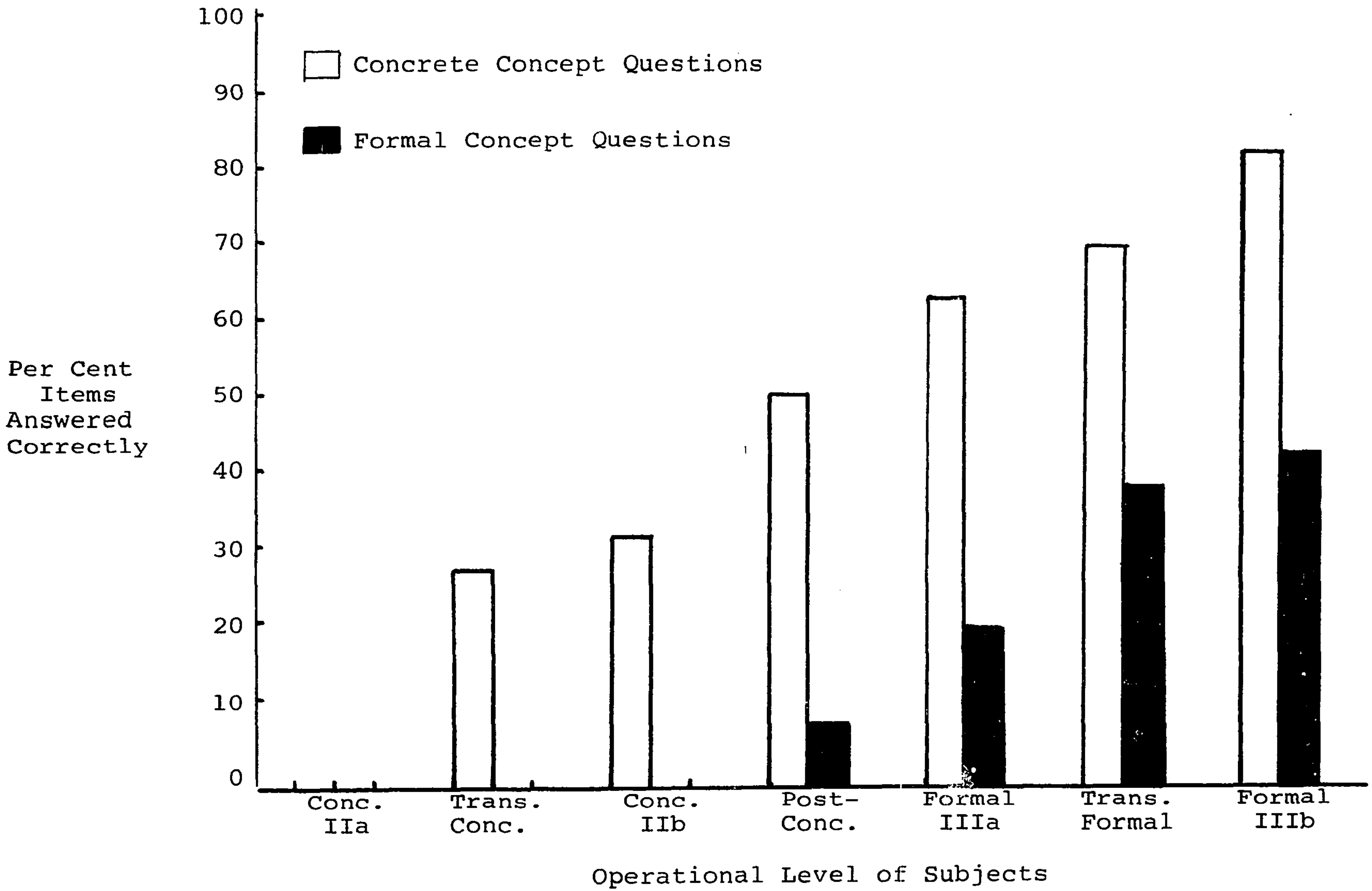


FIGURE 5-3

A COMPARISON OF SUCCESS ON CONCRETE AND FORMAL CONCEPTS
WITH CHANCE ELIMINATED-BIOLOGY

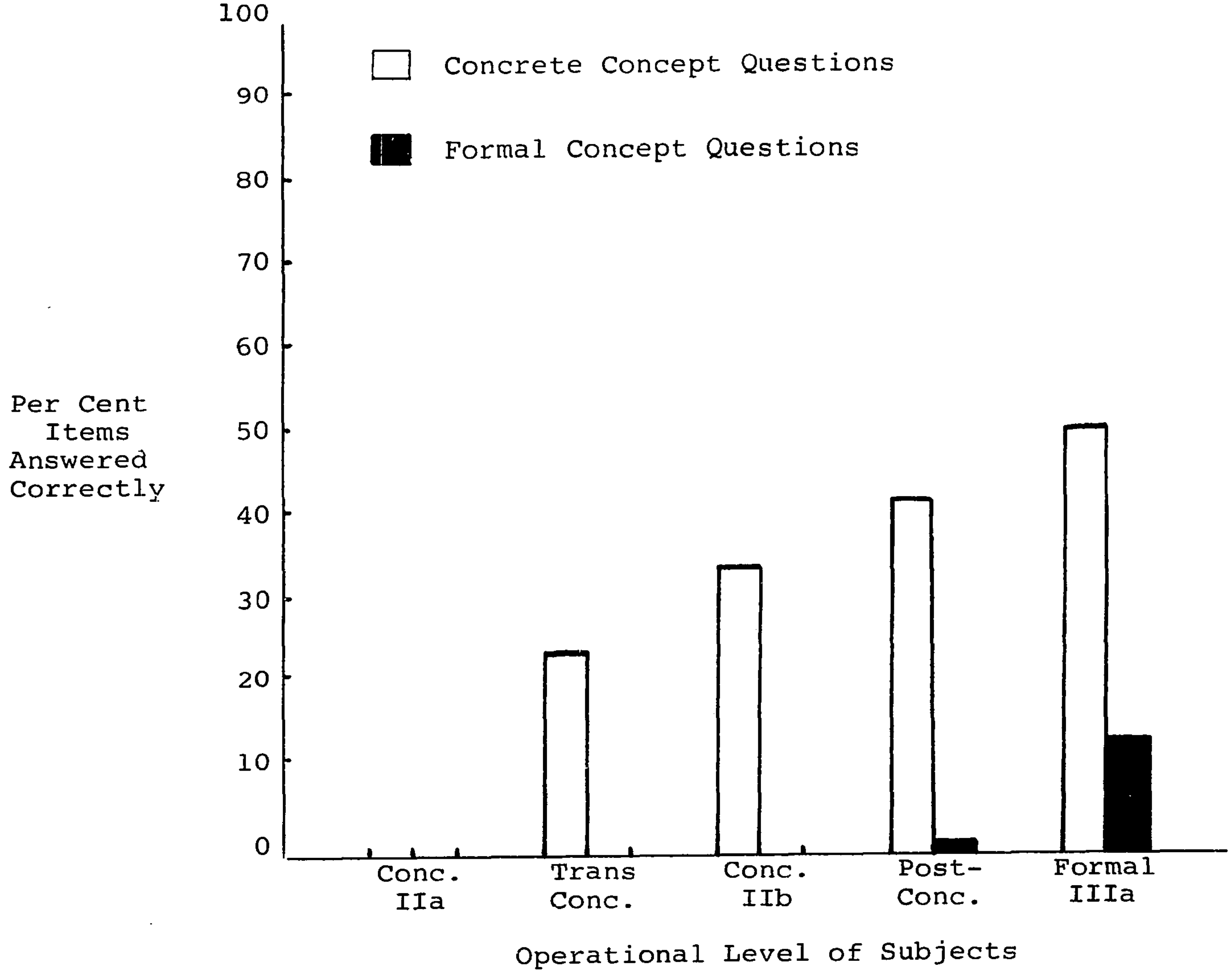


FIGURE 5-4

A COMPARISON OF SUCCESS ON CONCRETE AND FORMAL CONCEPTS WITH CHANCE ELIMINATED-CHEMISTRY

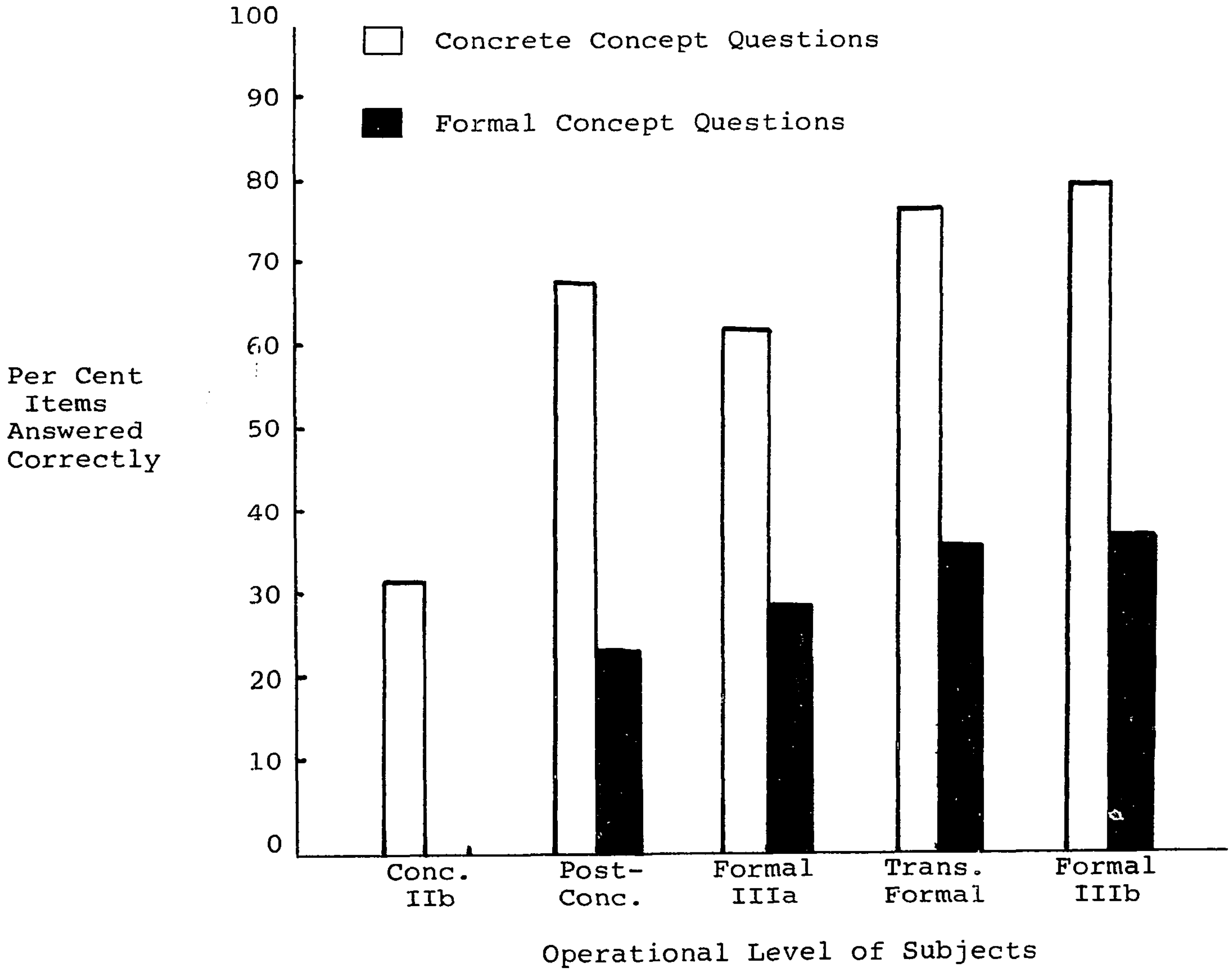
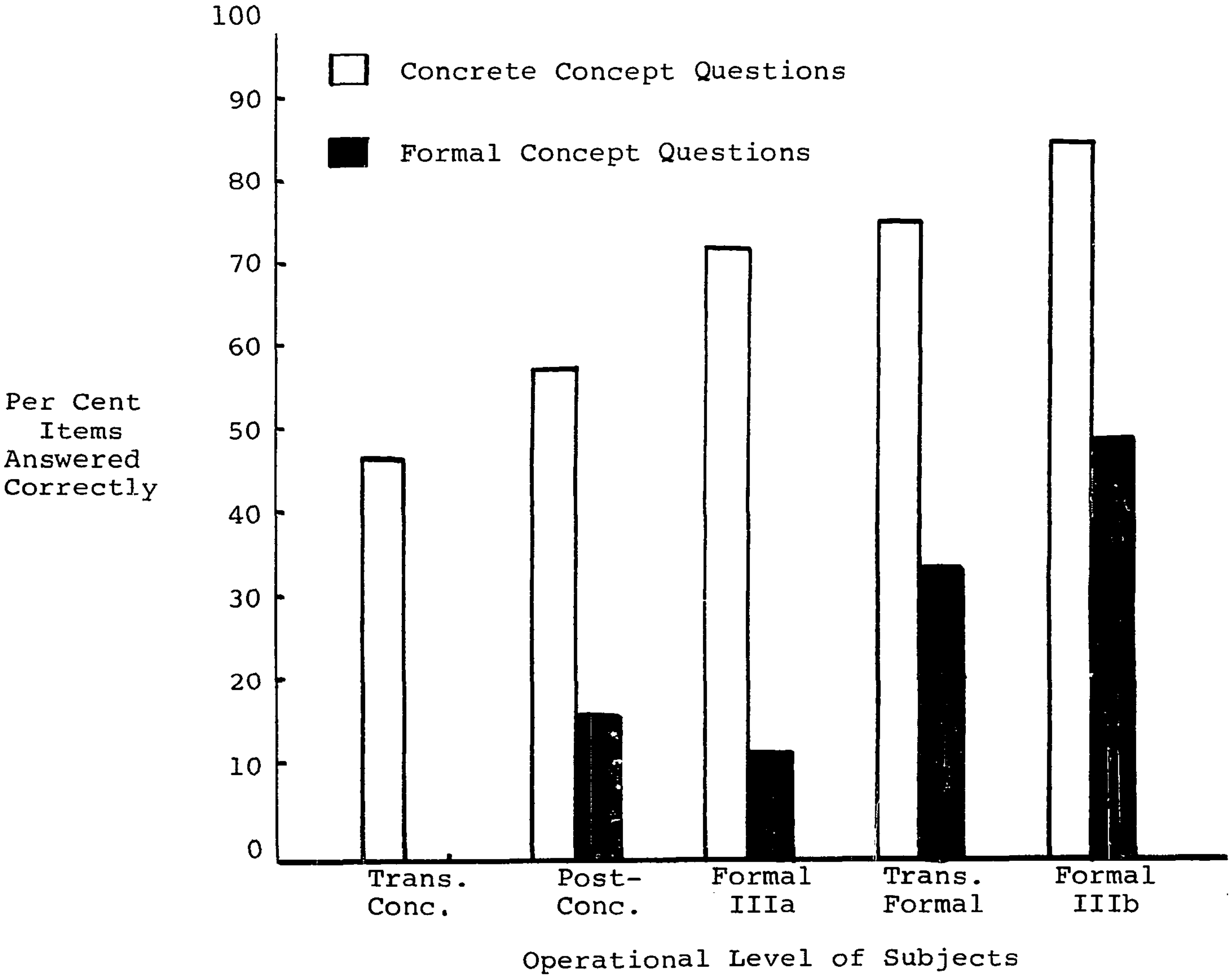


FIGURE 5-5

A COMPARISON OF SUCCESS ON CONCRETE AND FORMAL CONCEPTS
WITH CHANCE ELIMINATED-PHYSICS



understanding of formal concepts. Also, support is demonstrated for the other major premises of the study--concrete operational subjects are able to demonstrate understanding of concrete concepts and formal operational subjects are able to demonstrate understanding of both concrete and formal concepts.

The differences in mean scores of the seven operational categories of the pooled data were analyzed for significance using one-factor analysis of variance. Two analyses were performed. The first analysis tested for significant differences in the mean scores of the seven categories on the concrete operational concepts, while the second tested for significant differences in the mean scores on formal operational concepts.

The obtained F-ratio for the difference in mean concrete concept scores was 10.6752. This value exceeds the tabular value of 2.95 at the 0.01 level of confidence, therefore, it was concluded that these differences were significant.

The obtained F-ratio for the difference in mean formal concept scores was 8.8791. This value also exceeds the tabular value of 2.95 at the 0.01 level of confidence, therefore, it was concluded that these differences were also significant.

Data plotted for each discipline separately show trends similar to the pooled data.

CHAPTER VI

TESTS OF MAJOR HYPOTHESES

The major objective of this investigation was to determine the relationship between concrete and formal operational students and concrete and formal operational subject matter. The expectation was that concrete operational students could demonstrate understanding of concrete operational concepts, however, could not demonstrate understanding of formal concepts. On the other hand, students who were determined to be formal operational on the basis of Piagetian tasks could demonstrate understanding of both concrete and formal operational concepts.

In order to test these hypotheses the data were analyzed in two ways. First, multiple correlation coefficients were calculated for the Piagetian scores, the concrete operational concept scores, and the formal operational concept scores. The assumption was made that the higher a subject's formal task scores the higher his formal concept score would be, hence, a significant positive correlation should exist. However, the formal task scores should correlate less with concrete concepts because, presumably, both concrete and formal students can understand these concepts. This correlation should be non-significant. The second method for testing these relationships was by dividing the entire sample into two groups, concrete and formal operational thinkers, and analyzing differences in group mean scores on the concrete and formal exam questions. This was done using a two sample t-test of means.

Step-wise semi-partial regression analysis was also used to determine if multiple independent measures were significantly better at predicting examination scores than the best single predictor.

Multiple Correlations, Biology

In calculating multiple correlation coefficients the Conservation of Weight task was not included since it did not measure formal thought. The Islands Puzzle and the Ratio task were also omitted because they had been judged somewhat unreliable determiners of formal thought by the investigator (see Figure 5-1 and text, Page 64.)

Multiple correlation coefficients were determined in a step-wise fashion using Biomedical computer program BMDO2R[1].

Table 6-1 shows the initial correlation matrix. Notice that for scores on each Piagetian task and the formal operational concept question scores, the correlation was positive and significant at the 0.01 level of confidence. Correlations of

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[1] W. J. Dixon, ed., Biomedical Computer Programs, (Berkeley: University of California Press, 1970), pp. 233-257.

Piagetian tasks and concrete questions were also positive, however, only one correlation, that between the Equilibrium in the Balance task and the concrete questions, was significant at that level.

TABLE 6-1

PEARSON PRODUCT-MOMENT CORRELATIONS
BIOLOGY, N = 46

Variable	Cons. Vol.	Sep. Var.	Equil. Balance	Conc. Ques.	Formal Ques.
	1.	2.	3.	4.	5.
1. Cons. Vol.	1.000	**0.521	**0.438	*0.327	**0.496
2. Sep. of Var.		1.000	**0.464	0.199	**0.481
3. Equil. in Bal.			1.000	**0.414	**0.453
4. Concrete Ques.				1.000	**0.540
5. Formal Ques.					1.000

* $p < 0.05$
** $p < 0.01$

The obtained multiple correlation coefficient for the three Piagetian tasks and the concrete biology concepts was 0.4491 with a standard error of the estimate of 15.0792. The standard error of the estimate represents a 68 per cent confidence interval around an individual's obtained score on the dependent variable. Another interpretation of this statistic is that approximately 68 per cent of the subjects will have actual scores that lie within one standard error of estimate of their predicted score when the prediction equation is applied.

The dependent variable in this case was the concrete concepts examination score. The standard error of the estimate $\hat{\nabla}$ was obtained by the following equation:[2]

$$\hat{\nabla} = \sqrt{\frac{SS}{n-p-1}} ,$$

where SS = sum squared errors
n = number of subjects
p = number of predictor variables.

All examination scores were based on a 0-100 scale. The mean score on the concrete concept questions was 61 per cent.

Table 6-2 shows the results of an F-test to determine significance of the multiple correlation.

TABLE 6-2

MULTIPLE REGRESSION ANALYSIS, PIAGETIAN SCORES AND CONCRETE BIOLOGY CONTENT

Source of Variance	df.	M S	F
Regression	3	727.792	3.201
Residual	8	227.384	

The obtained F ratio of 3.201 is significant at the 0.05 level, however, is not significant at the 0.01 level of confidence. Therefore, null hypothesis 1 for the biology sample is rejected at the 0.05 level and accepted at the 0.01 level.

The multiple correlation coefficient calculated for the

[2]Glass and Stanley, Statistical Methods, pp. 141-143.

Piagetian tasks and formal operational concepts was 0.5919. A standard error of estimate of 15.70 with mean score of 31.3 per cent was obtained. The multiple coefficient yielded an F-ratio of 6.833 which was significant at the 0.001 level of confidence, see Table 6-3.

TABLE 6-3

MULTIPLE REGRESSION ANALYSIS, PIAGETIAN SCORES AND FORMAL BIOLOGY CONTENT

Source of Variance	df.	MS	F
Regression	3	1686.237	6.833
Residual	38	246.795	

Multiple Correlations, Chemistry

The same procedure was followed in obtaining correlation coefficients and multiple correlation coefficients for the chemistry sample.

Table 6-4 shows the initial correlation matrix.

TABLE 6-4

PEARSON PRODUCT-MOMENT CORRELATIONS CHEMISTRY, N = 48

Variable	Cons. Vol.	Sep. Var.	Equil. Bal-ance	Conc. Ques.	Formal Ques.
	1.	2.	3.	4.	5.
1. Cons. Vol.	1.000	**0.526	*0.313	0.230	0.249
2. Sep. of Var.		1.000	**0.396	**0.455	**0.510
3. Equil. in Bal.			1.000	0.224	*0.314
4. Concrete Ques.				1.000	**0.686
5. Formal Ques.					1.000

* $p < 0.05$ ** $p < 0.01$

Notice that in each case the Piagetian tasks correlated more highly with the formal concepts, than with the concrete concepts. A significant correlation of 0.455 between the Equilibrium in the Balance task and the concrete questions was obtained, however.

The multiple correlation coefficient for the three tasks and the concrete questions was 0.458 with a standard error of estimate of 15.08 and mean score of 76.8 per cent. An F-ratio was calculated, see Table 6-5.

TABLE 6-5

MULTIPLE REGRESSION ANALYSIS, PIAGETIAN SCORES AND CONCRETE CHEMISTRY CONTENT

Source of Variance	df.	MS	F
Regression	3	885.410	3.893
Residual	44	227.446	

This F-ratio of 3.893 represents a significant value at the 0.05 level, however, is not significant at the 0.01 level of confidence. Null hypothesis 3, that no significant relationship exists between Piagetian scores and concrete chemistry content, must be rejected at the 0.05 level and accepted at the 0.01 level.

The calculated multiple correlation coefficient for the Piagetian tasks and the formal concepts was 0.5255, with a standard error of estimate of 16.5 and mean of 51.1 per cent.

This correlation yielded an F-ratio of 5.596, see Table 6-6.

TABLE 6-6

MULTIPLE REGRESSION ANALYSIS, PIAGETIAN SCORES AND FORMAL CHEMISTRY CONTENT

Source of Variance	df.	MS	F
Regression	3	1517.961	5.596
Residual	44	271.256	

This F-ratio is significant at the 0.05 and 0.01 levels of confidence. Therefore, null hypothesis 4, that no significant correlation exists between Piagetian tasks and formal chemistry content, is rejected at both the 0.05 and 0.01 levels of confidence.

Multiple Correlations, Physics

The correlations for the physics sample appear in Table 6-7.

TABLE 6-7

PEARSON PRODUCT-MOMENT CORRELATIONS PHYSICS, N = 33

Variable	Cons. Vol.	Sep. Var.	Equil Bal-ance	Conc. Ques.	Formal Ques.
	1.	2.	3.	4.	5.
1. Cons. Vol.	1.000	*0.433	0.302	*0.422	-0.015
2. Sep. of Var.		1.000	**0.481	*0.440	**0.511
3. Equil. in Bal.			1.000	**0.545	*0.401
4. Concrete Ques.				1.000	*0.387
5. Formal Ques.					1.000

* $p < 0.05$ ** $p < 0.01$

Note that all the Piagetian tasks, with the exception of the Conservation of Volume task, correlate significantly with both concrete and formal questions.

The reason the Conservation of Volume task correlates near zero with the formal questions and significantly with the concrete questions is not clear. Eighty-five per cent of the sample scored the maximum on this task resulting in a small range of scores, therefore, the correlation may largely be an artifact. It also may reflect the misclassification of some of the questions on the subject matter examinations. This possibility was analyzed by an item analysis of the examination questions, the results of which are reported in Appendix I.

These multiple correlation coefficients were calculated without including the Conservation of Volume task scores. This was considered appropriate since this task was not designed to measure category IIIb responses while 88 per cent of the physics class demonstrated, on at least one occasion, this type of response.

The multiple correlation coefficient of 0.5815 was calculated between the Piagetian tasks and the concrete operational concepts. A standard error of estimate of 9.17 and a mean score of 78.8 was calculated. An F-ratio as shown in Table 6-8 of 7,663 was obtained. This value exceeds the tabular value for both 0.05 and 0.01 levels. Null hypothesis 5, that there exists no significant difference between multiple correlations of Piagetian tasks and concrete operational concepts, must be rejected at the 0.05 and 0.01 levels of confidence.

A multiple correlation coefficient between the same Piagetian tasks and formal operational content questions of

0.5412 was obtained. An F-ratio of 6.213 was calculated for this value. This F-ratio exceeded the table value at the 0.05 and 0.01 levels, therefore, null hypothesis 6, that there exists no significant correlation between Piagetian task scores and formal physics content, was also rejected at both levels of confidence. See Table 6-9.

TABLE 6-8

MULTIPLE REGRESSION ANALYSIS, PIAGETIAN SCORES AND CONCRETE PHYSICS CONTENT

Sources of Variance	df.	MS	F
Regression	2	644.504	7.663
Residual	30	84.108	

TABLE 6-9

MULTIPLE REGRESSION ANALYSIS, PIAGETIAN SCORES AND FORMAL PHYSICS CONTENT

Sources of Variance	df.	MS	F
Regression	2	956.332	6.213
Residual	30	153.918	

The standard error of estimate for this prediction was 12.40 with a mean score of 48.51 per cent.

Cross-Validation of Multiple Correlation Coefficients

The six multiple correlation coefficients for the samples were cross-validated assuming a random variable model. The cross-validated multiple correlation coefficients represent expected multiple correlations if the obtained beta weights from these samples (see Table 6-12) are applied to other sample scores which are assumed to be random.[3] The appropriate formula is

$$\hat{R}^2_{cv} = 1 - \left[\frac{(1-R^2)n-2}{n-P-2} \cdot \frac{n+1}{n-P-1} \cdot \frac{n-1}{n} \right]$$

where $\hat{R}^2_{cv}$ = cross-validated multiple correlation coefficient
R = obtained multiple correlation coefficient
n = sample size
P = number of predictor variables

Table 4-15 shows the cross-validated multiple correlation coefficients for the six regression equations. The cross-validated values represent the generalizability of the calculated multiple correlation coefficients.

TABLE 6-10

CROSS-VALIDATED MULTIPLE CORRELATION COEFFICIENTS

Predicted Variable	Multiple Correlation Coefficient, R	Cross-Validated R
1. Biology Concrete Concept Score	0.449	0.283
2. Biology Formal Concept Score	0.592	0.482
3. Chemistry Concrete Concept Score	0.458	0.284
4. Chemistry Formal Concept Score	0.526	0.395
5. Physics Concrete Concept Score	0.582	0.472
6. Physics Formal Concept Score	0.541	0.412

3. C. Stein, "Multiple Regression," p. 427

<u>T-test of Mean Differences</u>

One of the major premises of this study was that formal operational subjects are able to understand formal operational concepts while concrete subjects are not able to understand those concepts. If this is the case, then the scores of concrete and formal subjects on the formal portion of the content examinations should differ significantly.

Recall subjects from all three disciplines, biology, chemistry, and physics, were classified on the basis of Piagetian scores into seven categories, see Table 4-4. The subjects categorized as concrete IIa, transitional concrete, concrete IIb, and post-concrete were regrouped and labeled concrete operational. Those subjects categorized as formal IIIa, transitional formal, and formal IIIb were also regrouped and labeled formal operational. Mean scores were then calculated for both groups on the formal and concrete concept examination questions. These mean scores were then tested for significant differences using a two sample t-test. See Page 48 for the appropriate equation.

Notice that this analysis requires the pooling of data from the three content examinations. This procedure of pooling dependent measures when the dependent measures are not identical is statistically hazardous and, in most cases, unappropriate. However, due to the fact that the content examinations were designed to analyze the identical parameters in all three disciplines and the examination formats were identical, it was decided meaningful results could be obtained by such an analysis.

Table 6-11 shows the results of the analysis.

TABLE 6-11

T-TEST OF MEAN DIFFERENCES BETWEEN CONCRETE AND FORMAL STUDENTS

Group	Examination Item Mean		T
	Concrete	Formal	
1. Concrete n = 55	61.85	2.3818	27.21
2. Formal n = 69	77.71	51.50	34.88

Both obtained values exceed the table value at the 0.05 and 0.001 levels of confidence, therefore, the hypotheses that no significant differences occur between concrete and formal operational students and their ability to comprehend both concrete and formal operational concepts, must be rejected.

Semi-partial Regression Analysis

The multiple correlation coefficients calculated for the previous six sets of variables, were obtained in a stepwise fashion as shown in Table 6-12. As each additional predictor variable was added to the regression equation the value of the correlation between the predictor variables and the concept examination questions increased. For example, the calculated R for the Conservation of Volume task and the biology

TABLE 6-12

STEP-WISE MULTIPLE CORRELATION COEFFICIENTS, BETA WEIGHTS, AND CONSTANTS FOR REGRESSION EQUATIONS

Predicted Variable	Predictor Variables	Step Wise Multiple Correlations	Beta Weights	Regression Constant
1. Biology Concrete Concept Score	Cons. of Vol.	0.4141	0.2109	13.0822
	Sep. of Var.	0.4448	-0.0791	
	Equil. in Balance	0.4491	0.3583	
2. Biology Formal Concept Score	Cons. Vol.	0.4963	0.2795	-43.8856
	Equil. in Balance	0.5609	0.2329	
	Sep. of Var.	0.5919	0.2204	
3. Chemistry Concrete Concept Score	Sep. of Var.	0.4552	-0.0203	9.8028
	Equil. in Balance	0.4577	0.4452	
	Cons. of Vol.	0.4580	0.0525	
4. Chemistry Formal Concept Score	Cons. of Vol.	0.5098	-0.0459	-38.5699
	Sep. of Var.	0.5241	0.4788	
	Equil. in Balance	0.5255	0.1388	
5. Physics Concrete Concept Score	Sep. of Var.	0.5448	0.2318	35.3858
	Equil. in Balance	0.5815	0.4332	
6. Physics Formal Concept Score	Sep. of Var.	0.5114	0.4142	-4.9679
	Equil. in Balance	0.5412	0.2019	

concrete concept questions was 0.4141. When the next task, the Separation of Variables, was added to the regression equation the multiple correlation coefficient increased to 0.4448. Inclusion of the Equilibrium in the Balance task further increased the correlation to 0.4491. From this example, it is clear that the best single predictor is the Conservation of Volume task. The additional contribution of the next two tasks is relatively small, only an increase in correlation of 0.035.

The investigator asked these questions: (1) Is the increase in predictive power of using additional tasks large enough to justify their inclusion in the regression equation? (2) Conversely, can we justify using just one Piagetian task to predict student success on concrete and formal concepts examinations?

To answer the above, the following null hypothesis was tested for the preceeding six sets of regression equations.

$$\text{Ho:}\quad P^2_y\text{La, Lb} - P^2_y\text{Lb} = 0$$

where $P^2_y\text{La,Lb}$ = the squared multiple correlation between the entire set of predictor variables and the concept examination scores.

$P^2_y\text{Lb}$ = the squared multiple correlation beween the best single predictor and the concept examination scores.

The appropriate equation is

$$F = \frac{R^2_y La,Lb - R^2_y Lb/K}{(1-R^2_y La,Lb)/n-p-1}$$

where F = obtained F-distribution ratio.

$R^2_y La,Lb$ = squared sample multiple correlation between the entire set of predictor variables and the concept of examination scores.

$R^2_y Lb$ = squared sample multiple correlation between the best single predictor variable and the concept examination scores.

k = number of variables in set a, the additional variables.

p = number of variables in the full set of predictor variables.

Table 6-13 shows the obtained F-ratios for each of the six hypotheses tested. In each case the obtained F-ratio was less than the corresponding table value at the 0.05 level of confidence. The null hypothesis that the additional variables do not add significantly in prediction of success on concept scores was, therefore, accepted in all six cases. This result was expected. The tasks are designed to measure only one thing so a repetition of that measurement should add little in predictive power.

TABLE 6-13

STEP-WISE MULTIPLE REGRESSION, BEST SINGLE PREDICTORS AND CALCULATED F-RATIOS

Predicted Variable	Best Single Predictor	df k,n-p-1	F-ratio, Additional Predictors
1. Biology Concrete Concept Score	Con. of Vol.	2,38	0.719
2. Biology Formal Concept Score	Con. of Vol.	2,38	1.082
3. Chemistry Concrete Concept Score	Sep. of Var.	2,44	0.071
4. Chemistry Formal Concept Score	Con. of Vol.	2,44	0.491
5. Physics Concrete Concept Score	Sep. of Var.	1,30	0.872
6. Physics Formal Concept Score	Sep. of Var.	1,30	3.176

CHAPTER VII

CONCLUSIONS AND RECOMMENDATIONS

This investigation was carried out to find answers to the following questions. What are the levels of intellectual development of selected biology, chemistry, and physics students as determined by Piagetian tasks? What are the major concrete and formal operational concepts taught to those students? What are the relationships between students' scores on the Piagetian tasks and written test scores on concrete and formal operational concepts?

Conclusions

Data presented in Table 5-1 indicate that approximately 64.8 per cent of the biology students interviewed were operating entirely or partially at the concrete level. The chemistry sample was best characterized as transitional thinkers with 92 per cent of those interviewed categorized above concrete operational, IIb, and below fully formal operational, i.e. IIIb. The physics sample also consisted largely of students operating somewhere between fully concrete and fully formal operational.

Approximately 85 per cent scored above concrete, IIb, and below formal, IIIb. Only 4.8 per cent of the entire sample of 134 students interviewed were judged to be fully formal thinkers, i.e., IIIb.

These results in Table 5-1 show the vast majority of students in these classes were below the levels of intellectual development as outlined by Piaget. The investigator believes some of the responsibility for this apparent "retarded" development can be traced directly to inappropriate subject matter and teaching procedures in today's schools. This point will be discussed further under "Recommendations."

Major concepts taught during the year in the respective classes were isolated and categorized as concrete or formal. This was a significant step in that this type of classification scheme had not previously been attempted. The majority of the concepts taught in three science disciplines were categorized as formal.

On subject-matter tests which assessed the understandings of the major concrete and formal concepts in the respective disciplines of students in both the concrete and formal operational stages, the following results were obtained (see Figures 5-2, 5-3, 5-4, and 5-5). Subjects categorized as concrete operational, IIa, demonstrated understanding of neither concrete nor formal operational concepts. Scores obtained on the subject matter tests for these subjects after correction for guessing were zero for both categories of questions. Subjects categorized as transitional concrete, and concrete, IIb, demonstrated understanding of approximately 30 per cent of the concrete operational concepts, however, demonstrated no understanding of formal operational concepts. Of extreme significance is the finding that the understanding of formal concepts did not occur until at least some of the subjects' responses on the Piagetian tasks reached the level of formal operations. Not until the post-concrete category is any understanding of formal concepts apparent. This supports the premise that concrete operational subjects are unable to develop understanding of formal concepts.

In reference once again to Figures 5-2, 5-3, 5-4, and 5-5, notice that subjects in categories formal, IIIa, transitional formal, and formal, IIIb, demonstrated understanding of both concrete and formal concepts. As the intellectual level increased an increase occurred in the percentage of concrete and formal concept questions answered correctly. This increase in the percentage of formal concept questions answered correctly is perfectly understandable in a Piagetian frame of reference. The increase in the percentage of concrete questions answered correctly from categories post-concrete to formal, IIIb, was not entirely expected. Once a person had reached the highest level in concrete thought, it was expected that any additional increase in intellectual development would make no contribution to the understanding of concrete concepts. The indication is, however, that formal thought does contribute to the understanding of concrete concepts. Two tentative explanations are offered for this finding. (1) Formal operations may help in the understanding of concrete concepts by the elucidation of a more comprehensive system of both concrete and formal content. This larger frame-of-content reference allows the learner to see relationships involving concrete objects, situations or events previously unrecognized. This expanded frame of reference, thereby, brings deeper meaning to concrete as well as formal content. (2) The teaching procedures used in the classrooms are largely expository, consequently students seldom are confronted with first-hand concrete experiences with any aspects of the discipline. This procedure, in effect, renders potentially concrete material abstract or formal and the learner does not, therefore, have the opportunity to develop understanding of it until he enters the formal stage.

Analysis of the six Piagetian tasks used to assess levels of thinking with principal components analysis showed the tasks to have factorial validity. All six tasks including the Conservation of Weight and the two written tasks, the Ratios task and the Islands Puzzle loaded substantially on the first principal component. Correlations between 0.69 and 0.85 were obtained indicating that the tasks were measuring essentially the same psychological parameter. This result is significant in terms of Piagetian theory in that it supports Piaget's hypothesized construct of the unified nature of formal operations into the "structured whole."

The written tasks, however, were determined to be somewhat unreliable determiners of levels of thinking. Although these tasks presumably are measuring levels of intellectual development as defined by Piaget, scores on these tasks are often at considerable variance with those obtained during personal interviews. The Ratios task, for example, seems to involve a rather simple proportion, the solution of which is probably attainable at the IIIa level of formal operational thought rather than at the IIIb level as its authors indicate. Possibly the solution of this problem may also be obtained by the application of a previously memorized algorithm. Consequently, correct solutions may not demonstrate the acquisition of formal mental structures. Responses on the Islands Puzzle were often indicative of preoperational or concrete, IIa, operational thinking. This indeed was strange in that some of these same subjects responded very formally to the interview tasks.

Multiple regression analysis of the four Piagetian interview task scores and the concrete concept scores indicated significant positive multiple correlations for each discipline. Multiple correlations in biology and chemistry were significant at the 0.05 level of confidence, while that for the physics sample was significant at the 0.01 level.

These significant correlations were not expected as they indicate that the use of formal operational thinking facilitates the understanding of concrete concepts. A further possible explanation for these significant correlations is, in addition to the two offered above, the fairly obvious fact that the four formal tasks, although designed to measure formal thought, also measure levels of concrete thought. Therefore, these tasks would be expected to show some positive correlations with concrete concepts as well as formal concepts.

Multiple correlation coefficients between the same four Piagetian tasks and the formal concepts in biology, chemistry, and physics were all significant at the 0.01 level of confidence. This result further supports the premise that formal operational thinking facilitates the understanding of formal concepts as defined by the investigator.

These same data were analyzed in a different way to examine differences in mean scores obtained on the concept examinations by concrete versus formal groups of subjects. Subject scores from the three disciplines were pooled and subjects were dichotomized into concrete or formal operational levels of thinking. Subjects previously categorized as post-concrete or below were labeled "concrete," while those formal, IIIa, or above were labeled "formal." Mean scores obtained by the two groups were then calculated for both concrete and formal concept examination scores. T-tests showed significant differences existed on the concept examination scores of the concrete versus formal subjects. Formal subjects did significantly better than concrete subjects on both concrete and formal examination questions.

Step-wise semi-partial regression analysis of the biology sample data indicated the Conservation of Volume task to be the best single predictor of student success on both concrete and formal operational concept examination questions. The other Piagetian tasks did not add significantly to the predictive power. A similar analysis of the chemistry sample data showed the Separation of Variables task to be the best single predictor of success on concrete concept examination questions. However, the Conservation of Volume task was determined to be the best predictor of success on formal concept questions. Again additional Piagetian measures did not add significantly to the predictive power. Analysis of the physics data revealed the Separation of Variables task to be the best single predictor of student success on both concrete and formal portions of the examinations. Additional Piagetian measures once again did not add significantly to predictive ability. It appears that the Conservation of Volume task is best for groups with a large per cent of concrete thinkers, while the Separation of Variables task is best when most of the group is formal.

These results indicate that to obtain an initial indication of student levels of thinking a teacher or investigator is justified in using a single Piagetian task. The Conservation of Volume task is relatively simple to administer and the subject responses are extremely easy to categorize. For these reasons this task could serve as a practical initial indicator of student ability to operate with formal or abstract subject matter.

Recommendations

The results of this investigation indicate that a substantial portion of secondary school science subject matter is not suitable in terms of the intellectual level of the learner.

The biology sample investigated showed nearly 65 per cent of the students still largely at the concrete level of intellectual development. Since these students were found to be unable to develop appreciable understanding of formal abstract concepts, it appears clear that for them a science course which deals with abstractions and "basic unifying themes" is highly unappropriate.

In eagerness to update secondary school science programs during the 1960's one very important dimension apparently was left out--the learner. What is called for is a careful reevaluation of the major content of these science courses in an attempt to better fit that content to the level of the learner. Perhaps more important than major shifts in content matter is a careful evaluation of teaching procedures and sequencing of materials to help lead these learners from concrete to formal thinking patterns.

Indeed, if science courses were constructed with the learner, as well as the structure of the discipline in mind, then courses such as chemistry and physics might no longer be the choice of only the educationally elite but could become viable and meaningful disciplines for the majority of our youth.

BIBLIOGRAPHY

Books

Biological Science Curriculum Study, Biological Science: An Inquiry into Life, Yellow Version, New York: Harcourt Brace, 1968.

Bloom, Benjamin S., ed., Taxonomy of Educational Objectives: The Classification of Educational Goals, Handbook 1, Cognitive Domain, New York: David McKay, 1956.

Dixon, W. J., ed., Biomedical Computer Programs, Berkeley: University of California Press, 1970.

Flavell, John G., The Developmental Psychology of Jean Piaget, Princeton, New Jersey: D. Van Nostrand Co., Inc., 1963.

Ginsberg, Herbert and Opper, Sylvia, Piaget's Theory of Intellectual Development, Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1969.

Glass, Gene V. and Stanley, Julian C., Statistical Methods in Education and Psychology, Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1970.

Gorman, Richard, Discovering Piaget: A Guide for Teachers, Columbus: C. E. Merrill Co., 1972.

Guilford, J. P., Fundamental Statistics in Psychology and Education, New York: McGraw-Hill Book Co., 2nd ed., 1965.

Hurd, Paul Dehart, New Directions for Teaching Secondary School Science, Chicago: Rand McNally and Co., 1969.

Hurd , Paul Dehart, New Curriculum Perspectives for Junior High School Science, Belmont, California: Wadsworth Co., 1970.

Inhelder, Bärbel and Piaget, Jean, The Growth of Logical Thinking from Childhood to Adolescence, New York: Basic Books, Inc., 1958.

Merrill, Richard J. and Ridgeway, David W., The CHEM Study Story, San Francisco: W. H. Freeman and Co., 1969.

Phillips, John L., Jr., The Origins of Intellect: Piaget's Theory, San Francisco: W. H. Freeman and Co., 1969.

Piaget, Jean, The Psychology of Intelligence, Paterson, New Jersey: Littlefield, Adams, 1963.

Piaget, Jean, Science of Education and the Psychology of the Child, New York: Viking Press, 1971.

Renner, John W., Bibens, Robert F., and Shepherd, Gene D., Guiding Learning in the Secondary School, New York: Harper and Row Publishers, 1972.

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

Smoot, Robt.,Price, Jack, and Barrett, Richard, Chemistry: A Modern Course, Columbus, Ohio: C. E. Merrill, 1968.

Stein, C., "Multiple Regression," in Contributions to Probability and Statistics, edited by I. Olkin, et al., Stanford: Stanford University Press, 1960.

Tatsuoka, Maurice M., Multivariate Analysis: Techniques for Educational and Psychological Research, New York: John Wiley and Sons, Inc., 1971

Veldman, Donald J., Fortran Programming for the Behavioral Sciences, New York: Holt Rinehart and Winston, 1967.

Watson, Fletcher, Holton, Gerald, and Rutherford, F. James, The Project Physics Course, New York: Holt Rinehart and Winston, 1970.

Wallace, J. G., Concept Growth and the Education of the Child, The Mere, England: National Foundation for Educational Research in England and Wales, 1965.

Periodicals

Belanger, Maurice, "Learning Studies in Science Education," Review of Educational Research, 1969, 39, No. 4.

Brainerd, G. J., "The Development of the Proportionality Scheme in Children and Adolescents," Developmental Psychology, 1971, 5, No. 3.

Cattell, R. B., "The Scree Test for the Number of Factors," Multivariate Behavioral Research, 1966, 1.

Dale, L. G., "The Growth of Systematic Thinking: Replication and Analysis of Piaget's First Chemical Experiment," Australian Journal of Psychology, 1970, 20, No. 3.

Guilford, J. P., "The Determination of Item Difficulty When Chance Success if a Factor," Psychometrika, 1936, 1.

Higgins-Trenk, A., and Gaite, A. J. H., "Elusiveness of Formal Operational Thought," Proceedings, 79th Annual Convention, American Psychological Association, 1971.

Kaiser, H. F., "The Application of Electronic Computers to Factor Analysis," Educational and Psychological Measurement, 1960, 20.

Karplus, Robert and Karplus, Elizabeth F., "Intellectual Development Beyond Elementary School I: Deductive Logic," School Science and Mathematics, May, 1970.

Karplus, Robert and Peterson, Rita W., "Intellectual Development Beyond Elementary School II: Ratio, A Survey," School Science and Mathematics, December, 1970.

Kohlberg, Lawrence and Gilligan, Carol, "The Adolescent as a Philosopher: The Discovery of the Self in a Postconventional World," Daedlus, Fall, 1971, 100.

Lovell, Kenneth, "A Follow-Up Study of Inhelder and Piaget's The Growth of Logical Thinking," British Journal of Psychology, 1961, 52.

Lovell, K. A. and Butterworth, I. B., "Abilities Underlying the Understanding of Porportionality," Mathematics Teaching, 1966, 37.

McKinnon, Joe W. and Renner, John W., "Are Colleges Concerned with Intellectual Development?" American Journal of Physics, 1971, 39.

Mecke, Gunter and Mecke, Viola, "The Development of Formal Thought as Shown by Explanations of the Oscillations of a Pendulum: A Replication Study," Adolescence, 1971, 6, No. 22.

Neimark, Edith D., "A Preliminary Search for Formal Operations Structures," Journal of Genetic Psychology, 1970, 116.

Piaget, Jean, "Development and Learning," Journal of Research in Science Teaching, 1964, 2, No. 3.

Films

The Developmental Theory of Piaget: Conservation, San Francisco: John Davidson Film Producers, 1969.

Unpublished Materials

Adelson, Joseph, "Adolescent Perspectives on Law and Government," Paper presented at the annual meetings of the American Psychological Association, San Francisco, August, 1968. U. S. Department of Health, Education, and Welfare, Document No. CG003107.

Bart, William M., "A Construction and Validation of Formal Operational Reasoning Instruments," Paper presented at the annual meeting of the American Educational Research Association, Minneapolis, March, 1970.

Bridgham, Robert G., An Investigation of Piagetian Tests as Predictors of Students' Understanding of Electrostatics, Unpublished Doctoral Dissertation, Harvard University, 1967.

Friot, Faith E., The Relationship Between an Inquiry Teaching Approach and Intellectual Development, Unpublished Doctoral Dissertation, University of Oklahoma, 1970.

Hughes, M. M., A Four Year Longitudinal Study of Growth of Logical Thinking in a Group of Secondary Modern School Students, Unpublished M. Ed. thesis, University of Leeds, 1965.

Karplus, Robert, Karplus, Elizabeth, and Wallman, Warren, "Intellectual Development Beyond Elementary School IV: Ratio, The Influence of Cognitive Style,"Unpublished manuscript, 1973.

Keasey, Carol T., The Nature of Formal Operations in Preadolescence, Adolescence, and Middle Age, Unpublished Doctoral Dissertation, University of California, Berkeley, 1970.

Palmer, Ray A., The Development of Selected Concepts by Students in BSCS Biology, Unpublished Doctoral Dissertation, George Peabody College, Nashville, Tennessee, 1969.

APPENDIX I

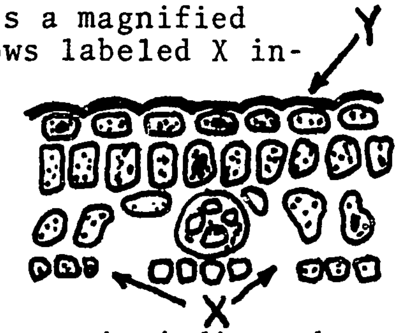
Subject Matter Examinations

BIOLOGY EXAM

Name ______________________

Date ______________________

1. The diagram at the right represents a magnified cross section of a leaf. The arrows labeled X indicate



stomata*
translation
concrete
55%, 0.00

A. food conducting openings.
*B. site of O_2 and CO_2 exchange.
C. protective areas.
D. water conducting locations.

2. Using the same diagram, what structure is indicated by arrow Y?

cutin
translation
concrete
71%, 0.29

A. site of O_2 and CO_2 exchange.
*B. protective area.
C. food conducting layer.
D. water exchange surface.

3. Cystine combines with iolase and forms an unstable molecule which quickly breaks down the cystine into simplier products. Following this, iolase combines with another molecule of cystine and the process starts over again. This represents a model for

enzymatic action
translation
formal
40%, 0.40

*A. enzymatic action.
B. molecular synthesis.
C. chemical reactions.
D. hydrolysis.

4. In photosynthesis the function of stomata is that of

stomata
interpretation
formal
48%, 0.37

A. oxygen in respiration.
B. enzymes in digestion.
*C. a value on a faucet.
D. a shell on a snail.

---

*Information in the left hand margin indicates: concept tested, type of examination question, concept classification, percent of subjects answering correctly, and biserial correlation with subjects' total Piagetian task scores.

5. Which of the following represents the best definition of the term "protoplasm"?

protoplasm
translation
formal
51%, 0.16

A. A complex liquid system made up of water proteins and fats.
B. Anything capable of growth by regular progressive series of changes into a more complex unit.
C. A complex mixture of proteins, fats, and carbohydrates, capable of responding to changes in its environment.
*D. A complex liquid system of proteins, fats, and carbohydrates, inorganic salts, and enzymes which manifests life.

6. If you were to go to a field and mark off an area of 100 square feet and capture and weigh every living plant or animal in that area you would have a measure of the area's

biomass
translation
concrete
42%, 0.38

A. productivity.
B. biotic potenital.
*C. biomass.
D. diversity.

7. In the early spring some chemical poison was dumped into a pond. It killed all the mold, bacteria, yeasts and other types of decomposers. By the end of the summer members of the bass population of the pond began to die. The most likely reason for the bass deaths is

ecosystem
application
formal
46%, 0.42

A. The poison that killed the decomposers also killed the bass.
B. the bass had used the decomposers as a food source; since the food is no longer available the bass starved.
C. bass ate the poisoned decomposers and poisoned themselves.
*D. the dead decomposers could no longer recyle nutrients so the productivity of the pond dropped to near zero.

8. In the city zoo there are 6 lions, 12 seals, 10 zebras, 6 bears, 535 birds and 55 horses. These are examples of

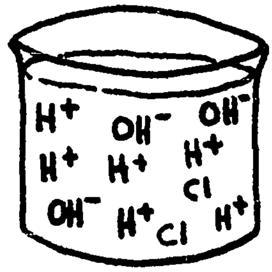
population
translation
concrete
75%, 0.28

A. ecosystems.
B. food chains.
C. biomes.
*D. populations.

9. The addition of a buffer to the solution in the diagram will have what effect?

buffer
application
formal
24%, -0.14

A. Reduce the pH.
*B. Increase the pH.
C. Not effect the pH.
D. Bind the Cl ions.



10. The diagram represents what type of reproduction?

budding
translation
concrete
46%, 0.09

A. sexual reproduction.
*B. budding.
C. spore formation.
D. mitosis.

11. The movement of molecules and ions in all directions as a result of their own motion or of being hit by other molecules and ions eventually leads to an even distribution of substance. This principle is illustrated by

diffusion
extrapolation
formal
73%, 0.06

*A. a drop of food coloring in water.
B. a burning match.
C. a bouncing ball on the floor.
D. a drunk driving a car.

12. Which of the following is the best example of a food chain?

food chain
translation
concrete
24%, 0.09

A. sparrow → seeds → hawk → bacteria.
*B. seeds → sparrow → hawk → bacteria.
C. hawk → seeds → bacteria → sparrow.
D. bacteria → seeds → sparrow → hawk.

13. Freon is a liquid that evaporates at room temperature and condenses at about 45°F. Some freon liquid was poured into a plastic bag. The bag was immediately tied shut and the freon evaporated. When an ice cube was placed on top of the bag drops of liquid fell from under the ice cube to the bottom of the bag. Which of the following is the best explanation of where the drops came from?

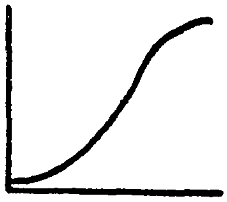
water cycle
interpreta-
tion
formal
75%, 0.14

A. the ice melts and forms the drops.
*B. freon condenses and forms the drops.
C. the plastic is dissolved by the freon and forms the drops.
D. the plastic is dissolved by the ice and forms the drops.

14. The idea that numerous factors such as water, light, fire, topography, other organisms, and wind interact to limit the size of producer and consumer populations is not illustrated by

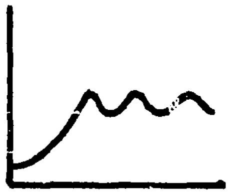
limiting factors
extrapolation
concrete
48%, -0.16

A. Size of population



Time

B. Size of population

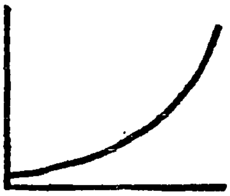


Time

C. Size of population

Time

*D. Size of population



Time

15. The difference between the amount of heat which is produced by partially burning a log and completely burning a log is most like the difference between

aerobic & anerobic respiration
translation
formal
22%, 0.21

A. combustion and respiration with oxygen.
*B. respiration with oxygen and respiration without oxygen.
C. hydrolysis and fermentation.
D. photosynthesis and respiration without oxygen.

16. An area of ground was completely stripped of life by a fire. Six months later small grass-like plants were covering the ground. In two years small bushes had replaced the grass. After ten years poplar trees were covering the same area. Thirty years later the poplar trees were being crowded out by pine trees. This process is called

succession
translation
concrete
73%, 0.19

A. the life cycle.
B. biotic potential.
C. ecological regression.
*D. succession.

17. In photosynthesis the function of chlorophyll is that of

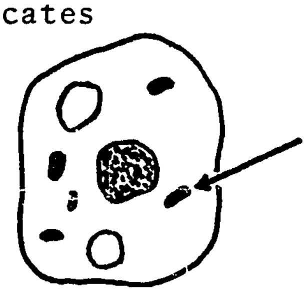
chlorophyll function
translation
formal
55%, 0.37

*A. an enzyme in digestion.
B. carbon dioxide in respiration.
C. bile in the digestion of fat.
D. glucose in respiration.

18. In the diagram the arrow indicates

mitochon-drion
translation
concrete
42%, 0.003

A. cell membrane.
B. nucleus.
*C. mitochondrion.
D. vacuole.



Animal cell

19. The process by which (1) CO_2 and H_2O are combined to produce glucose, (2) proteins are broken down into amino acids, (3) atoms are exchanged between ADP and ATP, and (4) atoms of RNA molecules are re-arranged is called

metabolism
translation
formal
24%, -0.14

*A. metabolism.
B. reproduction.
C. enzymatic synthesis.
D. photosynthesis.

20. Which of the following is an example of a primary consumer?

primary consumer
translation
concrete
48%, 0.30

A. mold that grows on bread.
B. hawks that eat mice.
*C. mice that eat leaves.
D. bacteria that eat dead logs.

21. Which of the following best described the term "photosynthesis"?

photosynthesis
translation
formal
42%, 0.003

*A. the process of trapping light energy by pigment molecules in the formation of ATP to produce glucose.
B. the process of converting water and carbon dioxide to oxygen.
C. the process of using sunlight by all plants to produce food for the entire biosphere.
D. any activity which produces food or oxygen.

22. Which of the following represents the best definition of the term "biosphere"?

biosphere
translation
concrete
44%, 0.09

A. all life which consists of radially symetrical forms.
B. all life on earth in the oceans and on land.
C. all life which has been described by biologists.
*D. all life on earth between the crust and the upper reaches of the atmosphere.

23. A physical principle states that transformation of energy always involves an overall change from concentrated to dispersed form. The useful conversion of one kind of energy into another is never 100 percent efficient. Best evidence of this is

1st Law of Thermodynamics
extrapolation
formal
24%, 0.25

A. small organisms eat proportionally more than large ones.
*B. food chains are limited to four or five links.
C. respiratory rate increases with age.
D. food left in the open decays and disintegrates.

24. Which of the following are <u>not</u> organisms?

organism
translation
concrete
77%, 0.12

A. human beings.
B. <u>Canis familiaris</u>.
*C. granite rocks.
D. sunflower plants.

25. A biologist studying enzymatic reactions noticed, when the pH of his reacting solution dropped below 5.0, the precipitation of silver nitrate, which was produced by the reaction, stopped. The best explanation for this is

pH effect on enzymatication
application
formal
26%, 0.06

A. silver nitrate forms only in a narrow range of pH.
B. the enzyme involved is unable to function in basic conditions.
C. the solutions ability to buffer the addition of acid is affected by the silver nitrate.
*D. the enzyme involved is unable to function in acid conditions.

26. An oak tree is surrounded by air, soil, water, other plants, insects, and sunlight. These surrounding features are

environmental factors
translation
concrete
73%, 0.27

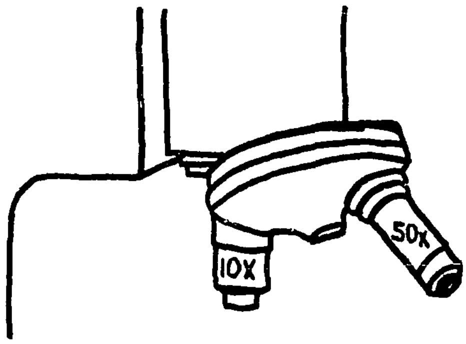
A. physical features.
B. food webs.
*C. environmental factors.
D. biotic components.

27. A freshwater plant is put into a saturated salt solution, the cells of the plant probably will

osmosis
application
formal
82%, 0.16

A. take in more fluid.
*B. lose fluid.
C. show no effect.
D. take in salt.

The following diagram represents the nosepiece and objectives of a microscope. Use the diagram to answer questions 28 and 29.



28. How many times does the high power objective lens of this microscope magnify an object?

magnification
interpretation
concrete
51%, 0.25

*A. 50 times.
B. 500 times.
C. 5 times.
D. 10 times.

29. Under high power magnification 95 evenly distributed bacterial cells can be seen on a slide. How many of these same cells will you be able to see when you turn the nosepiece to low power?

proportion
application
formal

A. 950
B. 19
C. 475
*D. 2375

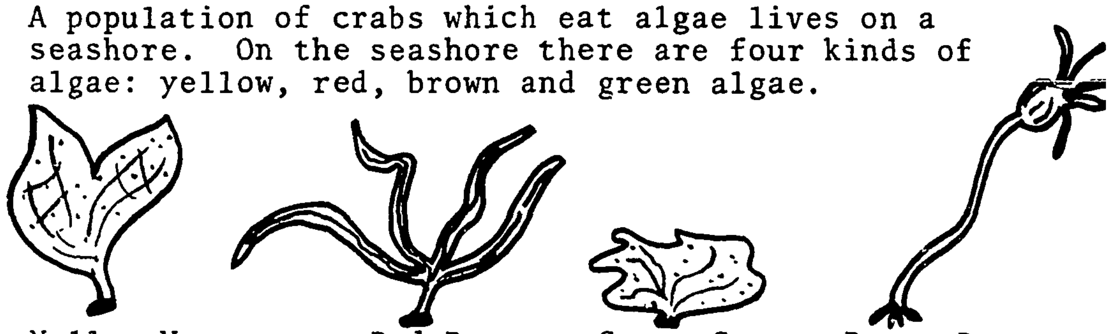
food chain
translation
concrete
66%, 0.21

30. Members of the clover population are consumed by members of the mouse population. Some of the mice are eaten by members of a weasel population. Some of the weasels are in turn consumed by eagles. This represents

A. biomass inversion.
B. food web.
C. population despersion.
*D. food chain.

combina-
torial
system
application
formal
10%, 0.56

31. A population of crabs which eat algae lives on a seashore. On the seashore there are four kinds of algae: yellow, red, brown and green algae.



Yellow-Y   Red-R   Green-G   Brown-B

Dr. Saltspray, a biologist, is interested in determining which of the types of algae are actually eaten by the crabs. He plans to find out by examining the stomach contents of the crabs. Before he does his investigation he listed all the combinations of algae he thought possible to find in the stomachs. How many possible combinations of algae diets are there? Use the letters Y, R, G and B to save space.

CHEMISTRY EXAM

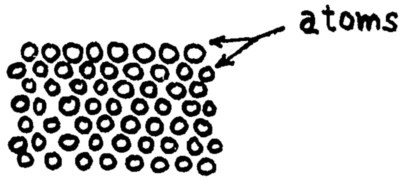
Name ____________________

Date ____________________

1. The most probable physical state of the substance diagramed at the right is

atomic model translation concrete 85%, 0.03

A. liquid.
*B. solid.
C. can not be determined from information available.
D. gas.



2. Assume the following observations obey the general gas law which states that the pressure is equal to a constant k multiplied by temperature and divided by the volume.

gas law extrapolation formal 77%, 0.48

Pressure	1	2.4	5.6	8
Volume	200	100	50	40
Temperature	150	180	210	240

The value of k in the above equation is

A. 1
*B. 4/3
C. 2
D. 3/4 [1]

3. In the molecular formula "$NH_4Ga(SO_4)_2 \cdot 12H_20$" how many atoms are present?

molecular formula translation concrete 75%, 0.42

*A. 52
B. 41
C. 47
D. 58

---

[1]William D. Hedges, <u>Testing and Evaluation for the Sciences in the Secondary Schools</u>, (Belmont, California: Wadsworth, 1966), p. 55.

4. Density is equal to the mass of an object divided by its volume. The density of boiling water is determined to be a certain value. Thirty minutes later after one half of the water has vaporized the density is found to be

density interpretation
formal
75%, 0.12

A. 1/2 its original density.
B. twice its original density.
*C. the same.
D. can not be determined until we know the original density.

5. Extensive properties of matter are properties that depend upon the amount of matter present. Which of the following is an extensive property?

extensive properties
translation
concrete
64%, 0.13

A. color.
B. boiling point.
C. density.
*D. length.

6. A principle states: the relative rates of diffusion of two gases under ideal conditions are inversely proportional to the square roots of their molecular weights. According to this

Graham's Law
translation
formal
77%, 0.31

*A. perfume vapor with a molecular weight of 16 can be smelled before onion vapor with a molecular weight of 32.
B. the higher the molecular weights of gas the sooner an equilibrium state is reached in a closed system.
C. onion vapor would be more offensive than perfume vapor.
D. perfume vapor with a molecular weight of 16 will be smelled after onion vapor with a molecular weight of 32.

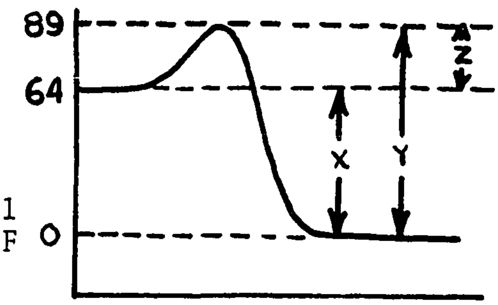
7. A rocket propellant can be made by allowing hydrogen and fluorine to react. The chemicals react spontaneously upon contact as below

endothermic reaction
translation
concrete
62%, 0.05

$$\tfrac{1}{2}\ H_2\ (g) + \tfrac{1}{2}\ F_2\ (g) = HF(g) + 64\ \text{kcal}$$

The potential energy diagram for the reaction is given below

potential kcal
energy mole HF



time
Reaction Coordinate

7. (Continued)

Which of the following statements concerning the energy relations of the above system is false?

A. The heat of the reaction per mole of hydrogen fluoride is represented by the distance X on the graph.
*B. The reaction is endothermic.
C. The heat of the reaction is 64 kcal per mole of hydrogen flouride gas.
D. The activation energy for the reaction is 25 kcal per mole of HF.[2]

volume displacement
application
formal
66%, 0.25

8. An irregularly shaped rock is placed in a square container partially filled with water. All sides of the container are six inches long. If the water level rose two inches when the rock was placed in the container the volume of the rock would be

*A. 72 cubic inches.
B. 36 cubic inches.
C. 20 cubic inches.
D. can't tell volume from information given.

covalent bond model
translation
concrete
54%, 0.15

9. In the chemical reaction indicated at the right what type of atomic bonds are formed?

A. hydrogen.
B. metallic.
C. ionic.
*D. covalent.

```
          .          H
                     ..
4H. +  .C.  →  H:C:H
                     ..
          .          H
```

electron dot model
translation
concrete
85%, 0.064

10. In the same diagram, how many electrons are involved in the bonds formed?

A. 4
*B. 8
C. 5
D. 13

gram molecular weight
extrapolation
formal
77%, -0.07

11. When 2 grams of hydrogen gas and 2 grams of oxygen gas combine the result is not 4 grams of H_2O. This is best explained by

A. some of the hydrogen is lost during the reaction.
B. the heat used to start the reaction destroys some of the molecules.
C. some of the water already in the air must be added to the total.
*D. the gram molecular weights of oxygen and hydrogen are not the same.

---

[2] *Ibid.*, p. 53.

12. If a mass of gas is heated, which of the following is true

mass extrapolation formal 35%, 0.18

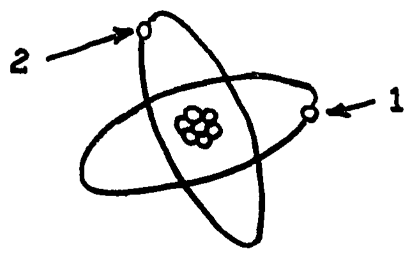
A. the volume will increase.
B. the density may increase.
*C. the density may decrease.
D. the volume may decrease.

13. The greater the difference in electronegativity of two types of atoms the more ionic the bonds formed between them will be. The best explanation for this is

ionic bond translation formal 56%, 0.23

*A. electrons will tend to be drawn closer to one atom resulting in a transfer.
B. repulsion of electrons by both atoms results in longer bonds.
C. less energy is required to hold electrons in a covalent bond.
D. bonds result from attraction between protons and electrons.

A model of the Bohr atom is shown below. Refer to it in answering questions 14 and 15.



14. What structure is indicated at point 1?

Bohr atom model translation concrete 83%, 0.01

*A. negatively charged particle.
B. positively charged particle.
C. positive and neutral particles.
D. neutral particles.

15. What structure is indicated at point 2?

Bohr atom model translation concrete 75%, 0.10

A. negatively charged particle.
B. positively charged particle.
*C. positive and neutral particles.
D. neutral particles.

16. A triple beam balance is used to weigh a sealed container. When 6 grams of substance X reacts with 5 grams of substance Y in the sealed container the recorded weight of the container and its contents is found to be two grams less than at the start. The best explanation for this is

conservation of matter
application
formal
64%, 0.16

A. 2 grams of substance X did not react.
B. 2 grams of the material formed evaporated.
*C. an error has been made in recording.
D. 2 grams of the material were destroyed by the heat of the reaction.

17. Intensive properties do not depend on the amount of matter present. Which of the following is an intensive property?

intensive properties
translation
concrete
93%, 0.13

*A. conductivity.
B. weight.
C. height.
D. volume.

18. Equilibrium defined for closed systems of liquids and gases is the state in which just as many molecules pass from liquid to gas as from gas to liquid; what would happen to the equilibrium condition if the closed container were doubled in volume?

equilibrium
extrapolation
formal
29%, 0.23

*A. The number of molecules in the gaseous state would increase.
B. The number of molecules in the liquid state would increase.
C. The balance would not change since it was already at equilibrium
D. The number of molecules in the entire system would double.

19. If atoms were divisible particles which of the following laws would probably be invalid?

atomic structure
extrapolation
formal
43%, 0.09

A. Raoult's Law.
B. Conservation of Energy.
*C. Law of Multiple Proportions.
D. Conservation of Matter.

20. Which of the following is <u>not</u> an exothermic reaction?

exothermic
translation
concrete
75%, 0.26

A. a burning candle
B. $Fe + S \rightarrow FeS + heat$
*C. $C + CO_2 + heat \rightarrow 2CO$
D. $2H_2 + O_2 \rightarrow 2H_2O + energy$

21. Raoult's Law states that the vapor pressure of a solution is inversely proportional to the mole fraction of the solvent present. The addition of 4 moles of ions to a solution will

Raoult's Law
extrapolation
formal
25%, 0.14

A. increase the number of molecules escaping from the liquid.
*B. decrease the number of molecules escaping from the liquid.
C. increase the vapor pressure.
D. decrease the freezing point of the liquid which will decrease the vapor pressure.

22. The test paper you are writing on is approximately how many centimeters long?

centimeter
translation
concrete
81%, 0.18

A. 1/3
B. 3
*C. 30
D. 300

23. Melting point is the temperature at which the vapor pressure of a solid and the liquid are equal. If the temperature increases to a point above the melting point

melting point
translation
formal
83%, 0.23

A. the vapor pressure of the solid will decrease.
*B. the vapor pressure of the liquid will increase.
C. the melting point will increase.
D. the melting point may decrease.

24. An acid solution is capable of conducting an electric current. To the solution is added a substance which lowered the conductivity. The substance added probably

conductivity
extrapolation
formal
25%, 0.14

A. lowered the pH of the solution.
B. did not affect the pH but decreased the number of free ions in solution.
*C. raised the pH of the solution.
D. was a very weak acid since it lowered the conductivity.

proportion
extrapolation
formal
62%, 0.39

25. The number of containers of chemicals that a laboratory can turn out varies directly as the time available and the number of chemists available. If ten chemists work 6 hours to produce 6 jars, how many containers can be turned out by 4 chemists working for 5 hours.

*A. 2
B. 20
C. 4
D. 3

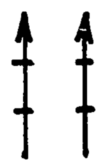
PHYSICS EXAM

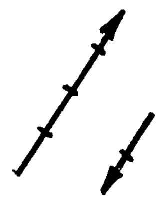
Name ______________________

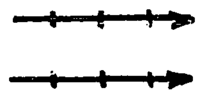
Date ______________________

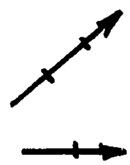
1. Which of the following pairs of vectors has the resultant with the smallest magnitude?

vector
translation
concrete
77%, 0.10

A. 

*C. 

B. 

D. 

2. The idea that once a body is set into motion it will continue at a constant velocity unless acted upon by some external force is not demonstrated by

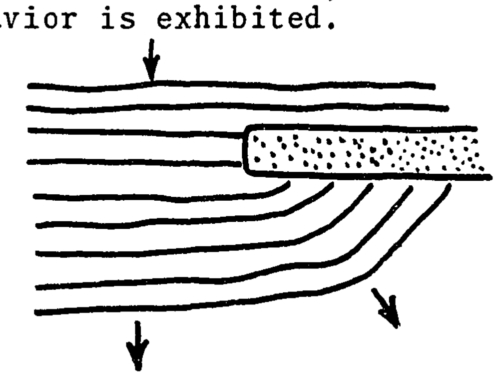
inertia
extrapolation
formal
3%, 0.27

*A. a pencil resting on a desk.
B. a baseball hit over the centerfield fence.
C. a golf ball driven 300 yards.
D. a lead ball dropped from a tower.

3. A diagram at the right represents wave crests as they move past the end of a breakwater; what property of wave behavior is exhibited.

diffraction
translation
concrete
64%, 0.34

A. reflection.
*B. diffraction.
C. refraction.
D. interference.



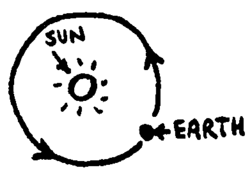
4. In Newton's theoretical model the pressure of a gas varies directly as one third of the product of the velocity of the gas molecules squared and their density. If a gas of pressure 100 and density of 300 is heated so the velocity of its molecules doubles what will the pressure become

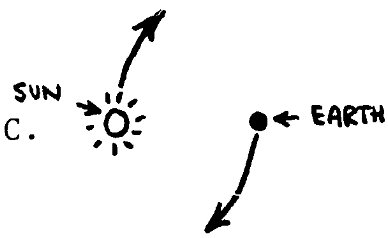
air pressure model
extrapolation
formal
48%, -0.02

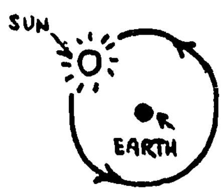
A. 200
*B. 400
C. 100
D. 10

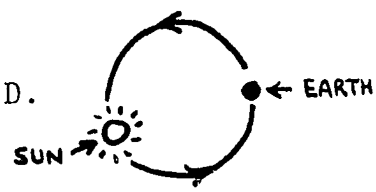
5. Which of the following represents a geocentric solar system?

geocentric
translation
concrete
93%, 0.09

A.


C.


*B.


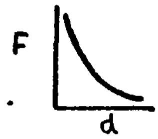
D.


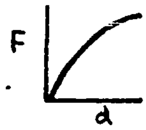
6. Newton's Law of Gravitation is expressed as

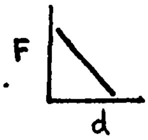
$F = G \frac{Mm}{d^2}$ where F is the force, M and m are two masses, G is a constant, and d represents the distance between the two masses. Assuming that M and m as well as G remain the same, which of the following graphs shows how the force changes as the distance between the masses varies?

Law of Gravitation
translation
formal
83%, 0.19

A.


*C.


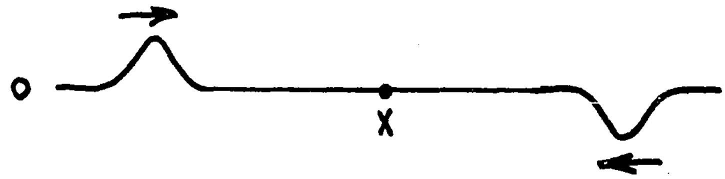
B.


D.


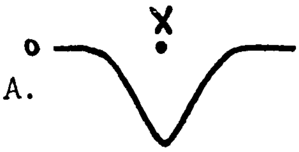
3

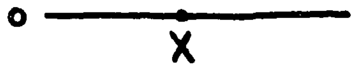
[3]Bloom, Taxonomy, p. 125.

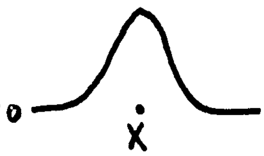
7. The principle of superposition states that the amplitudes of waves which coincide at a point are additive. According to this principle when the two waves shown meet at point X the result will be



Superposition interpretation concrete 90%, 0.32

A. 

*C. 

B. 

D. 

8. Which of the following objects has the greatest density? Recall: Density = mass/volume.

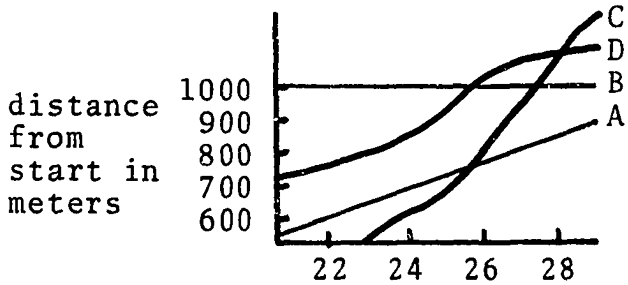
density extrapolation formal 61%, -0.01

*A. a weightless block of iron in a space ship.
B. a block of pinewood 3 cm. tall, 3 cm. wide and 3 cm. long which weighs 60 grams.
C. a block of metal 4 cm. tall, 4 cm. wide and 4 cm. long which weighs 60 grams.
D. a block of an unknown substance which is just slightly more dense than the block of metal (mentioned in C above).

9. The graph shows positions of four cars during part of a race. Which car has a displacement of zero during the time interval shown?

displacement interpretation concrete 83%, 0.32

A. car A.
*B. car B.
C. car C.
D. car D.



10. Which car is traveling at a uniform speed during the time interval shown? (Refer to question 9 above.)

uniform speed
interpretation
formal
80%, 0.42

*A. car A.
B. car B.
C. car C.
D. car D.

11. Suppose an elevator is descending with a constant acceleration of gravity. If a passenger attempts to throw a rubber ball upward, what will be the motion of the ball with respect to the elevator? The ball will

reference frame
application
formal
22%, 0.13

A. remain fixed at the point the passenger releases it.
B. rise to the top of the elevator and stay there.
*C. rise, bounce off the ceiling, then move toward the floor at a constant speed.
D. rise, bounce off the ceiling, then move to the floor at an increasing speed.[4]

12. The rule of parsimony is a rule of economy of explanation. Following this rule, which of the following is the best explanation? The world is composed of

parsimony
extrapolation
formal
3%, -0.27

A. fire, air, water, or earth.
B. matter and motion.
C. atoms and energy.
*D. water.

13. If the earth were not inclined on its axis which of the following would be true?

axis inclination
application
formal
70%, 0.03

*A. All the solar days would be of equal length.
B. The orbital speed of the earth would not vary during the year.
C. Objects would weigh more at the equator than they do now.
D. The average amount of sunlight at the poles would be greater.

14. This test paper is sitting at rest on your desk. Which of the following statements best describes the situation?

balanced forces
extrapolation
concrete
100%, 0.00

A. There are no forces acting on the paper.
*B. There are many forces acting on the paper but they are balanced.
C. The paper exerts no force on the desk.
D. Your paper is at rest in any coordinate system.

---

[4]Ibid., p. 136.

15. Work done on an object is defined as the product of the magnitude of force and the distance the object is moved. If a 2 newton force can move an object 20 meters, a 4 newton force will move an object of 3 times the weight about how many meters?

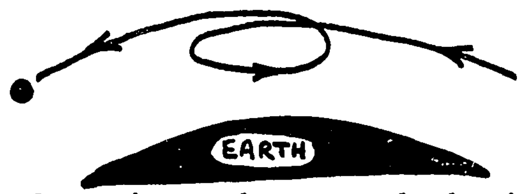
work
extrapolation
formal
70%, 0.36

*A. 13 meters.
B. 40 meters.
C. 120 meters.
D. 7 meters.

16. The diagram represents the path taken by a celestial object as seen from the earth. The object is most likely a

retrograde motion
translation
concrete
64%, 0.03

A. sun.
B. star.
C. moon.
*D. planet.



17. Despite changes in location, shape, and chemical composition the mass of any closed system remains constant. According to this principle which of the following is true?

mass conservation
extrapolation
formal
77%, 0.16

A. When a tree with a 30 kg mass is burned its ashes will also have a mass of 30 kg.
B. An object that weighs 10 grams on earth will also weigh 10 grams in space.
C. A dead mouse sealed in a closed jar will not decay.
*D. A candle in a closed jar may burn, however, the weight of the contents will not change.

18. The acceleration of an object is directly proportional to and in the same direction as the unbalanced force acting on it and inversely proportional to the mass of the object. A force of 2 kg x 1 meter/sec^2 accelerates an object of 10 kg 1/5 m/sec^2. If the force were tripled and the mass of the object doubled, acceleration would be

Newton's Second Law
extrapolation
formal
64%, 0.188

A. 3/5 m/sec^2
B. 2/5 m/sec^2
*C. 3/10 m/ sec^2
D. 1/10 m/sec^2

19\. During part of an automobile race four cars were timed as they traveled one time around the track. If the following times were obtained for each car, which car traveled with the greatest speed?

speed interpretation
concrete
93%, 0.09

A. car 1, 85 seconds.
*B. car 2, 70 seconds.
C. car 3, 83 seconds.
D. car 4, 74 seconds.

20\. The inverse square law states that an object moving in an orbit around a center of force is acted on by a centripetal force that varies inversely with the square of the distance from the center. An object revolves in a circle with a radius of 9 miles under a centripetal force. If for some reason the force were doubled, what would happen to the radius? It would become approximately

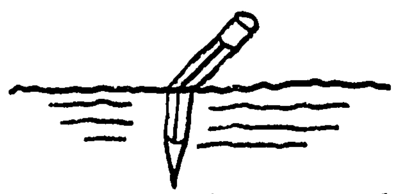
inverse square law
extrapolation
formal
12%, 0.37

A. 3 miles.
*B. 6 miles.
C. 27 miles.
D. 81 miles.

21\. The fact that an object partially submerged in water appears to be bent at the surface is due to

refraction
translation
concrete
96%, -0.14

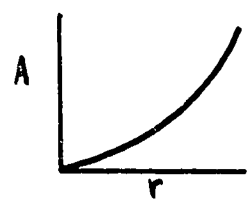
A. dispersion.
B. reflection.
*C. refraction.
D. interference.

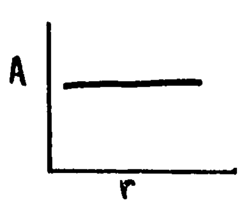


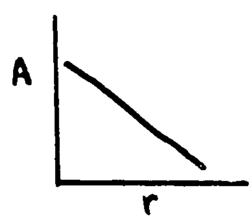
22\. A circling object has an acceleration towards the center of the circle which varies directly as the square of the velocity of the object and inversely with the radius of the circle. Which of the graphs shows the correct relationship between the radius of the circle and the acceleration of the object when velocity is held constant?

centripetal acceleration
translation
formal
25%, -0.09

*A.

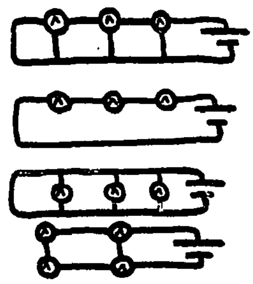

C.


B.


D.


Questions 23 and 24 refer to the diagram below.

A.
B.
C.
D.



23. Which diagram represents cells in a parallel circuit?

A. A
B. B
*C. C
D. D

parallel circuits
translation
concrete
87%, 0.13

24. Which diagram represents cells in a series circuit?

A. A
*B. B
C. C
D. D

series circuits
translation
concrete
90%, 0.15

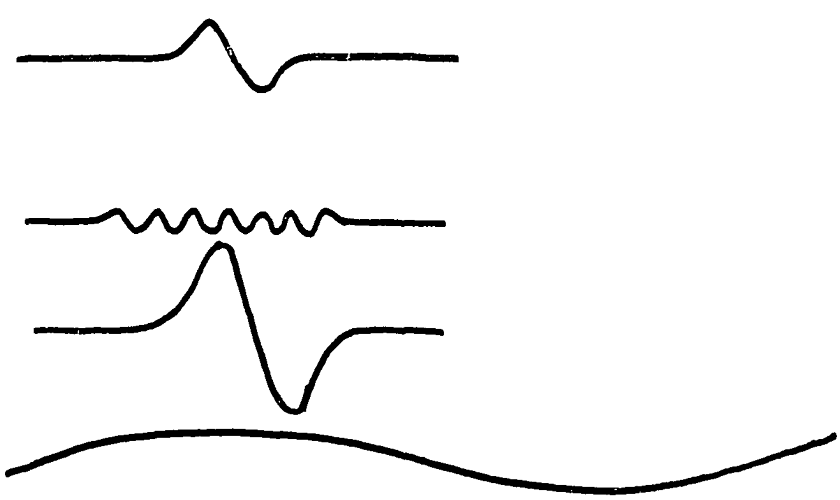
25. The relative observed position of some stars changes about 1/2500° from January to July. The best explanation for this is

A. the earth rotates on its axis.
*B. the observer moves.
C. the stars move.
D. light rays from the stars bend.

stellar parallax
translation
formal
25%, 0.40

26. The following diagrams represent four ropes with waves traveling through them. Which rope exhibits waves of the largest amplitude?

A.
B.
*C.
D.



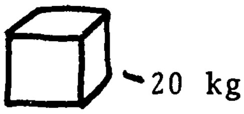
amplitude
translation
concrete
70%, 0.58

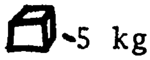
27. Instantaneous speed is the limit approached by the average speed as the time interval becomes smaller and smaller. "Limit approached" means

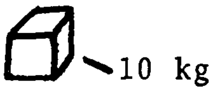
A. highest velocity.
*B. zero.
C. largest average speed.
D. infinity.

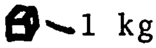
instantaneous speed
translation
formal
19%, 0.01

28. Which of the following objects exerts the greatest force due to gravity?

*A. 

C. 

B. 

D. 

weight
translation
concrete
100%, 0.00

29. If the earth had no moon which of the following would be true?

A. The force of gravity would be twice as great.
B. All months would be of equal length.
C. High tides would be higher and low tides would be lower.
*D. We would know much less about the nature of the sun.

solar system
interpretation
formal
45%, 0.36

30. A boat rowed in water is propelled forward by the water that pushed forward on the oar. This represents

*A. Newton's Third Law.
B. conservation of momentum.
C. conservation of energy.
D. conservation of mass.

Newton's Third Law
extrapolation
formal
67%, -0.12

APPENDIX II

Concept Definitions

CHEMISTRY CONCEPTS[1]

Concrete Concepts

1. Exothermic reaction: A reaction in which heat is given off. p. 67. (Note: this concept has formal aspects, however, as defined here it is concrete.)

2. Extensive properties of matter: properties which depend upon the amount of matter present. p. 45.

3. Intensive properties of matter: properties which do not depend upon the amount of matter present. p. 45.

4. Bohr Atom Model: a model of an atom which consists of a nucleus composed of positively charged protons, neutrons and electrons which travel in orbits around the nucleus. The electrons carry a negative charge. pp. 123-125.

5. Molecular formula: a series of letters and numbers which indicate the number and kinds of atoms in a molecule. p. 83.

6. Solid atomic model: model in which the atoms, molecules or ions remain in fixed positions relative to neighboring particles. p. 222.

7. Electron dot diagram: a diagram in which the outer shell of electrons is represented by dots around the chemical symbol of the atom. Covalent bonds are indicated by pairs of dots. p. 152.

8. Centimeter: a unit of length one one hundreth of a meter. p. 15.

Formal Concepts

1. Boyle's Law: the pressure exerted by a gas is inversely proportional to the volume and directly proportional to the temperature of the gas. p. 273.

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[1]Robert Smoot, Jack Price, Richard Barrett, Chemistry: A Modern Course, (Columbus, Ohio: C. E. Merrill, 1968).

2. Mass: the quantity of matter that is being considered, a measurement of the inertia of a body. p. 10.

3. Activation energy: the minimum energy needed to cause reactants to change from the reactant state to the product state. p. 341.

4. Direct variation: the relationship that exists between two quantities when an increase in one produces a proportional increase in the other. p. 30.

5. Equilibrium: in closed systems is a state in which just as many molecules pass from liquid to gas as from gas to liquid or just as many molecules pass from solid to liquid as pass from liquid to solid. p. 227.

6. Raoult's Law: the vapor pressure of a solution is inversely proportional to the mole fraction of the solvent present. p. 325.

7. Gram molecular weight: the relative weight of a molecule of an element or compound expressed in grams. p. 77.

8. Melting point: the temperature at which the vapor pressure of the solid and the liquid are equal. p. 230.

9. Conservation of Mass: the mass of a given quantity of matter can not be increased or decreased. p. 11.

10. Law of Multiple Proportions: if two or more compounds can be formed by the same two elements, the ratio of the masses of one which can unite with a constant mass of the other can be expressed in small whole numbers. p. 109.

11. Graham's Law: the relative rates of diffusion of two gases under ideal conditions is inversely proportional to the square roots of their molecular weights. p. 285.

12. Displacement volume: the volume of water displaced by a submerged solid object.

13. Density: the mass of an object divided by its volume. p. 17.

14. Electronegativity: the relative tendency of an atom to attract electrons to itself in a bond with other atoms. p. 199.

15. Electrolytes: substances which conduct electric currents due to the ionization of compounds in solution. pp. 320-321.

PHYSICS CONCEPTS[2]

Concrete Concepts

1. Refraction: the bending of waves when they pass from one medium to another. pp. 130-132 (12).

2. Speed: a measure of how fast an object gets from one place to another, speed is the rate of change of position. p. 12 (1).

3. Vector quantity: a quantity which has both direction and magnitude and which can be added by the graphical construction of the head to tail representation of arrows. p. 75 (3).

4. Weight: force due to gravity of an object. p. 84 (3).

5. Uniform speed: speed which stays the same between successive distance intervals. p. 15 (1).

6. Displacement: measure of the distance an object has moved.

7. Amplitude: the maximum displacement from an equilibrium position. p. 111 (12). (Note: aspects of the term "equilibrium" are formal, however, in the context used here equilibrium refers only to a central position.)

8. Balanced forces: the sum of forces acting on a body are equal. pp. 70-72 (3).

9. Parsimony: unless forced to do otherwise, assume the simpliest possible hypothesis to explain natural events. p. 48 (2).

10. Retrograde motion: westward or wrong way motion of planets. pp. 12-13 (5).

11. Diffraction: the phenomeon of wave energy or fronts spreading into what we would expect to be "shadow" regions. p. 125 (12).

12. Principle of Superposition: the displacement of waves when they meet is the sum of the individual displacements. p. 113 (12).

13. Geocentric: a system with the earth at the center of revolution. p. 17 (5). (Note: this system can be modeled by the use of diagrams which render aspects of the system concrete. A complete understanding of any system however involves formal thinking.)

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[2] F. James Rutherford, Gerald Holton, Fletcher Watson, The Project Physics Course, (New York: Holt, Rinehart and Winston, 1970).

14. Deferent: a circle which revolves at a uniform rate. It was a device used in Ptolemaic astronomy. p. 23 (5).

15. Epicycle: a circle which revolves at a uniform rate about a point on a deferent and used in Ptolemaic astronomy to account for retrograde motion of planets. p. 23 (5).

Formal Concepts

1. Newton's Law of Gravitation: the force of gravitational attraction between two bodies is directly proportional to the product of their masses and inversely proportional to the square of the distance between them. pp. 98-101 (8).

2. Newton's Second Law: the acceleration of an object is directly proportional to and in the same direction as the unbalanced force acting on it and inversely proportional to the mass of the object. p. 68 (3).

3. Newton's Third Law: to every action there is an opposed and equal reaction; or, mutual actions of two bodies upon each other are always equal and opposite in direction. p. 68 (3).

4. Instantaneous speed: the limit approached by the average speed as the time interval involved gets smaller and smaller, $v =$ limiting value $\frac{\Delta d}{\Delta t}$ as Δt approaches zero. pp. 23-25 (1).

5. Inverse Square Law: any object moving in an orbit that is a conic section around a center of force is being acted upon by a centripetal force that varies inversely with the square of the distance from the center of force. pp. 90-91 (8).

6. Air pressure: force due to gas molecules colliding with the walls of a container. It is proportional to the speed of the molecules and the density of the gas. p. 86 (11).

7. Work: work done on an object by a force that acts on it is defined as the product of the magnitude of the force and the distance the object moves in the direction of the force while the work is being exerted. p. 31 (10).

8. Inertia: every object continues in its state of rest or in uniform rectilinear motion unless acted upon by an unbalanced force. p. 76 (3).

9. Conservation of Mass: despite changes in location, shape chemical composition and so forth, the mass of any closed system remains constant. pp. 7-8 (9).

10. Density: is the total mass of a substance per unit volume. p. 85 (11).

11. Centripetal acceleration: acceleration directed toward the center of rotation which varies directly with the velocity and inversely with the distance from the center. p. 110 (4).

12. Stellar parallax: a shift in the relative observed positions of stars that is caused by the displacement of the observer. p. 20 (5).

13. Solar System: the sun, the planets that revolve around it, the satellites which revolve around the planets and the relationships which exist between these objects.

BIOLOGY CONCEPTS[3]

Concrete Concepts

1. Primary consumer: an organism which lives directly at the expense of green plants. p. 686.

2. Food chain: a series of organisms which serve as food sources for one another. p. 699.

3. Succession: changes in the kinds of species which occupy an area due to early colonizing species altering the area such that new species are able to eventually become established and crowd them out. pp. 701-702.

4. Limiting factors: environmental factors which exist in amounts too small or too large to permit the existance of a particular population of organisms.

5. Environment: surroundings of an organism including such factors as light, water, temperature, fire, gravity, green plants, animals, and nongreen plants. p. 677.

6. Population: a group of two or more organisms of the same species.

7. Abiogenisis: the idea that living things can arise from nonliving things. p. 26.

8. Budding: a type of asexual reproduction in which a new individual is produced as a bud, or outgrowth, on an older individual. p. 474.

9. Internode: portion of a plant stem between the nodes. p. 297.

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[3]Biological Sciences Curriculum Study, Biological Science: An Inquiry into Life, Yellow Version, (New York: Harcourt Brace, 1968).

10. Stomata: hole or opening on the lower surface of a leaf through which a free exchange of gases between the external atmosphere and the internal atmosphere of the leaf takes place. p. 102.

11. Biomass: amount of living material in an area. p. 699.

12. Species: a group of organisms that can breed with one another. p. 348.

13. Biosphere: the entire world of life on earth between the solid crust and the upper reaches of the atmosphere. p. 704.

14. Cutin: a waxlike substance on the surface of some leaves which prevent evaporation. p. 256.

Formal Concepts

1. Chlorophyll: a green pigment inside chloroplasts in plants which is a complex substance composed of over 100 atoms. Its function is essentially to trap light energy and serve as an energy source for the conversion of ADP to ATP molecules. p. 282-284.

2. Cytoplasm: a complex colloidal system of proteins, fats, carbohydrates, inorganic salts, and enzymes which manifests life.

3. Metabolism: the sum of the following cellular processes in which large molecules are synthesized from smaller ones, molecules are decomposed into smaller ones, atoms are exchanged between molecules, and atoms of a molecule are rearranged. p. 108.

4. Ecosystem: a system of organisms, energy, matter, cycles, and climates all interacting to constitute living nature. p. 686.

5. Enzyme action: enzymes facilitate reactions by forming unstable combinations with substrates which cause the substrates to break down into simplier products. The enzyme molecules are then freed to combine with other substrate molecules to continue the process. p. 107.

6. Fermentation or Anerobic Respiration: cellular process of glucose molecule partial breakdown without oxygen which yields only part of the energy contained in the glucose. The end products of fermentation are alcohol and acid. pp. 227-228.

7. Osmosis: the movement of water across a semi-permiable membrane from an area of high concentration of water to an area of lower concentration of water. p. 112.

8. Diffusion: the movement of molecules and ions in all directions as a result of their own motion or of being hit by other molecules and ions which eventually leads to an even distribution of substance. p. 91.

9. Water cycle: the passage of water through a continuous circle by way of evaporation and transpiration, condensation, precipitation, run off and evaporation. p. 680.

10. Buffer: a substance that tends to prevent major shifts in pH by binding hydrogen ions when a solution begins to become more acidic and by releasing hydrogen ions when a solution begins to become more basic. p. 42.

11. Photosynthesis: the process by which green plants utilize pigment molecules to trap light energy which is then used in the formation of ATP. This energy is stored in the relatively stable molecules of glucose. p. 291.

12. First Law of Thermodynamics: transformation of energy always involves an overall change from concentrated to dispersed form. The useful conversion of one kind of energy into another is never 100 percent efficient. p. 697.

APPENDIX III

Principal Components Analysis Description

PRINCIPAL COMPONENTS ANALYSIS

The following discussion is not intended as an exhaustive discussion of the statistical procedure of principal components analysis. Rather it is intended to serve as a brief introduction for the reader unfamiliar with this technique. For a more detailed treatment of the procedure see Tatsuoka 1971.[1]

Basically, principal components analysis is a multivariate technique which is often considered a first-stage solution in factor analysis. The technique can be used to determine factorial validity of psychological tests and that is one way in which it is used here. Generally, the technique mathematically attempts to reduce a set of many measures to a smaller number of factors by extracting weighted sums of these measures which account for a maximum amount of the variance of the total set. For example, if you test school teachers with 25 separate tests to measure teacher effectiveness you obtain 25 separate scores. By analysis of this set of 25 scores with principal components, the number of scores which contribute to the majority of the variance between good and bad teaching may be accounted by perhaps only four or five of the measures. Instead of using 25 separate tests to determine teacher effectiveness you need now use only four or

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[1]Maurice M. Tatsuoka, Multivariate Analysis: Techniques for Educational and Psychological Research, (New York: John Wiley and Sons, 1971).

five. Principal components analysis, therefore, effects a parsimony of description.

Suppose five persons obtained the following scores on three separate tests.

TABLE III-1

SAMPLE DATA, PRINCIPAL COMPONENTS ANALYSIS

Subject No.	Test 1 X_1	Test 2 X_2	Test 3 X_3	Weighted Sums L_i^1
1	5	20	1	L_1
2	8	11	6	L_2
3	2	10	4	L_3
4	1	16	2	L_4
5	6	4	1	L_5

The task of principal components analysis is to obtain weighted sums of scores

$$L_i^{(1)} = b_1 X_{1i} + b_2 X_{2i} + b_3 X_{3i}$$

such that the variance of $L_i^{(1)}$ is maximal with the constraint that

$$\sum b_i^2 = 1.0$$

$L_i^{(1)}$ then represents the first principal component. The second and subsequent principal components are determined by obtaining different sets of weights

$$L_i^{(2)} = a_1 X_{1i} + a_2 X_{2i} + a_3 X_{3i}$$

These weights are again selected such that the variance of

$L_i^{(2)}$, the second principal component, is maximal. The weights are also subject to the constrait

$$\sum a_i^2 = 1.0$$

The principal components are subject to one additional constraint; they must be uncorrelated. The maximum number of components possible is equal to the rank of the original data matrix. In this case, that is three.

To use the technique to validate psychological tests such as the Piagetian tasks, the procedure is relatively simple. A set of six formal operational Piagetian tasks, for instance, should be reduced to only one factor using principal components. Since the tasks presumably measure only one thing, only one principal component should be extracted and all six tasks should correlate highly or load heavily on the component. This result would validate the tasks in that they would indeed seem to all be measuring the same thing, namely, formal operational thought. If the technique extracted more than one principal component or root, then you would conclude that the tasks measure more than one thing. A result such as this would invalidate the tasks.

If a series of both concrete and formal tasks is analyzed it would be possible to determine the number of psychological factors (components) which underly success on these tasks. Keep in mind that it remains the job of the investigator to determine "psychological meaningfulness" of the factors.

APPENDIX IV

Interview Scoring Consistency

BIOLOGY SAMPLE

Table IV-1 shows the number of biology subjects interviewed and the mean scores for each day.

TABLE IV-1

MEANS AND SAMPLE SIZES FOR BIOLOGY INTERVIEWS

	Day				
	1	2	3	4	5
No. of Subjects Interviewed	15	11	13	6	5
Mean Score	13.13	12.64	12.64	14.16	14.00

Table IV-2 shows the analysis of variance for the 5 mean values. The null hypothesis is stated

$$HO: u_1 = u_2 = u_3 = u_4 = u_5.$$

This hypothesis is tested at the 0.25 level of confidence.

TABLE IV-2

ANALYSIS OF VARIANCE: BIOLOGY

Source	df	MS	F
Between Groups	4	4.0	0.945
Within Groups	45	4.232	

The table value for an F-distribution with 4 and 45 degrees of freedom at an alpha of 0.25 is 1.40. The obtained F value of 0.945 is less than the table value, therefore, the null hypothesis is accepted. No significant differences occur between scores on separate days of interviewing.

CHEMISTRY SAMPLE

Tables IV-3 and IV-4 show similar data for the chemistry sample. Interviews were conducted on three separate days.

TABLE IV-3

MEANS AND SAMPLE SIZES FOR CHEMISTRY INTERVIEWS

	Day		
	1	2	3
No. of Subjects Interviewed	14	26	10
Mean Score	14.63	14.92	14.5

The null hypothesis, H0: $u_1 = u_2 = u_3$, is tested at the 0.25 level of confidence.

TABLE IV-4

ANALYSIS OF VARIANCE: CHEMISTRY

Source	df	MS	F
Between Groups	2	10.58	0.9297
Within Groups	47	11.38	

The table value for an F-distribution with 2 and 47 degrees of freedom at an alpha of 0.25 is 1.43. The obtained F value of 0.9297 is less than the table value, therefore, this null hypothesis is also accepted.

PHYSICS SAMPLE

Tables IV-5 and IV-6 show the data for the physics sample. Interviews with the 33 physics students were conducted on five separate days.

TABLE IV-5

MEANS AND SAMPLE SIZES FOR PHYSICS INTERVIEWS

	Day				
	1	2	3	4	5
No. of Subjects Interviewed	5	6	5	9	7
Mean Score	14.4	14.6	15.4	14.8	15.0

The null hypothesis, H0: $u_1 = u_2 = u_3 = u_4 = u_5$, is also tested at the 0.25 level of confidence.

TABLE IV-6

ANALYSIS OF VARIANCE: PHYSICS

Source	df	MS	F
Between Groups	4	0.725	0.286
Within Groups	30	2.533	

The table value for an F-distribution with 4 and 30 degrees of freedom at an alpha of 0.25 is 1.42. The obtained F value of 0.286 is less than the table value, therefore, this null hypothesis is accepted.

All three null hypotheses were accepted. The conclusion was then made that the interviewer scored each sample consistently.