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RELATIONSHIPS AMONG M-POWER, TEACHING METHODOLOGY, COGNITIVE DEVELOPMENT, AND CONTENT ACHIEVEMENT

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RELATIONSHIPS AMONG M-POWER, TEACHING METHODOLOGY COGNITIVE DEVELOPMENT, AND CONTENT ACHIEVEMENT

A DISSERTATION

PRESENTED TO

THE FACULTY OF THE COLLEGE OF EDUCATION

THE UNIVERSITY OF OKLAHOMA

In Partial Fulfillment

of the Requirements for the Degree of

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BY

ROGER K. PURSER

1980

RELATIONSHIPS AMONG M-POWER, TEACHING METHODOLOGY, COGNITIVE DEVELOPMENT, AND CONTENT ACHIEVEMENT

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RELATIONSHIPS AMONG M-POWER, TEACHING METHODOLOGY, COGNITIVE DEVELOPMENT, AND CONTENT ACHIEVEMENT

CHAPTER I

INTRODUCTION

In recent years the low performances of high school graduates on college entrance exams has provided the stimulus for a renewed examination of the efficacy of various curricular activities. Insofar as programs in science are concerned, the need for providing hands-on laboratory activities for each student has been particularly debated.

On one extreme, Ausubel has inferred that laboratory experiences take so much time that they should be used only occasionally in order to portray the "method and spirit of science."[1] In his opinion, the higher priority should be the "systematic transmission of an organized body of knowledge."[2] Ausubel has even gone so far as to say that the raw data generated in an experiment are confusing to the students. Educators committed to this traditional outlook generally agree with the point of view that didactic verbal transmission of the organized data is ordinarily

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[1] David P. Ausubel, "Some Psychological Considerations in the Objectives and Design of an Elementary-School Science Program," Science Education, Vol. 47, Issue 3, (April, 1963), pp. 278-284.

[2] Ibid.

the most preferred teaching method.

Proponents of the Piagetian theory base, on the other hand, insist that time spent with concrete materials is valuable for at least two important reasons. First, it helps students develop understandings of concepts as they organize raw data themselves. Second, these concrete experiences are helping the students to develop certain types of thought processes, such as the ability to use proportional reasoning and to separate and control variables.

Recent research by Case[3] indicates that the size of a subject's working memory, or M-power, is also involved in developing both cognitive processes and specific concepts.

The purpose of this investigation has been to gather data with which to explore the relationships among M-power, cognitive development, content achievement, and instructional methodologies. The investigation considers two specific methodologies - concrete and formal. A concrete teaching methodology provides a wide background of concrete, hands-on experiences for each student and then encourages each student to take an active role in interpreting the meanings of those experiences. In contrast, formal teaching methodology uses traditional didactic exposition of an exhaustive body of concepts and information. The occasional laboratory demonstration used with this instructional method is typically done by the teacher and provides verification of a concept explanation which either the

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[3] Robbie Case, "Piaget and Beyond: Toward a Developmentally Based Theory and Technology of Instruction," Advances in Instructional Psychology, Vol. 1, Robert Glaser, ed. (Hillsdale, New Jersey: Lawrence Erlbaum Assoc., 1978), pp. 195-201.

teacher or the text had previously provided. Both teaching methodologies are considered in greater detail in Chapter III.

The Statement of the Problem

What are the relationships which exist among M-power, teaching methodologies, the rate of transition from concrete to formal operational thought, and achievement in specified concrete and formal science concepts?

The Definitions of Terms

For the convenience of the reader, a compendium of terms and their specific meanings for this investigation has been provided.

Action. An action is a system of coordinated movements functioning for a result or an intention.[4]

Scheme. A scheme, according to Piaget, is whatever is repeatable and/or generalizable.[5] According to Philips, a scheme is that property of an action which can be generalized to other contents.[6]

Figurative schemes. Figurative schemes are schemes that represent facts, states, or meanings.[7]

Operative schemes. Operative schemes are schemes that operate on one set of figurative schemes and that generate as products a new figura-

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[4] Jean Piaget, The Child and Reality, (New York: Grossman Pub., 1972), p. 63.

[5] ______, "Genetic Epistemology," Columbia Forum, Fall, 1969, p. 5.

[6] John L. Phillips, Jr., The Origin of Intellect: Piaget's Theory, Second Edition, (San Francisco: W.H. Freeman & Co., 1975), p. 11.

[7] Case, op. cit., p. 186.

tive scheme or set of schemes.[8]

Executive schemes. Executive schemes are schemes that serve a control function - that is, schemes that represent the series of operations a subject intends to execute in order to get from one figurative state to another.[9]

M-power. M-power is the maximum number of independent schemes that can be attended to at any moment in the absence of direct support from the perceptual field.[10]

> Although this construct is very similar to short-term memory (STM), several important differences should be noted. From a theoretical point of view, STM is defined in terms of external responses, not internal schemes; thus, schemes triggered by sensory (e.g., acoustic) effects would be counted in STM estimates, whereas they would not be counted in estimates of M-power. From an empirical point of view, tests of STM would require only that subjects perceive and reproduce a number of units. Tests of M-power would also require that the units be transformed in some fashion. The distinction is thus akin to the one between short-term memory and operating memory.[11]

Structures. Structures are those "mental data processing procedures"[12] which transform sensory information from the environment in a way which allows it to be mentally assimilated.

Mental operations. Mental operations are means for mentally trans-

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[8] *Ibid.*

[9] *Ibid.*

[10] *Ibid*, p. 195.

[11] M.I. Posner, "Short Term Memory Systems in Human Information Processing," *Attention and Performance I.*, A.F. Sanders, ed. (Amsterdam: North Holland, 1970).

[12] John W. Renner and Donald G. Stafford, *Teaching Science in the Elementary School*, Third Edition, (New York: Harper & Row, 1979), p. 50.

forming data about the real world so they can be organized and used selectively in the solution of problems.[13]

> Knowledge is not a copy of reality....To know an object is to act upon it. To know is to modify, to transform the object, and to understand the way the object is constructed. An operation is thus the essence of knowledge; it is an interiorized action.[14]

Cognitive development. Cognitive development is the development of the ability to think. This development proceeds by continued (quantitative and qualitative) modification of the cognitive structures.[15]

Concrete operations. Concrete operations is Piagetian terminology for the qualitative stage of thought characterized by the emergence of mental actions which can return to their starting points, can be integrated with other reversible actions, and are dependent on physical objects.

Formal operations. Formal operations is the qualitative stage of thought characterized by the emergence of propositional logic or hypothetical reasoning.[16]

> The adolescent...takes the results of concrete operations, casts them in the form of propositions, and then proceeds to operate further upon them, i.e., make various kinds of logical connections between them. Formal operations, then, are really operations performed upon the results of prior (concrete) operations.[17]

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

[14] Jean Piaget, "Development and Learning," The Journal of Research in Science Teaching, Vol 2, Issue 3, 1964, pp. 176-186.

[15] John W. Renner and Donald G. Stafford, Teaching Science in the Secondary School, (New York: Harper & Row, 1972), p. 78.

[16] Inhelder and Piaget, loc. cit.

[17] J.H. Flavell, The Developmental Psychology of Jean Piaget, (New York: Van Nostrand Reinhold, 1963), p. 205.

Concrete instruction. Concrete instruction is defined as a consistent teaching methodology growing out of the philosophical commitment that the primary purpose of public education is the maximum development of each individual's ability to think. Further, that methodology must be consistent with the following research findings:

1. A great majority of public school children begin to enter the concrete operations stage of thought shortly after entering the K-12 sequence.[18,19]

2. Concrete operational students can fully understand only those concepts whose meaning can be developed from first hand experience with objects or events. They cannot fully understand hypothetical, "abstract" concepts.[20]

3. Adolescents do not completely enter the formal operational stage of thought unless they are allowed to personally interpret some minimum quantity and quality of concrete experience.[21,22,23]

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[18] Jean Piaget, *The Psychology of Intelligence,* (Paterson, New Jersey: Littlefield, Adams, 1963), p. 147.

[19] John W. Renner, et. al., *Research, Teaching, and Learning with the Piaget Model*, (Norman, Okla.: University of Oklahoma Press, 1976), p. 46.

[20] Anton E. Lawson and John W. Renner, "Relationships of Science Subject Matter and Developmental Levels of Learners," *Journal of Research in Science Teaching*, Vol. 12, No. 4, 1975, pp. 351-353.

[21] Inhelder and Piaget, *op. cit.*, p. xxii.

[22] Renner, et. al., *op. cit.*, p. 89.

[23] Lawrence Kohlberg and Carol Gilligan, "The Adolescent as Philosopher: The Discovery of the Self in a Postconventional World," *Daedalus: Journal of the American Academy of Arts and Sciences*, Vol. 100, No. 4, (Fall, 1971), pp. 1051-1086.

As mentioned earlier, these considerations, in general, result in a pattern of instruction which could be characterized as first hand exploration, with students not only being allowed to interact with the materials and problems representative of a content area, but also being led to inductively interpret and expand the meanings of their own experiences.

A more specific discussion of the day-to-day implementation of concrete instruction in the area of biology follows in the experimental design section.

Formal instruction. Formal instruction may be defined as a teaching methodology consistently based on a philosophical commitment that the primary purpose of public education is the transmission of an exhaustive body of information, thereby giving the students the perspective they need to understand and accept the value of their culture as well as their roles in it. Further, the general methodology used to transmit information is based upon the most efficient means available.

The assumption is made with formal instruction that the student is capable of postulatory-deductive reasoning, no matter what the student's maturational level. The overall approach to information transmission methods is predominantly postulatory-deductive exposition since "hands-on," inductive methods are, according to this teaching procedure, more time consuming.

A more specific discussion of the day-to-day implementation of formal instruction in the area of biology follows in the experimental design section.

Abbreviations

Several of the instruments used to gather data necessary in this research investigation have somewhat lengthy titles. For convenient reference, a list of commonly used abbreviations for those instruments has been provided below. These instruments are described more completely in Chapter III.

CAP is the abbreviation used for the Cognitive Analysis Project's[24] index of cognitive development.

GEFT is the abbreviation used for the *Group Embedded Figures Test*.

FIT is the abbreviation used for the *Figural Intersection Test*.

BDS is the abbreviation used for the *Backward Digit Span Test*.

The Subproblems

1. *The first subproblem.* The first subproblem was to determine whether a correlation exists between M-power and success on Piagetian task scores, as measured by the CAP written index of cognitive development.

2. *The second subproblem.* The second subproblem was to determine whether correlations exist between M-power and success on examination questions involving concrete biology content and formal biology content.

3. *The third subproblem.* The third subproblem was to determine whether 14-16 year old students taught Biology I concretely have a pattern of growth in M-power different from that of subjects taught biology formally.

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[24] John W. Renner, "The Relationships Between Intellectual Development and Written Responses to Science Questions," *Journal of Research in Science Teaching*, 1979, Vol. 16, No. 4.

4. The fourth subproblem. The fourth subproblem was to determine whether 14-16 year old students who are taught Biology I concretely have a pattern of cognitive development different from that of subjects taught biology formally.

5. The fifth subproblem. The fifth subproblem was to determine whether 14-16 year old students taught Biology I concretely have a pattern of achievement on specified concrete and formal biology concepts different from that of subjects taught biology formally.

The Hypotheses

1. H_A: High school Biology I students' scores on the CAP's indicator of cognitive development correlate positively with their respective scores on two tests of M-power, the FIT and the BDS.

   H_O: No correlation exists between high school Biology I students' scores on the CAP's indicator of cognitive development and either the FIT or BDS test of M-power.

2. H_A: High school Biology I students' scores on teacher-made tests of specified concrete or formal biology concepts correlate positively with their respective scores on two tests of M-power, the FIT and the BDS.

   H_O: No correlation exists between high school Biology I students' scores on teacher-made tests of specified biology concepts and either the FIT or the BDS test of M-power.

3. H_A: High school students taught Biology I concretely have a different pattern of M-power development, as measured by the FIT and the BDS, than students taught formally.

   H_O: There are no differences between the mean M-power development scores of concretely taught high school Biology I students and formally taught students.

4. H_A: High school students taught Biology I concretely have significantly greater cognitive development, as measured by the CAP tasks, than students taught formally.

   H_O: There are no differences between the mean cognitive development scores of concretely taught high school Biology I students and formally taught students.

5. H_A: High school students taught Biology I concretely have significantly greater achievement on specified concrete and formal biology concepts, as measured by teacher-made examinations, than students taught formally.

   H_O: There are no differences between the mean concrete or formal concept achievement scores of concretely taught high school Biology I students and formally taught students.

The Assumptions

At the start of the investigation, several assumptions were made. Data gathered during the investigation provided evidence in favor of accepting each assumption.

The first assumption. A substantial majority of the 14-16 year old students in the Biology I sample would begin the school year using concrete operational thought processes.

The second assumption. Each student's M-power and cognitive stage placed ceilings on his/her ability to correctly interpret specific experiences.

The Delimitations of the Investigation

Generalizations of the results of this investigation must be made in view of the limiting factors listed below.

The study was limited to first year biology students attending high school in a suburban, predominantly Caucasian community in the state of Oklahoma.

The study did not attempt to predict the success, as measured by teacher-assigned grades, of first year biology students.

The different methods of instruction were administered by two different teachers.

The study neither determined nor evaluated the professional preparations or competencies of the two teachers administering the respective teaching treatments.

The statistical data used in the study were derived from instruments that could be conveniently administered to groups of students, rather than being administered individually.

CHAPTER II

REVIEW OF RELATED LITERATURE

Background of the Investigation

Beginning in the late 1950's, Russian advances in missile technology stimulated a comprehensive review of all aspects of American education. In particular, the renovation and updating of educational goals and curricula became a national priority. Jerome Bruner was one of a group of educators who met at Woods Hole, Massachusetts, to initiate a new orientation for curriculum development. Although this orientation began with science, it slowly broadened to include other disciplines as well. In *The Process of Education*, Bruner said that the main objective of new curricula should be to present "subject matter effectively - that is, with due regard not only for coverage but also for structure."[1]

This attitude differed from the previous curricula. The new emphasis was to be on the "structure" of a discipline, with structure being interpreted as the manner in which the elements of a discipline

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[1] Jerome S. Bruner, *The Process of Education*, (Cambridge, Massachusetts: Harvard University Press, 1960), p. 2.

were organized and related to each other. Bruner maintained that understanding the structure of a discipline would not only facilitate learning the associated concepts but also promote understandings of how the knowledge within that discipline changed over a period of time. Processes such as "inquiry," "discovery," and "problem-solving" evolved as the primary curricular means for achieving this understanding of structure in the sciences and, to a lesser degree, some other disciplines. In particular, the epistemology of Jean Piaget began to emerge as the paradigm on which inquiry instruction is based.

A decade later, Jerome Bruner himself looked at the educational flux of the 1960's and reflected, "...we realize that The Process of Education was the beginning of a revolution, and one cannot yet know how far it will go. Reform of curriculum is not enough."[2]

At about the same time, Charles Silberman, who had just completed a three-year study of education, reached the same conclusion as Bruner. In his book, Crisis in the Classroom, Silberman found the majority of educators were well-meaning, intelligent people, but people who had not thought seriously enough about the purposes of education or what they were really accomplishing in the classroom. In one of many passages on the same theme, he expressed this idea.

> This mindlessness--the failure or refusal to think seriously about educational purpose, the reluctance to question established practice--is not the monopoly of the public school; it is diffused

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[2] _______, "The Process of Education--Reconsidered," Dare to Care/Dare to Act: Racism and Education, Robert R. Leeper, ed. (Washington, D.C.: Association for Supervision and Curriculum Development, 1971), p. 30.

> remarkably evenly throughout the entire educational system, and indeed the entire society.
>
> If mindlessness is the central problem, the solution must lie in infusing the various educating institutions with purpose, more important, with thought about purpose, and about ways in which techniques, content, and organization fulfill or alter purpose.[3]

Silberman's statement should not be taken to mean that American educational leaders had failed to identify the proper purposes of public education. In fact, in 1961, the Educational Policies Commission had stated very succinctly that the central purpose of education is "the development of the ability to think."[4] That commission further provided an operational definition of thinking and inferred a methodology for reaching this goal. In their own words, "The rational powers are...the essence of the ability to think....The development of this ability depends ...on methods that encourage the transfer of learning from one context to another and the reorganization of things learned."[5]

The "crisis" to which Silberman refers, however, springs from the failure of professional educators to translate those goals into practice. Although the era of rapid curriculum change is largely over at this point, science educators must still selectively implement the available curricular materials with the aim of achieving the purposes of education. As Bybee

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[3] Charles Silberman, Crisis in the Classroom, (New York: Random House, Inc., 1970), p. 11.

[4] Educational Policies Commission, The Central Purpose of American Education, (Washington, D.C.: National Education Association, 1961), p.12.

[5] Ibid, pp. 4-5.

put it, "As science teachers, we need both good curriculum materials and good instruction."[6]

One of the most widely known components of Jean Piaget's theories of intellectual development is that the child thinks in qualitatively different terms than adults. For the most part, however, science educators have continued to ignore the research findings which have a direct bearing on facilitating cognitive development in the classroom. Lawson and Renner, for example, found that students using those patterns of reasoning which Piaget calls concrete operational could only understand thirty percent of the concrete operational concepts presented and few or none of the abstract, formal operational concepts.[7] Yet, when samples of the typical high school science texts were analyzed for content level, numerous investigators have found the content to be mostly formal operational, whereas most of the students were found to be only concrete operational.[8,9,10,11]

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[6] Roger W. Bybee, Personalizing Science Teaching, (Washington, D.C.: National Science Teachers Association, 1974), p. 1.

[7] Anton E. Lawson and John W. Renner, "Relationships of Science Subject Matter and Developmental Levels of Learners," Journal of Research in Science Teaching, 1975, Vol. 12, No. 4, p. 347.

[8] Leticia B. Bautista, The Relationship Between Intellectual Levels and Achievement in the Comprehension of Concepts Classified According to a Scheme Derived from the Piagetian Model, Unpublished Doctoral Dissertation, University of Oklahoma, 1974.

[9] Norris H. Grant, The Validity of Objective Testing as a Process of Appraising the Thinking Ability of Students in High School Biology and Physics, Unpublished Doctoral Dissertation, University of Oklahoma, 1974.

[10] Linda M. Johnson, Biology Concepts Taught Compared to the Intellectual Level of the Biology Student, Unpublished Masters Thesis, University of Oklahoma, 1975.

[11] Rosalie Grant, Group and Individual Problem Solving High School Students, Unpublished Doctoral Dissertation, University of Oklahoma, 1978.

The research findings of Marek show that concrete operational biology students taught with concrete instructional practices made significant gains in both cognitive development and content achievement when compared to a control group.[12] In addition to this study, other investigations with other content areas and age groups have demonstrated similar findings.[13,14,15,16] Yet, many science teachers have failed to ever seriously attempt teaching concrete operational students with identifiable concrete instructional practices.

Pascual-Leone recently theorized that a child's working memory or M-power can place substantial restrictions on his ability to solve problems.[17] The research findings of Case[18] have not only lent support

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[12] Edmund A. Marek and John W. Renner, "Intellectual Development, IQ, Achievement, and Teaching Methodology," The American Biology Teacher, 1979, Vol. 41, No. 3, pp. 145-150.

[13] Don G. Stafford and John W. Renner, "SCIS Helps the First Grader to Use Logic in Problem Solving," School Science and Mathematics, February, 1971, pp. 159-164.

[14] John W. Renner, et. al., Research, Teaching, and Learning with the Piaget Model, (Norman, Okla.: University of Oklahoma Press, 1976), pp. 79-89.

[15] Joe W. McKinnon and John W. Renner, "Are Colleges Concerned with Intellectual Development?" American Journal of Physics, 1971, Vol. 39, No. 9, pp. 1050-1052.

[16] Livingston S. Schneider, Relationships Between Concrete and Formal Instructional Procedures and Content-Achievement, Intellectual Development, and Learner IQ, Unpublished Doctoral Dissertation, University of Oklahoma, 1977.

[17] Juan Pascual-Leone, Cognitive Development and Cognitive Style, Unpublished Doctoral Dissertation, University of Geneva, 1969.

[18] Robbie Case, "Validation of a neo-Piagetian Capacity Construct," Journal of Experimental Child Psychology, 1972, Vol. 14, pp. 287-302.

to Pascual-Leone's idea, but also shown that selected experience may help the student overcome M-power restrictions and solve specific problems.[19]

Once again, however, many educators continue to see their responsibility as efficiently "covering" the majority of the concepts from the available text, with little regard as to who understands the information and who does not.

It would obviously be demanding much of teachers to ask them to evaluate many research findings on both instructional practices and psychological factors which limit learning and then synthesize a comprehensive, appropriate system of instructional techniques. Out of the Science Curriculum Improvement Study has evolved one approach to science instruction, however, which has, thus far, proven to be consistent with both the purposes of education and the structure of science. This approach is often described as the "learning cycle."[20]

One purpose of this investigation, therefore, has been to bring to the attention of pre-service and in-service educators a detailed description of the learning cycle, which follows in the design portion of the paper. Another purpose of this investigation was to elaborate the relationships among M-power, instructional methodology, cognitive development, and achievement in selected concrete and formal content so that the

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[19] ______, The Process of Stage Transition in Cognitive Development, (Berkeley: University of California, 1977).

[20] John W. Renner and Donald G. Stafford, Teaching Science in the Elementary School, Third Edition, (New York: Harper & Row, 1979), pp. 144-151.

reader may better evaluate the efficacy of the learning cycle as compared to his/her own instructional style.

Theoretical Framework of the Investigation

"Before one human being, the teacher, can teach another, the learner, the teacher must know how the learner learns and what he can learn."[21]

According to Jean Piaget, an individual may pass through four qualitatively distinct phases of intellectual development during a lifetime. The first of these four stages of thought quality extends from birth to around two years and is called the sensori-motor period. During this time, Lawson says the child's "major objective is to learn about objects and their spatial relationships.[22] It is also Lawson's opinion that from age two to about seven, the child primarily develops an understanding of symbols and their conventional meanings. This time is known as the pre-operational stage of intellectual development. The third stage is labeled concrete operations since the child begins to perform mental, reversible actions based on understandings of classes, relations, and quantities. As the label concrete operations suggests, however, these mental operations must originate with concrete objects or personal experiences.

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[21] John W. Renner, "Learning, Motivation, and Piaget," Engineering Education, March, 1974, p. 416.

[22] Anton Eric Lawson, Relationships Between Concrete and Formal Operational Science Subject Matter and the Intellectual Level of the Learner, Unpublished Doctoral Dissertation, University of Oklahoma, 1973, p. 11.

The highest stage of thought quality is less dependent upon concrete experience. Here the child develops the ability to operate on propositions as if they were reality. He sees implications and, in Piaget's words, "thinks beyond the present and forms theories about everything, delighting especially in considerations of that which is not."[23] His departures from reality are based on logic, however, not fantasy, and use a characteristic form, thus giving this stage the label formal operations.

Flavell has said that the overall effect of such formal operations is to imbue in people what he describes as:

> ...not so much this or that specific behavior as it is a generalized orientation, sometimes explicit and sometimes implicit, towards problem solving, an orientation towards organizing data (combinatorial analysis), towards isolation and control of variables, towards the hypothetical, and towards logical justification and proof.[24]

In the year 1961, the Educational Policies Commission inferred that this problem solving orientation results, at least in part from the well developed "rational powers" of "...recalling and imagining, classifying and generalizing, comparing and evaluating, analyzing and synthesizing, and deducing and inferring."[25] In their own words, "these processes enable one to apply logic and the available evidence to his ideas,

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[23] Jean Piaget, The Psychology of Intelligence, (Paterson, New Jersey: Littlefield, Adams, 1963), p. 148.

[24] J.H. Flavell, The Developmental Psychology of Jean Piaget, (New York: D. Van Nostrand, 1963), p. 211.

[25] Educational Policies Commission, loc. cit.

attitudes, and actions, and to pursue better whatever goals he may have."[26]

As an end product of intellectual development then, one arrives at an individual who is not only capable of the use of logical thought processes with propositions but also insists upon the use of logic and available evidence in the solution of problems. The attainment of that capability and orientation in as many students as possible is the central purpose of education as defined by the Educational Policies Commission. Although they identified several other purposes as worthy, legitimate outcomes of learning, they pointedly stated,

> The purpose which runs through and strengthens all other educational purposes - the common thread of education - is the development of the ability to think.
>
> Upon (the rational powers) depends (a student's) ability to achieve his personal goals and to fulfill his obligations to society.
>
> The rational powers are the...essence of the ability to think.
>
> In this context, therefore, the development of every student's rational powers must be recognized as centrally important.[27]

Of primary concern to the educator is that the child probably does not automatically enter into formal operational thought. Piaget has said that a child has the maturational capacity to enter this stage as early as age eleven or twelve.[28] Nonetheless, research has shown

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[26] Ibid, p. 5.

[27] Ibid, pp. 4-12, (parentheses added).

[28] Piaget, op. cit., p. 123.

that the majority of high school students and about half of a typical sample of undergraduate college students are still concrete operational.[29,30] As Piaget and his associate, Inhelder, have themselves stated,

> A particular social environment remains indispensable for the realization of these possibilities. It follows that their realization can be accelerated or retarded as a function of cultural and educational conditions.[31]

The main thrust of Piaget's theory is structural instead of functional. As Case has pointed out, Piaget's primary concern has been to describe "the systems of logical operations that children possess at different points in their development, not to provide a psychological description of the processes by which these operations are acquired and utilized."[32] Two major questions are thus left to be answered in detail by any theory of instruction which is based on Piaget. The first is how to promote cognitive development in the learner. The second is how to adapt the instruction of culturally valued skills and concepts to the operational level of the learner.

Piaget has suggested that there are four factors which influence the rate of a child's progress through the first three phases of cognitive development. These are maturation, physical experience, social interaction,

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[29] Renner, et. al., _op. cit._, pp. 90-109.

[30] _Ibid_, pp. 110-129.

[31] Barbel Inhelder and Jean Piaget, _The Growth of Logical Thinking from Childhood to Adolescence_, (New York: Basic Books, Inc., 1958), p. 337.

[32] Robbie Case, "Piaget and Beyond: Toward a Developmentally Based Theory and Technology of Instruction," _Advances in Instructional Psychology_, Vol 1, Robert Glaser, ed. (Hillsdale, New Jersey: Lawrence Erlbaum Assoc., 1978), p. 177.

and equilibration.[33] He further contends that none of the first three factors is sufficient by itself to account for the move from one stage of thought processes to anything higher. Disequilibration and equilibration are thus deemed necessary for substantial cognitive development.

In contrast to traditional learning theory, Piaget views learning as more than just an accumulation of associations. In addition to the gradual accumulation of isolated "schemes," Piaget's theory infers an intermittent revision of the relationships that are drawn among them. The process by which "structures," i.e. hierarchical arrangements of schemes, are revised is referred to as "equilibration" by Phillips.[34]

Again, since Piaget is more concerned with describing the stages of cognitive development than the mechanisms for transitions from one stage to another, his writings are rather vague concerning what is specifically involved in equilibration processes. According to Case, Piaget does make it clear that these processes involve a "reflection on the adequacy of the current set of operations and on experimentation with new operations."[35] This reflection on the adequacy of his current set of operations may be initiated by the learner's perceiving some anomaly from his environment, but the mental search for adequate explanations is a continuing, active process. As Phillips has described it,

> Structures continually move toward a state of equilibrium, and when a state of relative equilibrium has been attained,

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[33] Jean Piaget, "Development and Learning," The Journal of Research in Science Teaching, Vol. 2, Issue 3, 1964, pp. 176-186.

[34] John L. Phillips, Jr., The Origin of Intellect: Piaget's Theory, Second Edition, (San Francisco: W.H. Freeman & Co., 1975), p. 14.

[35] Case, "Piaget and Beyond," op. cit., p. 170.

> the structure is sharper, more clearly delineated, than it had been previously. But that very sharpness points up inconsistencies and gaps in the structure that had never been salient before. Each equilibrium state therefore carries with it the seeds of its own destruction.[36]

A child thus begins life, according to Piaget, with a simple repertoire of action schemes. Through equilibration interacting with experience and maturation, the initial repertoire gradually becomes more differentiated and coordinated. Case has identified the Piagetian stages of cognitive development as those points in the child's life when the repertoire of schemes is so coordinated and interdependent as to give them the property of an organized system.[37]

One contribution of computer simulation to the study of cognitive development was Simon's suggestion that the series of Piagetian stages may be modeled as a series of "increasingly complex and powerful executive strategies."[38] Extending this model, Pascual-Leone theorized that two factors are responsible for such progressions of complexity: experience with the strategy in question and an increase in the size of the working memory or M-power.[39]

In the context of Pascual-Leone's identification of working memory size as a factor involved in Piagetian stage transition, Case has

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[36] Phillips, op. cit., p. 10.

[37] Case, "Piaget and Beyond," loc. cit.

[38] H. A. Simon, "An Information Processing Theory of Intellectual Development," Thought in the Young Child, W. Kessen & C. Kohlman, ed., Society for Research in Child Development Monographs, 1962, pp. 150-155.

[39] Pascual-Leone, loc. cit.

postulated the following details for equilibration:[40]

1. Whenever two incompatible schemes are activated, the learner experiences "disequilibration" or cognitive conflict.

2. Upon being disequilibrated, the learner temporarily abandons his current executive scheme and initiates a search for more information so as to resolve the conflict.

3. The mental search for other relevant information takes place in discrete steps, each of which takes a certain amount of time before the next is started.

4. Each mental step consists of either the memory retrieval of one or more figurative schemes representing facts, states, or meanings or the generation of a new, figurative scheme by an operative scheme.

5. The number of schemes that can be coordinated in a single mental step is limited by two factors. First the number of schemes which can be activated by something in a person's perceptual inputs is limited by the size and sensitivity of that person's perceptual field. Second, the number of schemes which can be recalled in any one mental step, i.e. M-power, is also limited. Recall of any scheme from memory, without support from the perceptual field, requires the person to exert mental effort to activate and then maintain the scheme. Since the amount of mental energy available for this at any one moment is limited, the number of schemes which can be recalled is, therefore, limited as well.

6. In resolving conflicts between two incompatible schemes, the learner will favor the response congruent with the greatest number of

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[40] Case, "Piaget and Beyond," op. cit., p. 189.

currently activated schemes if a new figurative scheme is not generated.

7. After practice, the sequence of steps by which cognitive conflict has been resolved is consolidated as a new strategy or executive strategy, which is automatically activated on subsequent trials. Equilibration has, therefore, occurred.

The maximum number of independent schemes that can be successfully coordinated from memory at any one moment and used in the solution of a specific mental task is referred to as the subject's working memory, or M-power.[41] According to Pascual-Leone, M-power increases linearly as a function of age, reaching a maximum when the subject reaches approximately 15-16 years of age.[42]

Not all disequilibrations require the learner's maximum M-power. For many facilitating tasks, the necessary M-power is thought to be only two schemes. Whenever the accommodation of an anomaly demands more M-power than the learner has available, the M-power becomes a limiting factor on understanding.[43]

For example, Phillips defines "conservation" as the subject's realization that certain properties of a system remain the same in spite of transformations performed within the system.[44] A common Piagetian task

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[41] Anton E. Lawson, "M-Space: Is It a Constraint on Conservation Reasoning Ability?" Journal of Experimental Child Psychology, Vol. 22, 1976, p. 41.

[42] Ibid, pp. 40-41.

[43] Case, "Piaget and Beyond," op. cit., p. 183.

[44] Phillips, op. cit., p. 97.

for assessing conservation of continuous quantity involves the filling of two identical beakers with equal amounts of water. The water from one beaker is then poured into a tall, thin graduated cylinder. In order for a subject to then realize that the amounts of liquid are still the same, Case predicted that he must be able to coordinate three schemes at the same moment - one scheme to represent the initial equality of the amounts of liquid in the two beakers, one to represent the act of pouring, and one to represent the rule that pouring does not change quantity.[45] It has been shown that children do not normally activate three schemes at one time until the age at which conservation reasoning is attained.[46] M-power has also been seen to correlate positively with various conservation tests even after age has been partialed out.[47]

Lawson's results, however, did not always support Pascual-Leone's contention that M-power is a necessary condition for solving a Piagetian task at the normal age level and under normal learning conditions.[48] A "large percentage" of the subjects whose M-power measured less than the ability to coordinate three schemes at the same moment were seen by Lawson

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[45] Case, "Piaget and Beyond," *op. cit.*, p. 181.

[46] Juan Pascual-Leone, "A Mathematical Model for the Transition Rule in Piaget's Developmental Stages," *Acta Psychologica*, Vol. 63, 1970, pp. 301-345.

[47] Robbie Case, "Responsiveness to Conservation Training as a Function of Induced Subjective Uncertainty, M-space, and Cognitive Style," *Canadian Journal of Behavioral Science*, Vol. 9, 1977, pp. 12-26.

[48] Lawson, "M-Space," *op. cit.*, pp. 40-45.

to demonstrate conservation reasoning in a "normal" classroom, without prior training on the Piagetian tasks.

Lawson considered the possibility that the Backward Digit Span test of M-power might not test a subject's maximum M-power under all situations. He further reasoned that task analysis of the maximum M-demand necessary for specific tasks might not yield the same figurative scheme estimates for different investigators or might not actually be the reasoning patterns used by the subjects in solving the task.[49]

Regardless of the specific number of schemes which must be activated to succeed on a particular task, Pascual-Leone has postulated that the learner's M-power is dependent primarily on factors such as maturation or general experience and is independent of the effects of specific experience.[50] Research has shown that a few specific experiences usually produce little effect on cognitive growth.[51] This is not unexpected if cognitive development is viewed as a sequence of stages which stems from a succession of qualitatively distinct executive strategies. Such strategies continue unchanged until experience provides the disequilibrating stimulus of an anomaly to the student. Furthermore, the equilibration processes involve the student in a great deal of reflecting,

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[49] Ibid.

[50] Pascual-Leone, "A Mathematical Model," loc. cit.

[51] Barbel Inhelder, H. Sinclair, and M. Bovet, Learning and the Development of Cognition, (Cambridge, Mass.: Harvard University Press, 1974).

comparing, coordinating, and constructing. As Case puts it, "Because the task of cognitive reorganization is such a massive and fundamental one, Piaget assumes that there is a limit to how much acceleration of development can be expected by any sort of environmental manipulation."[52]

On the other hand, a broad background of concrete experience should effect cognitive growth. Using the Piagetian frame of reference, concrete operational subjects (which most public school children are) can only assimilate data from experience and then accommodate to it. They cannot operate on propositions. Personal, discrepant sensory experiences are thus necessary to trigger equilibration.

In the Pascual-Leone extension of the Piagetian model, equilibration is not possible whenever a task's greatest M-demand is larger than the subject's M-power. However, schemes which continue to be activated by sensory inputs from the subject's perceptual field are not counted in figuring a task's M-demand, since the mind does not have to exert mental effort to recall these schemes. Thus, although a subject's ability to profit from experience might be limited by his M-power, such limitations might be overcome when the subject's concrete experiences act so as to reduce the demands on his working memory.

This investigator hypothesized that, over a long enough period of time, subjects who were taught with many concrete experiences should equilibrate significantly more schemes than subjects taught with

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[52] Case, "Piaget and Beyond," op. cit., p. 170.

traditional lecture techniques. If cognitive development is viewed as a succession of qualitative revisions of the relationships drawn among schemes, then the group differences in equilibration activity should eventually produce significant differences between the two instruction groups in measures of both cognitive development and content achievement. This investigation, therefore, had the objective of gathering data to explore the nature of these postulated relationships among teaching methodologies, M-power, rate of cognitive development, and achievement in selected biology content.

CHAPTER III

PROCEDURES OF THE STUDY

Selection of the Subjects

In order to gather data to test the previously stated hypotheses, both an experimental group of students and a control group of students were required. These were selected from the Yukon Mid-High, Yukon, Oklahoma, a suburban school of over nine hundred ninth and tenth grade students.

Although Biology I is an elective subject at this school, most students typically fulfill their laboratory science graduation requirement with Biology I. For the 1979-80 school year, there were fourteen sections of Biology I.

The external validity of any findings from this investigation are founded on the assumption that the experimental group resembled the control group in as many characteristics as possible. Since randomization is the best technique for equalizing any differences between these groups, the administrators at Yukon Mid-High cooperated with the investigator's request for maximum randomization by computer of class assignments for Biology I for the 1979-80 school year. Science class sizes were also equalized with about twenty-five students being the norm. These administrators also cooperated by minimizing the number of student transfers between class sections. Only one student was transferred between the two instructional procedures, and this student was transferred within two weeks after the start of the school year.

Three sections of Biology I were assigned to the investigator as well as three sections to the other participating instructor. To avoid random errors in treatment as much as possible, all three sections for each teacher were used for data-gathering purposes. Individual students who were repeating Biology I were eliminated from consideration, as well as students missing more than twenty percent of the classes. For the group receiving concrete instruction, five students were subsequently eliminated from consideration, leaving sixty-eight students in the experimental group. Four students were likewise removed from the group receiving formal instruction, leaving sixty-seven students in the control group.

Instrumentation

This investigation proposed to identify the nature of postulated relationships among teaching methodology, M-power, the rate of cognitive development, and achievement in specified biology content. Upon assignment to one of the two instruction methodologies, each student was asked his or her chronological age in months for determining correlations among age, M-power, and cognitive development.

Cognitive development was measured by each student's performance on three written incidents developed by the Cognitive Analysis

Project (CAP),[1] in combination with the Group Embedded Figures Test (GEFT).[2] A regression equation developed by the CAP was then used to generate a single "cognitive development" score for each student.

More specifically, the CAP generated a set of written materials that could be administered to large groups and still provide individual scores having a substantial positive correlation with their scores on the individually administered, Piagetian task-interview which Lawson had earlier determined to be a valid measure of intellectual development.[3]

The three written incidents developed by the CAP and titled "The Shadows Problem" (S), "The Frog Problem" (F), and "The Geranium Problem" (G), were used to measure the formal operations of proportional reasoning as well as the separation and control of variables. The GEFT was used to discriminate between field dependent and field independent thinkers, which the CAP had also determined to be related to intellectual development.[4]

A student's separate scores on both the three incidents of the CAP and the GEFT were combined by a regression equation, developed by the CAP which yielded a single cognitive development score, called the "Entire

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[1] John W. Renner, "The Relationships Between Intellectual Development and Written Responses to Science Questions," *Journal of Research in Science Teaching*, Vol. 16, No. 4, 1979, pp. 284-293.

[2] Philip K. Oltman, Evelyn Raskin and Herman A. Witkin, *Group Embedded Figures Test*, (Palo Alto, Calif.: Consulting Psychological Press, 1971).

[3] Anton Eric Lawson, *Relationships Between Concrete and Formal Operational Science Subject Matter and the Intellectual Level of the Learner*, Unpublished Doctoral Dissertation, University of Oklahoma, 1973, pp. 28-30.

[4] Renner, *op. cit.*, p. 296.

Interview" or EI score. The regression equation is as follows:

$$EI = 0.17\ (GEFT) + 0.38\ (S) + 0.37\ (F) + 0.30\ (G) + 3.95$$

Normative data on this EI indicator of cognitive development have shown a standard error of 1.85 and a multiple correlation coefficient of .70 with students' Piagetian task-interview scores.[5] Grant recently established the validity of the EI score as a reliable measure of a student's level of cognitive development.[6]

In view of the finding of Lawson and Renner that formal operational thought is necessary to fully understand a formal operational concept,[7] instruments used for evaluating student content achievement should distinguish between success on concrete operational concept questions and success on formal operational concept questions. Lawson and Renner have defined concrete operational concepts as "concepts whose meaning can be developed from first-hand experience with objects or events."[8] They have defined formal operational concepts as "concepts whose meaning is derived through position within a postulatory-deductive (theoretical) system."[9]

The instruments to be used for evaluating content achievement were developed by the investigator. Before a test was administered, its

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[5] Ibid.

[6] Rosalie Grant, Group and Individual Problem Solving High School Students, Unpublished Doctoral Dissertation, University of Oklahoma, 1978.

[7] Anton E. Lawson and John W. Renner, "Relationships of Science Subject Matter and Developmental Levels of Learners," Journal of Research in Science Teaching, 1975, Vol. 12, No. 4, p. 348.

[8] Ibid.

[9] Ibid, (parentheses added).

criterion validity was considered. The investigator and John W. Renner used the previously listed criteria to identify which questions measured understanding of concrete concepts and which questions measured understanding of formal concepts. Since concrete operational students were not expected to understand formal concepts, that portion of each content achievement test which was identified as requiring formal operational thought was not used to assign student grades.

Both the Educational Policies Commission[10] and the Oklahoma Curriculum Improvement Commission[11] recognized that the higher values of education are reflected in the development of the student's ability to reorganize information and transfer learnings from one context to another. It was the investigator's judgment that questions measuring concept understandings require more of the student than the identification of concept labels. Otherwise, students could regularly provide, through memory, the correct labels for concepts they did not fully understand. Both formal and concrete content questions were therefore designed to emphasize the *applications* of information in new situations.

Since the content achievement instruments were constructed by the investigator, their content validity was established by *a priori* content validation of all test questions by a panel of at least the investigator, the cooperating instructor, and John W. Renner. The reliability of these

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

[11] Oklahoma Curriculum Improvement Commission, *The Improvement of Science Instruction in Oklahoma, Grades K-6*, (Oklahoma City: Oklahoma State Department of Education, 1968).

tests was estimated using the Kuder-Richardson formula 20 illustrated below.[12]

$$r_{tt} = \frac{n}{n-1} \times \frac{\sigma^2 t - \Sigma pq}{\sigma^2 t}$$

where, n = the number of items in the test

σ^2 = the variance

p = the proportion passing a question

$q = 1 - p$, the proportion failing a question

Reliability coefficients for each of the content examinations are presented in Table 3-1.

TABLE 3-1

KUDER-RICHARDSON TEST RELIABILITIES

Content Examination	r_{tt}
1 - Ecology	.79
2 - Energy Utilization	.82
3 - Energy Production	.63

M-power was measured for each student with two instruments. The first of these was the 1977 version (752) of the Figural Intersection Test (FIT),[13] a group administered paper and pencil test of M-power which has been used for adults as well as children. It required subjects to find the intersecting point of several simple figures which form a complex design as they overlap.

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[12] David Magnusson, Test Theory, (Reading, Mass.: Addison-Wesley Pub. Co., 1967), pp. 115-119.

[13] Juan Pascual-Leone, FIT - Figural Intersection Test: A Group Measure of M-Space, Unpublished manuscript, York University, 1977.

Pascual-Leone theorized that M-power normally increases linearly with age. In his opinion, the construct validity of the FIT has been established by examining the percentage of items of each degree of difficulty which have been passed by each of the several age groups he used for extimating M-power.[14]

More specifically, Pascual-Leone considered a subject to have performed successfully on a certain class of FIT items if he marked 75% of them correctly.[15] Using this 75% criterion, his research showed that most children of age seven passed class three. Most children of age nine passed class four. This trend continued until students reached age fifteen to sixteen, whereupon subject performance leveled off at the passing of class seven.[16]

The reliability estimates of the present revision of the FIT have not yet been determined by Pascual-Leone. He did, however, use the split-half method[17] to determine that previous versions of the FIT had an average reliability of .88.

A second measure of M-power was used in order to reduce measurement error possible from the large group-administered FIT. Case indicated that the size of a subject's backward digit span validly measures his level of M-power. His research showed its split-half reliability to be

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[14] ______, Manual for FIT, pp. 9-10.

[15] Ibid.

[16] Ibid.

[17] Ibid, p. 11.

.83.[18] The Backward Digit Span Test (BDS) was therefore used as a second measure of M-power, but problems developed with this test which are discussed in Chapter IV.

The procedure used to measure a student's backward digit span was to determine the highest number of digits the subject could repeat in reverse order before making two consecutive failures. As an adaptation for small group testing, both the instructions to the subjects and the examination series of random digits were tape recorded. The test was preceded by an instruction period which included several practice series. The rate of digit presentation was 1 - 1.5 seconds and each series was preceded by an auditory signal. The same tape recording was used for both pretests and posttests.

Description of the Treatment Procedures

Concrete Instructional Procedures

According to Piaget, people are constantly assimilating data from the environment. In order to assign meaning to these experiences, a person must have previously developed mental transformation processes or structures.[19] Thus, when some data are assimilated for which there are no structures, those data are not understood. At the point a person realizes he/she does not understand, however, his/her disequilibrium motivates the equilibration processes by which a new structure is constructed, probably

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[18] Robbie Case, "Validation of a neo-Piagetian Capacity Construct," Journal of Experimental Child Psychology, 1972, Vol. 14, pp. 287-302.

[19] John W. Renner and Donald G. Stafford, Teaching Science in the Elementary School, Third Edition, (New York: Harper & Row, 1979), p. 50.

by reconstructing existing structures. In Piagetian terms, the person accommodates to the new data. Further, any understanding developed as the person accommodates these data must be organized or brought into accord with previous understandings. The mental comparison processes not only organize an individual's understandings by modifying the previously existing mental structures as necessary, but also gradually develop higher quality thought processes as well. Certain assimilations, therefore, are desirable since they lead the student to accommodate and initiate an interdependent sequence of mental reorganizations which also help develop the student's ability to think.

One of the basic tenets of Piagetian learning theory is that a concrete operational student cannot assimilate data unless it is concrete, i.e. real objects or experiences.[19] If the student does not assimilate, then disequilibrations will not occur. Since the great majority of students in grades K-12 are concrete operational,[20] the Piagetian science teacher must therefore select and provide concrete experiences from the discipline of science which are appropriate for providing desirable disequilibrations.

In view of the time required to provide concrete experiences to each student, everything from a discipline such as biology cannot be included in any one particular course. The teacher using concrete instructional procedures must carefully decide what specific content to

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[19] John L. Phillips, Jr., The Origin of Intellect: Piaget's Theory, Second Ed., (San Francisco: W.H. Freeman & Co., 1975), p. 152.

[20] John W. Renner, et. al., Research, Teaching, and Learning with the Piaget Model, (Norman, Oklahoma: University of Oklahoma Press, 1976), pp. 90-109.

have the students interact with and think about. These representative ideas are judged by the following criteria:

1. Any idea chosen for classroom investigation must be one in which the learner is "given the chance to solve problems, to conjecture, to quarrel, as these are done at the heart of the discipline."[21] The reason for this is that activities such as these not only reflect the discipline of science but also develop the rational powers. In the words of the Oklahoma Curriculum Improvement Commission,

> Science is a natural vehicle with which to develop a child's ability to think objectively. In order to accomplish this goal, however, the emphasis in science teaching must shift from the teaching of "facts" to the development of a child's ability to observe carefully, collect information, and draw logical inferences. In other words, the child acquires his scientific information only through his own powers of observation and inductive inference.[22]

2. Theories and mathematical constructs must have their roots in the learner's prior personal investigations. In other words, the learner's involvement with the subject materials has to provide him with the mental structures needed for any theoretical work.

Assuming that an instructor wishing to use concrete instructional techniques has judged a particular idea to be representative and wants his/her students to develop understandings of it, he or she may then initiate that specific approach known as the learning cycle, which is based upon the Piagetian concepts of assimilation, accommodation, and organization.

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[21] Jerome S. Bruner, Toward a Theory of Instruction, (Cambridge, Massachusetts: Harvard University Press, 1966), p. 155.

[22] Oklahoma Curriculum Improvement Commission, op. cit., p. 1.

Phase one of the learning cycle encourages the entire class to interact with specified materials and experiences. This is time set aside for personal assimilations by each student. During this time, the teacher provides a minimum of instruction, although continuously maintaining safety as a prime consideration. If the teacher has provided a suitable environment for the group, there will be at least one potentially disequilibrating observation which is likely to be noticed by most of the class members.

In fact, this initial time of exploration is valuable for three reasons. First, it gives each student an opportunity to develop confidence in his/her ability to investigate with any unfamiliar materials. Second, it provides each student an opportunity to identify personal anomalies about the natural phenomena being investigated and to disequilibrate. Third, through his/her own equilibration processes and through socially interacting with the other students, the student may begin to accommodate some mental structures about the representative idea.

After a suitable amount of exploration time, the students reach a point where they need an organizing idea for the information they have assimilated. This second phase of the learning cycle is often referred to as conceptual invention since, at some point during their explorations, one or more students may spontaneously accommodate or invent their own explanations for their disequilibrating experiences. During this time, the teacher may suggest a way of presenting data which the students have gathered or focus the class discussion on particular hypotheses from various students but does not reject any rational explanations from any of the students. Again, in concrete instruction, it is the development of thought processes which is more important than the development of any currently accepted or text explanation. The concrete teacher encourages as many students as possible to accommodate or invent ideas for themselves. Whether or not any student makes the primary conceptual invention, however, the teacher may then meaningfully explain the concept and assign the proper language to it.

One distinguishing factor of this instructional approach is that the proper language for each concept is introduced, usually by the teacher, *after* the students have experienced the concept. This common language allows the students to better communicate their understandings of the concepts with each other and thus promotes the organization of new concepts in relation to previous understandings.

During the *expansion of the idea* phase of the learning cycle, the teacher provides further opportunities for the students to test the validity of their various conceptual inventions in contexts other than those situations which were used to develop the initial understandings. As the student assimilates new concrete experiences and materials, new disequilibrations result and previous explanations may have to again be modified in order to accommodate the additional data. It may thus be seen that the concrete instructional process is an ongoing cycle of assimilation, accommodation, and organization which reflects the nature of both science and the learning process while producing cognitive development, therefore, the name learning cycle.

Figure 3-1 presents a list of the specific functions of the teacher and the student throughout a typical learning cycle.

FIGURE 3-1

TEACHER AND LEARNER FUNCTIONS IN AN INQUIRY-CENTERED CLASSROOM[23]

	Teacher	Learner	
Exploration	1. Provides materials from environment and establishes minimal guidelines for exploration	Explores materials	Learner Feedback
	2. Questions learners individually to give directions; listens and observes	Investigates observed phenomena	
	3. Asks for report from class, and acts as moderator for report	Reports results of investigations and/or observations	
	4. Asks questions concerning meaning of data	Searches for patterns or generalizations in data; proposes hypotheses	
	5. Questions class concerning how hypotheses concerning patterns can be tested	Proposes experiments and tests hypotheses; observes and records related data	
Invention	6. Asks for report of tests. Provides labels for concepts developed in exploration; encourages use of *eye of mind* (i.e., What do you see in your mind?) to construct a model for explanation of patterns; discusses model(s) presently in widespread acceptance	Discusses concept or model invented as it applies to explorations completed	
Expansion	7. Provides materials for concept or model expansion	Enlarges concept or model through explorations guided by model or concept	
	8. Questions concerning interconcept relationships and their relationships to original materials provided	Grasps interconcept relationships and fits into developing structure of major conceptual scheme and doing so uncovers another missing piece in the conceptual puzzle and the exploration begins again	

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[23] John W. Renner, Don G. Stafford, and William B. Ragan, *Teaching Science in the Elementary School*, Second Edition, (New York: Harper & Row, 1973), p. 113.

There are times in the learning cycle when the teacher does provide information, explain data, or invent concepts. However, the lecture in this mode of instruction is used primarily to summarize whatever data the students have generated, redirect mistakes in their logic, or give encouragement. The student is always characterized in the learning cycle as an active participant in explaining his own experiences.

Formal Instructional Procedures

Formal instruction, on the other hand, uses traditional didactic exposition of an exhaustive body of concepts. This treatment is sometimes referred to as the lecture-demonstration method for science classes since the instructor may utilize demonstrations of experiments as well as simply lecture about a body of concepts. Such demonstrations, however, are done by the teacher or a student volunteer, and, as the name suggests, "demonstrate" the validity of a concept which has previously been explained in some form of exposition.

Lecture-demonstration methods may be referred to as formal instructional procedures because they operate on the assumption that the students involved are capable of assimilating propositional data and using postulatory-deductive reasoning systems with such data to achieve understandings of any desired concept. Piaget's theory says that only formal operational students can do this.[24]

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[24] Phillips, op. cit., p. 134.

In formal instruction, concepts which students have a difficult time understanding are made more accessible with pictures, diagrams, explanations of analogous situations, work sheets, and reading assignments, in addition to the aforementioned laboratory demonstrations. However, laboratory demonstrations are used infrequently because of their time-consuming nature. They are primarily used for building an appreciation of the working conditions of a scientist while providing a "prop" to better explain a few difficult concepts.

The role of the teacher in formal instructional procedures is predominantly one of the authority who, after selecting the concepts to be learned in any particular class, then transmits them in the least time-consuming manner, which is usually a lecture. The role of the student in formal instruction is usually that of the passive receiver of the content which the teacher transmits.

In general it should be noted that the first content the teacher transmits in formal instruction is the concept label. The teacher then uses this language to explain the concept, assuming, once again, that the students can assimilate propositional data and understand concepts defined in terms of other concepts, both of which are formal operations.

In contrast, it should again be noted that learning cycle instruction introduces the appropriate concept labels <u>after</u> the students have had ample opportunities to define or invent the selected concepts through their own hands-on experiences with concrete objects. Here concept language is primarily a tool with which students can communicate and organize understandings they have already reached.

Instructional Comparison on a Sample Concept

As a short example which contrasts the two teaching methodologies, assume that both types of teachers wish their students to know the values for the normal human body temperature in both degrees Fahrenheit and Celsius. The formal instructional teacher would simply tell the students, "Normal body temperature is 98.6°F or 37°C." Additionally, he might tell them that their personal temperatures may vary somewhat and do change slightly during the day. Finally, he might demonstrate this point with a thermometer to show them the information is correct. The students' primary responsibility is to memorize the information and identify it on a multiple choice or fill-in-the-blank written assignment.

In order for the concrete instructional teacher to have the students invent these concepts about body temperature for themselves, the teacher would begin the exploration phase by having all the students measure their own personal body temperatures using thermometers showing both °F and °C scales. Most students would disequilibrate over their finding that their personal temperature readings were neither the 98.6°F they had memorized from some previous science class nor the same values as their friends. The teacher would have them continue their exploration by again taking their body temperatures, but this time using different thermometers. Again they would probably disequilibrate over their finding that the two different thermometers gave different values.

Although some students may spontaneously invent the idea that 98.6°F is the average of the temperatures of many people when measured on many different thermometers, the instructor would promote this accomodation by having everyone in the class put his/her individual temperature readings in a data list on the chalkboard. Students would then be directed to average these values themselves which would help them to accommodate the 98.6°F/37°C normal body temperature concept.

To expand upon this idea, the students would further be directed to take their temperatures at several times during the following day and record them to share with the class. The combined class data would show a pattern whereby the normal temperature would be seen to rise and fall during the day. As a result of having mentally organized the temperature fluctuations, the concrete instructional student would not only have developed his cognitive processes, but also learned the same concepts in a personal way.

Sample worksheets in which this concrete learning cycle has been integrated into a unit on various measurements are presented in Appendix A. Samples of some formal instructional worksheets for the measurement unit are likewise presented in Appendix B.

The Design of the Study

This investigation used the pretest-posttest control group design to experimentally determine the nature of the relationships among M-power, cognitive development, teaching methodology, and achievement in selected biology content.

Different instructors obviously develop different attitudes regarding the best instructional methodologies for achieving the goals of education, even when they agree upon those goals. Because of these attitudes, it is difficult to precisely control the teacher personality variable in the implementation of experimental teaching treatments.

A teacher who is committed to concrete instructional methods may unintentionally bias his implementation of a formal instructional method. Likewise, the formally-oriented teacher may not be able to properly implement a concrete instructional treatment. Schneider[25] found the tendency to bias instruction toward his own philosophy to be a real problem in the study in which he endeavored to simultaneously teach his experimental group concretely and his control group formally.

To preclude this possibility in the present study, this investigator, who is philosophically committed to concrete instructional techniques, and his advisor decided to ask a traditionally-oriented teacher to instruct the control group with formal methods. The teacher so selected was also an instructor in the same building as the investigator and volunteered to take an active and ongoing part in the research.

Two months before the project began, the investigator asked the teacher using formal methods to select the content and its order of presentation for the project year. During a series of discussions with the investigator, the cooperating teacher specifically identified from each content unit those concepts which he planned to teach. The investigator next selected representative concrete and formal concepts from those concepts which the formal instructor had listed. The investigator then adapted his instruction so as to concretely teach the representative concrete and formal concepts in the same order of presentation and within

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[25] Livingston S. Schneider, Relationships Between Concrete and Formal Instructional Procedures and Content-Achievement, Intellectual Development, and Learner I.Q., Unpublished Doctoral Dissertation, University of Oklahoma, 1977, pp. 13-14.

a parallel time frame as the lesson sequence previously selected by the formal instructor.

The formal instructor also furnished the investigator with samples of his 1978-79 worksheets and tests for each chapter, explaining in detail what content he typically emphasized in his lectures. During the project year, 1979-80, he further made a conscientious effort to avoid deviating from those lesson plans and worksheets in any significant manner. In view of that teacher's efforts plus the fact that his worksheets and text assignments alone constituted an estimated seventy-five percent of his typical class hour, the view of the investigator was that the effects of the differences between the two teachers' personalities were minimized.

A typical period for the formal classes consisted of one or more of the following: (1) the students taking notes from the text via fill-in-the-blank worksheets, (2) the students studying and memorizing a vocabulary list of concepts from the text chapter, (3) the students taking notes over a filmstrip or film explaining some ideas from the content area, or (4) the students listening as the teacher explained in more detail those concepts they judged to be difficult to understand. Many short films were shown to supplement the text, but few laboratory demonstrations were provided. The majority of the students did not manipulate any laboratory materials on a regular basis or perform experiments. Instead, the teacher simply told the students the results of selected experiments referred to in the text. With all these various activities, a great deal of repetition was involved with the intent of reinforcing the students' memory and understanding of the course content.

Worksheets of fill-in-the-blank questions directly relating to the text reading assignments were the preferred routine for this instructor. Each of these typically required two to three class periods to complete and were done concurrently with reading assignments from the text. In many cases, the answers could be found as direct quotes from the text in order to encourage the students to read the assignments carefully. Students were discouraged from sharing such answers with each other but were encouraged to ask the instructor for assistance with areas unclear to them.

Because of the lengths of the worksheets, students would work on these about forty minutes each day and then have a short film, filmstrip, or lecture to reinforce the content area. Upon completion of each set of worksheets, a lecture review was provided by the teacher. Students were then given a content achievement examination before the next set of worksheets and text assignments were begun.

A typical class period for the concrete instruction classes varied according to which phase of the learning cycle students were experiencing. During the exploration phase of the learning cycle, students were usually provided with concrete materials and a sequence of written handouts. In contrast to formal handouts, however, these sheets provided guidelines for helping the students observe, measure, experiment, interpret, predict, or build mental models as they personally interacted with the selected concrete materials. (See Appendix A) Such direction sheets did not explain or give specific information about the desired concept, but rather were designed to stimulate mental disequilibrations and help provide the background of concrete experience which the students needed to either invent the concept themselves or understand it when it was later invented for them. An average of two to three pages of these handouts was usually found to take up a full period for most students, so faster students were encouraged to work with slower students. Students were encouraged not only to work in groups but also to share with each other concepts they invented.

Upon completion of this exploration phase, the teacher explained the primary conceptual invention to all the students and attached a name to it. The students were then encouraged to discuss the understandings they had developed, using this concept label, and relate this concept back to their hands-on exploration activities.

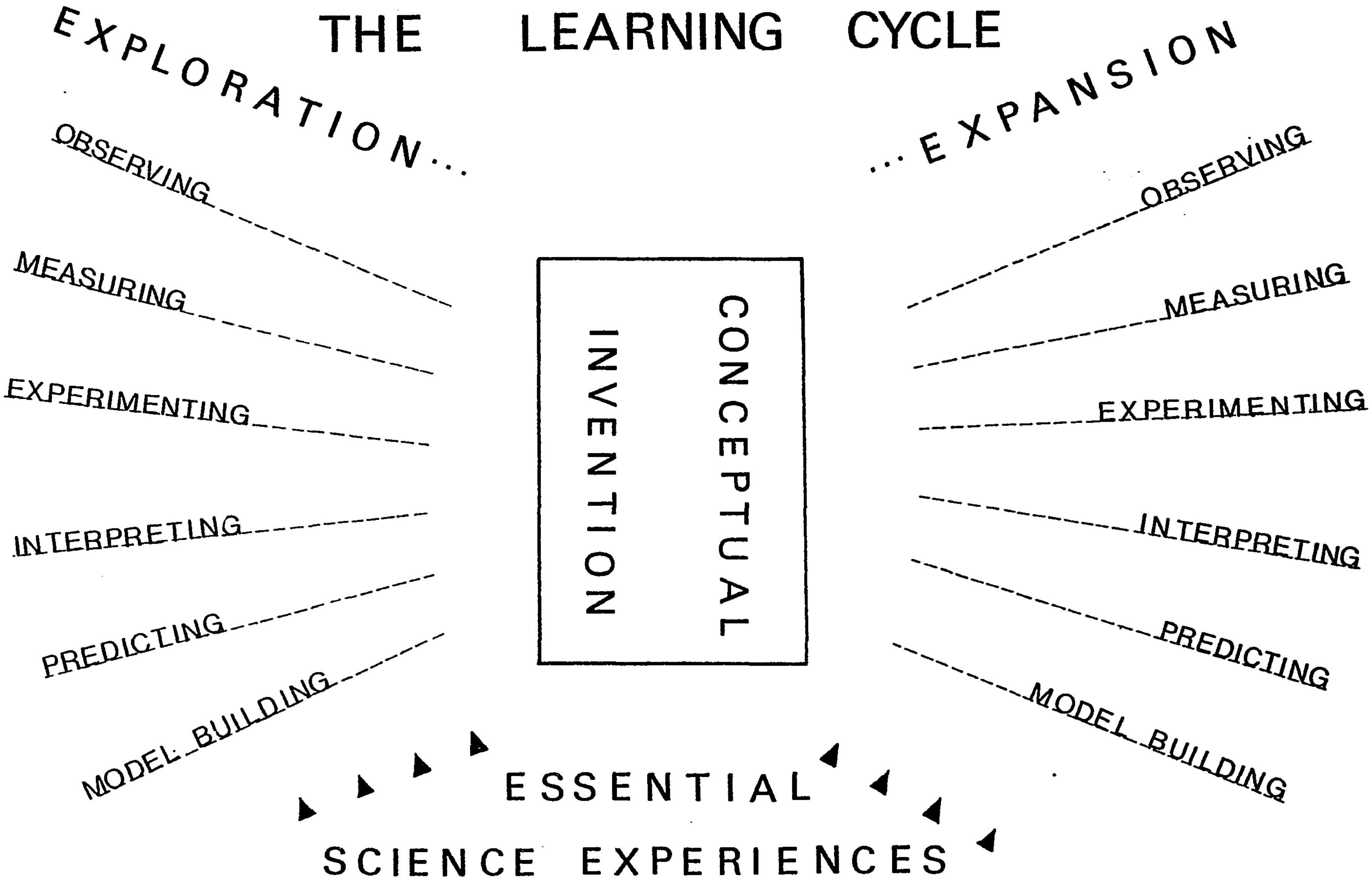
Follow-up activities were then suggested by students or by the teacher to consolidate the conceptual invention and extend its applicability to other situations. Again these expansion activities typically involved handouts which had the students comparing, observing, measuring, interpreting, predicting, or model-building with some new concrete experiences. This sequence is graphically shown in Figure 3-2.

Chronology of the Study

This investigation was conducted over a time frame of more than eight months, from September 3, 1979 to May 16, 1980. Students assigned to the concrete instruction group met during class periods one, five, and six. Those students receiving formal instruction met during class periods two, three, and four. One class period, fourth hour, met an extra five minutes each day due to lunch schedules. Students followed the same schedule each day, Monday through Friday.

FIGURE 3-2

THE LEARNING CYCLE



Administration of pretests measuring cognitive development and M-power was begun September 7, 1979 and pretesting was completed within five days. Whenever possible, these tests were administered to both instruction groups on the same day. The posttesting for cognitive development and M-power was begun on May 7, 1980 and was completed on May 16, 1980.

Content examinations were given immediately following each content unit. Since both instructional groups were studying each content unit at a parallel rate and order of presentation, these examinations were administered on the same day to all classes. Students absent on the day of a particular content examination were allowed to make up these tests for grading purposes, but their scores were not used for statistical analyses. The first content examination was administered December 12, 1979, the second on March 11, 1980, and the third on May 6, 1980.

Instruction for the concrete instructional group began on September 3, 1979 and continued through May 5, 1980, with the exception of weekends and school holidays. The procedures used were consistent with the learning cycle described previously. Formal instruction began and ended within the same time frame as concrete instruction.

Statistical Considerations for Each Subproblem

Subproblem One

The first subproblem was to determine whether a positive correlation exists between M-power scores and success on Piagetian task scores, as predicted by the Cognitive Analysis Project's written index of cognitive development.

The Data Needed. The data needed for the solving of subproblem one were (a) the students raw scores on the tests of M-power and (b) the same students' corresponding Piagetian task scores, defined as the EI scores generated by the CAP written instruments in combination with the GEFT.

The Treatment of the Data. A Pearson product-moment correlation was obtained by using the two scores for each student in the raw score formula for computing r.[26] Statistical tables were then consulted to determine the significance level of the obtained r.

Subproblem Two

The second subproblem was to determine whether positive correlations exist between M-power and success on questions involving concrete and formal biology content.

The Data Needed. The data needed for the solving of subproblem two were (a) the students' scores on one or more tests of M-power and (B) the same students' corresponding scores on the three instructor-made content examinations.

The Treatment of the Data. Pearson product-moment correlations were obtained for each content examination by using the achievement and M-power scores for each student with the raw score formula for computing r.[27] Statistical tables were then consulted to determine the significance level of the obtained r values.

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[26] N.M. Downie and R.W. Heath, Basic Statistical Methods, (New York: Harper & Row, 1970), p. 93.

[27] Ibid.

Subproblem Three

The third subproblem was to determine whether 14-16 year old subjects taught Biology I concretely have a pattern of growth in M-power different from subjects taught biology formally.

The Data Needed. The data needed for the solving of subproblem three were (a) the M-power pretest and posttest scores for each student in the group experiencing concrete instruction and (b) comparable M-power scores for students in the group experiencing formal instruction.

The Treatment of the Data. The Student's t-test[28] was then employed to determine whether the mean gains in M-power for the experimental group differed from the mean gains in M-power for the control group.

Subproblem Four

The fourth subproblem was to determine whether 14-16 year old subjects who are taught biology concretely have a pattern of cognitive development different from subjects taught biology formally.

The Data Needed. The data needed for the solving of subproblem four were (a) the cognitive development pretest and posttest scores for each student in the group experiencing concrete instruction and (b) comparable cognitive development scores for students in the group experiencing formal teaching.

The Treatment of the Data. The Student's t-test was then employed to determine whether the mean gains in cognitive development for

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[28] *Ibid*, p. 178.

the experimental group differed significantly from the mean gains in cognitive development for the control group.

Subproblem Five

The fifth subproblem was to determine whether 14-16 year old subjects taught Biology I concretely have a pattern of achievement on specified concrete and formal biology concepts different from that of subjects taught biology formally.

The Data Needed. The data needed for the solving of subproblem five were (a) concrete and formal biology concept achievement scores for each student in the group experiencing concrete instruction and (b) comparable concrete and formal biology concept achievement scores for students in the group experiencing formal instruction.

The Treatment of the Data. The Student's t-test was then employed to determine whether the mean achievement scores on concrete or formal biology concepts for the experimental group differed significantly from the mean achievement scores on concrete or formal biology concepts for the control group.

Upon finding significant differences between the mean performance levels of the experimental and control groups on the variables concrete content achievement and cognitive development, an analysis of covariance was performed in order to statistically control the influence of the concomitant variable M-power on each of these dependent variables and then determine whether concrete learning cycle instruction still effected significantly greater concrete achievement and cognitive development than formal instruction.

Decision Errors and Their Consequences

Evaluating the significance of differences between means involves a judgment on the part of the researcher and anyone using the research findings. In this investigation, it has been postulated that concretely taught students would show significant gains in content achievement and cognitive development, even after taking into account the idea that M-power may place restrictions on the content understandings of students from both groups. In regard to this investigation, then, committing a Type I error would imply that concrete instruction produced the postulated gains in cognitive development and content achievement when, in fact, it did not produce any effect. The consequences of a Type I error might be a switch from formal instruction procedures to the more expensive concrete instructional methods.

On the other hand, a Type II error would infer that concrete instruction did not produce any gains in either cognitive development or content achievement when, in fact, it did produce a significant effect. The consequences of a Type II error might be a failure to switch to a teaching method that not only enabled students to achieve significantly greater understandings of the structure and content of biology but also promoted the ability to think, a stated central purpose of education.[29]

Due to the serious educational implications in committing a Type II error, the level of significance used to evaluate the findings of this research should be generous. A precise level used to predetermine

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[29] Educational Policies Commission, op. cit., p. 12.

significance was not set by the investigator. Rather, the level to which findings were significant has been reported so as to allow a greater latitude of interpretation.

CHAPTER IV

PRESENTATION OF RESULTS

Exclusion of an Invalid Measure of M-Power

One purpose of this investigation was to determine whether the M-power development of ninth and tenth grade Biology I students was significantly accelerated by the use of concrete instructional techniques. Although the FIT was recommended by Case[1] as the most sensitive group-administered test of M-power, the investigator decided to also adapt the BDS for group administration in order to minimize measurement error of this new construct.

However, during pretesting the BDS was judged to be invalid for this sample. In the BDS, the subject listens to a series of random digits, mentally reverses that series, and then writes the reversed series from left to right on an answer sheet. Students in both instructional groups quickly realized while taking this pretest that they could get the number series correctly reversed by simply writing the digits from right to left, without the necessity of mentally reversing them at all.

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[1] Robbie Case, personal telephone discussion with the investigator, June 29, 1979.

The use of this incorrect test-taking procedure would mean that the BDS would only measure a subject's short-term memory instead of his/her M-power. Since there was no way to be sure which students' BDS tests had measured M-power and which students' tests had measured short-term memory, the investigator and his advisor decided to use the students' scores on the Figural Intersection Test as the only measures of their M-power.

Pretreatment Evaluations of the Sample

Data were gathered in this investigation which allowed pretreatment comparisons of the sample with regional standards for cognitive development. The CAP classified students as being concrete operational if they scored from four through eight on the CAP measures.[2] Students were likewise classified as being transitional from concrete operations to formal operations if they scored nine through eleven and formal operational if they scored twelve or above on the CAP incidents. Pretest CAP scores for each student sampled are presented in Figures 4-3 and 4-4.

Based on this classification system, the percentage of sampled students in each of the three categories was compared to the percentages Renner[3] obtained by Piagetian task-interviews with 188 ninth and tenth grade students from various locations in the state of Oklahoma. Each

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[2] John W. Renner, "The Relationships Between Intellectual Development and Written Responses to Science Questions," Journal of Research in Science Teaching, Vol. 16, No. 4, 1979, pp. 284-293.

[3] John W. Renner, et. al., Research, Teaching, and Learning with the Piaget Model, (Norman, Oklahoma: University of Oklahoma, 1976), pp. 90-96.

of the students in that study was assigned a particular Piagetian classification based on his or her explanations of how to solve the following six tasks:

(1) Conservation of solid amount
(2) Conservation of weight
(3) Conservation of volume using clay
(4) Conservation of volume using cylinders
(5) Elimination of contradictions
(6) Exclusion of irrelevant variables.[4]

In view of the accepted use of these tasks as valid measures of cognitive development, the percentages obtained by Renner thus served as the high school norms for the Oklahoma population. Table 4-1 contains a summary of the sample's Piagetian pretest percentages compared to those norms.

TABLE 4-1

PIAGETIAN CLASSIFICATION DISTRIBUTION OF STUDENTS

Classification	9th and 10th Grade Oklahoma Norms[5]	Instruction Sample Concrete Group	Formal Group	Overall Sample
Fully concrete-operational	78%	69%	63%	66%
Transitional	12%	28%	27%	28%
Formal-operational	10%	3%	10%	6%

Although the sample had a higher percentage of transitional or post-concrete students than might have been predicted using the norms, the combined portion of the entire sample which pretested below formal

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[4] Ibid, p. 93.

[5] Ibid, p. 97.

operational was 94 percent. This figure was quite comparable to the 90 percent predicted from the population as a whole.

Student's t-tests were used in order to determine any significant pretreatment differences between the means of the two instruction groups regarding age, cognitive development, or M-power. The results of these tests are presented in Table 4-2. Tha appropriate raw scores for each student are also presented in Tables 4-3 and 4-4. The calculated t-ratio for each pretreatment comparison led to the acceptance of the null hypothesis that there was no difference between the pretreatment means of the instructional groups with regard to age, cognitive development, and M-power.

TABLE 4-2

PRETEST t-RATIO COMPARISON
OF THE INSTRUCTION GROUPS

Pretest Type	Concrete Instruction		Formal Instruction				
	Mean	S. Dev.	Mean	S. Dev.	t	df.	p
Age (in months)	177.20	7.06	179.30	7.75	-1.65	131	.10
CAP	9.07	1.23	9.32	1.53	-1.01	117	.32
FIT	130.05	39.33	142.56	39.12	-1.83	129	.07

Pearson Product Moment Correlations

Data were gathered in this investigation in order to test this investigation's first two hypotheses, i.e. that correlations exist between M-power, cognitive development, and achievement of examination questions involving concrete biology concepts and formal biology concepts.

The raw scores for each student are presented in Tables 4-3 and 4-4. Columns labeled "Pre" are students' pretest scores and columns labeled "Post" are students' posttest scores. Scores representing each student's average achievement in concrete biology concepts are reported as Z scores. Any score which was not available is indicated on those tables with an asterisk (*).

The correlation matrix in Table 4-5 presents all the Pearson product moment correlations between the variables of age, pre- and post-cognitive development, pre- and post-M-power, and content achievement. Also presented immediately below each correlation in Table 4-5 are the number of subjects sampled and the significance level for the correlation. Significance levels less than .001 are reported as .000.

The symbols used to label the columns in Table 4-5 are defined below:

AgeM = Age in months
PrCD = Pretest for cognitive development
PoCD = Posttest for cognitive development
PrMP = Pretest for M-power
PoMP = Posttest for M-power
CCA$_1$ = Concrete Concept Achievement, Test 1
CCA$_2$ = Concrete Concept Achievement, Test 2
CCA$_3$ = Concrete Concept Achievement, Test 3
CCA$_Z$ = Concrete Concept Achievement, Average Z
FCA$_1$ = Formal Concept Achievement, Test 1
FCA$_2$ = Formal Concept Achievement, Test 2
FCA$_3$ = Formal Concept Achievement, Test 3
FCA$_S$ = Formal Concept Achievement, Sum

TABLE 4-3

RAW DATA FOR CONCRETE INSTRUCTION GROUP

			Cognitive			M-Power			Concrete Achievement				Formal Achievement			
Ss	Age in		Development			(FIT)			1	2	3		1	2	3	Sum
No.	Months	Pre	Post	Change	Pre	Post	Change		Raw	Raw	Raw	Ave. Z	Raw	Raw	Raw	Raw
1	183	9.44	11.99	2.55	135	185	50		15	11	15	-.28	2	0	1	3
2	173	9.48	11.02	1.54	38	33	-5		10	19	*	-.40	2	1	*	*
3	189	8.13	9.56	1.43	74	76	2		19	18	16	.46	2	0	0	2
4	169	7.27	*	*	41	*	*		13	16	*	-.35	1	0	*	*
5	185	9.54	10.59	1.05	157	*	*		18	16	*	.16	0	1	*	*
6	179	*	11.09	*	155	145	-10		12	21	18	.32	3	1	1	5
7	185	7.84	9.22	1.38	70	54	-16		8	15	8	-1.10	0	1	1	2
8	176	8.29	9.49	1.20	75	72	-3		15	25	14	.43	0	2	2	4
9	168	8.62	10.25	1.63	*	82	*		18	20	16	.51	1	0	1	2
10	187	11.08	11.93	.85	190	*	*		22	19	*	.81	0	2	*	*
11	181	*	13.31	*	194	196	2		25	25	19	1.50	2	1	4	7
12	177	10.28	11.99	1.71	188	225	37		19	25	20	1.18	4	3	2	9
13	181	8.53	*	*	206	*	*		14	10	10	-.81	1	1	4	6
14	180	9.80	11.86	2.06	85	189	104		13	24	15	.32	1	2	1	4
15	189	7.25	8.86	1.61	128	101	-27		17	18	13	.08	1	1	3	5
16	184	9.74	11.57	1.83	119	158	39		21	25	20	1.32	4	2	2	8
17	171	7.62	7.75	.13	22	20	-2		16	17	12	-.12	1	3	1	5
18	181	10.62	12.54	1.92	141	149	8		21	28	20	1.49	4	3	0	7
19	180	7.95	8.75	.80	125	118	-7		16	20	11	-.03	2	2	3	7
20	180	9.61	12.20	2.59	117	108	-9		11	18	9	-.64	3	2	2	7
21	168	8.98	10.16	1.18	137	116	-21		17	16	13	-.03	2	0	1	3
22	180	7.89	12.77	4.88	137	214	77		22	25	17	1.14	3	2	2	7
23	190	*	13.61	*	150	138	-12		25	30	22	2.03	7	2	2	11
24	184	11.87	13.01	1.14	139	193	54		22	29	*	1.66	4	3	*	*
25	190	7.23	9.19	1.96	73	55	-18		14	15	*	-.34	0	1	*	*
26	177	*	12.86	*	161	195	34		17	21	16	.50	4	1	1	6
27	184	9.26	*	*	146	195	49		16	19	*	.21	3	0	*	*
28	174	7.90	11.44	3.54	120	178	58		24	25	18	1.35	3	4	3	10
29	166	10.62	13.24	2.62	192	195	3		25	25	25	1.99	2	0	3	5
30	170	6.97	8.35	1.38	77	73	-4		9	12	17	-.47	1	0	2	3
31	188	8.26	10.68	2.42	120	159	39		11	12	9	-.98	1	2	1	4
32	181	11.28	12.56	1.28	137	168	31		24	28	16	1.36	0	4	2	6

TABLE 4-3 CONTINUED

Ss No.	Age in Months	Cognitive Development Pre	Post	Change	M-Power (FIT) Pre	Post	Change	Concrete Achievement 1 Raw	2 Raw	3 Raw	Ave. Z	Formal Achievement 1 Raw	2 Raw	3 Raw	Sum Raw
33	175	9.27	11.43	2.16	156	199	43	19	26	20	1.24	0	5	2	7
34	166	10.17	11.45	1.28	129	131	2	13	*	17	.17	1	*	2	*
35	171	8.80	11.02	2.22	151	166	15	22	19	15	.64	1	3	3	7
36	171	8.25	9.45	1.20	117	83	-34	14	15	12	-.37	1	0	2	3
37	182	9.44	11.06	1.62	183	186	3	15	29	16	.81	0	3	3	6
38	172	8.81	*	*	93	*	*	23	15	*	.57	1	1	*	*
39	178	8.09	10.59	2.50	151	198	47	20	27	17	1.12	2	1	3	6
40	176	11.70	13.61	1.91	117	167	50	24	30	24	2.12	7	4	3	14
41	184	9.65	10.67	1.02	170	160	-10	17	19	16	.38	0	2	3	5
42	168	9.73	11.27	1.54	175	173	-2	15	*	11	-.36	1	*	1	*
43	173	8.50	9.07	.57	172	189	17	21	*	15	.74	1	*	3	*
44	167	8.72	11.36	2.64	113	145	32	19	15	12	-.03	2	2	1	5
45	177	9.77	10.12	.35	108	93	-15	15	14	*	-.33	2	0	*	*
46	181	8.35	10.37	2.02	141	178	37	18	22	20	.94	2	0	3	5
47	177	11.43	13.27	1.84	151	201	50	23	29	20	1.68	3	6	2	11
48	170	9.01	12.00	2.99	87	148	61	18	17	16	.34	3	1	1	5
49	170	10.94	13.10	2.16	141	132	-9	23	25	22	1.61	6	4	2	12
50	169	6.02	10.17	4.15	*	61	*	12	20	14	-.06	3	0	1	4
51	178	8.17	11.73	3.56	75	161	86	19	15	15	.63	3	2	2	7
52	171	9.14	11.79	2.65	140	167	27	21	26	16	1.05	0	0	1	1
53	169	10.42	11.53	1.11	120	130	10	22	15	16	.49	2	1	1	4
54	168	7.57	6.99	-.58	128	149	21	10	18	11	-.55	0	3	1	4
55	171	8.60	10.22	1.62	142	170	28	21	22	19	1.07	1	1	3	5
56	191	9.37	9.61	.24	112	92	-20	14	13	10	-.64	1	0	1	2
57	187	9.28	10.72	1.44	198	211	13	16	28	22	1.31	4	0	2	6
58	170	10.54	12.33	1.79	121	205	84	22	25	17	1.14	4	4	2	10
59	191	7.70	9.22	1.52	*	*	*	6	14	11	-1.04	1	2	0	3
60	176	8.47	9.23	.76	132	*	*	18	16	*	.16	3	1	*	*
61	177	10.32	12.88	2.56	188	216	28	20	32	22	1.80	3	3	2	8
62	172	7.24	9.78	2.54	128	141	13	17	10	15	-.20	1	2	3	6
63	180	9.48	12.33	2.85	99	143	44	20	28	17	1.17	5	2	1	8
64	169	8.72	9.06	.34	105	129	24	22	21	14	.67	1	2	3	6
65	171	9.47	11.19	1.72	144	172	28	20	25	16	.92	2	3	1	6
66	174	9.26	10.08	.82	138	168	31	20	15	13	.11	0	1	3	4
67	184	9.41	12.17	2.76	141	216	75	19	23	15	.66	3	3	3	9
68	176	9.31	11.60	2.29	138	210	72	18	23	12	.35	0	2	1	3

TABLE 4-4

RAW DATA FOR FORMAL INSTRUCTION GROUP

Ss	Age in	Cognitive Development			M-Power (FIT)			Concrete Achievement				Formal Achievement			
								1	2	3		1	2	3	Sum
No.	Months	Pre	Post	Change	Pre	Post	Change	Raw	Raw	Raw	Ave. Z	Raw	Raw	Raw	Raw
1	170	8.16	9.57	1.41	91	120	29	11	14	6	-1.11	0	0	2	2
2	173	8.39	8.72	.33	100	127	27	16	14	10	-.45	2	0	3	5
3	186	8.80	8.86	.06	94	100	6	9	15	14	-.54	1	1	3	5
4	185	8.80	11.09	2.29	142	215	73	10	10	10	-1.08	1	1	2	4
5	171	8.97	10.12	1.15	106	148	42	15	16	12	-.24	1	1	2	4
6	173	10.47	11.20	.73	188	186	-2	13	15	18	.05	2	1	2	5
7	197	7.03	9.49	2.46	100	78	-22	8	11	*	-1.28	1	0	*	*
8	177	12.24	10.75	-1.49	147	138	-9	18	*	12	.07	2	*	3	*
9	176	11.09	10.58	-.51	142	139	-3	12	17	13	-.31	2	2	1	5
10	176	12.19	12.47	.28	122	115	-7	14	11	17	-.19	2	3	2	7
11	168	10.70	9.23	-1.47	181	162	-19	6	12	12	-1.07	1	2	0	3
12	185	9.37	12.30	2.93	170	161	-9	11	17	14	-.29	1	2	1	4
13	179	9.27	10.14	.87	189	199	10	10	11	12	-.86	1	0	0	1
14	188	8.54	10.97	2.43	133	151	18	11	15	11	-.65	3	1	3	7
15	174	7.88	8.38	.50	118	165	47	16	*	12	-.14	2	*	4	*
16	185	12.04	13.08	1.04	184	198	14	16	20	*	.29	3	3	*	*
17	186	11.39	12.33	.94	137	129	-8	19	22	11	.28	2	2	2	6
18	173	8.42	10.42	2.00	161	203	42	7	11	15	-.82	4	1	1	6
19	180	9.96	11.18	1.22	179	196	17	18	*	14	.31	2	*	2	*
20	168	9.40	10.50	1.10	187	187	0	12	12	11	-.75	0	1	2	3
21	186	7.71	8.26	.55	100	130	30	12	18	9	-.58	0	2	2	4
22	169	8.08	8.39	.31	110	132	22	10	17	10	-.69	0	2	3	5
23	186	9.48	9.61	.13	175	159	-16	6	8	12	-1.30	0	1	1	2
24	173	10.03	12.70	2.67	206	214	8	*	16	12	-.34	*	4	2	*
25	176	7.48	8.89	1.41	132	149	17	10	17	12	-.53	2	1	3	6
26	190	9.02	*	*	134	*	*	19	12	*	-.09	1	0	*	*
27	184	11.22	*	*	159	172	13	16	17	16	.20	1	3	2	6
28	167	8.08	9.20	1.12	152	184	32	12	15	12	-.50	1	0	2	3
29	177	7.95	9.52	1.57	118	193	75	15	10	9	-.83	1	2	2	5
30	190	8.94	*	*	178	174	-4	14	16	13	-.23	2	0	0	2
31	178	11.58	12.00	.42	147	154	7	13	15	8	-.76	1	1	3	5
32	179	9.39	*	*	130	128	-2	10	15	13	-.56	0	1	1	2
33	177	9.31	10.71	1.40	133	157	24	*	19	15	.28	*	1	2	*

TABLE 4-4 CONTINUED

		Cognitive Development			M-Power (FIT)			Concrete Achievement				Formal Achievement			
Ss No.	Age in Months	Pre	Post	Change	Pre	Post	Change	1 Raw	2 Raw	3 Raw	Ave. Z	1 Raw	2 Raw	3 Raw	Sum Raw
34	179	10.40	11.22	.82	178	173	-5	19	13	15	.10	1	2	3	6
35	186	9.05	11.09	2.04	183	214	31	17	20	19	.68	3	1	1	5
36	186	10.96	11.52	.56	197	189	-8	18	23	18	.84	4	3	1	8
37	176	8.58	*	*	164	186	22	8	13	11	-.96	1	1	0	2
38	174	9.61	*	*	165	211	62	14	19	*	-.01	1	1	*	*
39	172	11.09	12.30	1.21	153	181	28	16	15	17	.17	4	3	2	9
40	185	7.61	8.08	.47	99	135	36	16	14	10	-.45	1	0	2	3
41	192	9.39	11.26	1.87	153	119	-34	15	*	18	.49	1	*	2	*
42	179	*	8.16	*	41	66	25	5	8	*	-1.85	1	1	*	*
43	187	9.76	10.78	1.02	121	135	14	14	15	12	-.37	0	1	1	2
44	180	8.05	8.46	.41	164	*	*	9	8	7	-1.51	2	0	3	5
45	176	9.14	11.01	1.87	135	179	44	15	17	8	-.51	1	0	2	3
46	171	9.57	10.21	.64	124	178	54	16	10	15	-.27	0	0	1	1
47	170	8.54	8.12	-.42	157	181	24	10	6	4	-1.80	2	0	3	5
48	179	*	12.03	*	181	186	5	12	10	10	-.94	2	0	3	5
49	170	6.93	7.07	.14	142	159	17	9	12	8	-1.20	0	2	0	2
50	180	7.27	8.63	1.36	166	163	-3	12	11	8	-1.05	1	0	0	1
51	196	*	6.59	*	73	*	*	9	14	8	-.89	2	1	1	4
52	188	9.40	9.87	.47	88	88	0	6	*	8	-1.63	0	*	1	*
53	181	8.77	8.97	.20	159	124	-35	12	9	14	-.68	3	1	2	6
54	185	6.35	7.07	.72	155	138	-17	9	7	6	-1.64	2	1	1	4
55	170	*	8.03	*	88	124	36	8	*	7	-1.03	1	*	2	*
56	190	13.22	13.01	-.21	214	216	2	13	17	16	.00	5	0	2	7
57	176	10.85	11.94	1.09	218	223	5	18	18	18	.55	5	4	2	11
58	177	8.20	7.50	-.70	67	76	9	14	13	12	-.48	0	1	1	2
59	185	7.92	8.77	.85	185	174	-11	18	13	8	-.53	1	2	1	4
60	186	12.17	12.03	-.14	205	174	-31	23	14	16	.50	4	3	1	8
61	170	10.44	11.56	1.02	150	201	51	15	16	14	-.08	2	1	1	4
62	171	9.87	8.42	-1.45	83	126	43	14	11	10	-.75	0	3	2	5
63	189	10.68	10.47	-.21	100	160	60	7	11	10	-1.22	1	3	2	6
64	195	7.45	9.09	1.64	*	80	*	9	*	11	-.97	1	*	2	*
65	166	8.63	9.90	1.27	153	180	27	10	*	11	-.87	1	*	1	*
66	170	*	8.98	*	82	100	18	14	11	10	-.75	2	3	3	8
67	177	6.56	9.53	2.97	121	178	57	16	*	11	-.23	3	*	1	*

TABLE 4-5

PEARSON PRODUCT MOMENT CORRELATIONS

	AgeM	PrCD	PoCD	PrMP	PoMP	CCA_1	CCA_2	CCA_3
AgeM	1.00 135 ***	.04 126 .32	.03 125 .32	.09 131 .16	-.06 125 .26	-.12 133 .08	-.02 123 .43	-.05 120 .28
PrCD		1.00 126 ***	.73 116 .000	.40 122 .000	.36 117 .000	.34 124 .000	.31 115 .000	.42 112 .000
PoCD			1.00 125 ***	.43 121 .000	.49 119 .000	.58 123 .000	.58 113 .000	.65 115 .000
PrMP				1.00 131 ***	.76 122 .000	.20 129 .012	.12 120 .090	.27 116 .002
PoMP					1.00 125 ***	.32 123 .000	.26 113 .003	.29 116 .001
CCA_1						1.00 133 ***	.66 121 .000	.66 118 .000
CCA_2							1.00 123 ***	.72 108 .000

(r/cases/significance level)

TABLE 4-5 CONTINUED

PEARSON PRODUCT MOMENT CORRELATIONS

	AgeM	PrCD	PoCD	PrMP	PoMP	CCA_1	CCA_2	CCA_3
CCA_3								1.00 120 ***
CCA_Z	-.07 135 .200	.40 126 .000	.69 125 .000	.23 131 .004	.34 125 .000	.88 133 .000	.89 123 .000	.89 120 .000
FCA_1	.07 133 .220	.35 124 .000	.53 123 .000	.22 129 .005	.28 123 .001	.38 133 .000	.41 121 .000	.53 118 .000
FCA_2	-.07 123 .220	.42 115 .000	.37 113 .000	.10 120 .150	.24 113 .006	.36 121 .000	.44 123 .000	.32 108 .000
FCA_3	-.09 120 .180	.04 112 .340	.08 115 .210	.06 116 .250	.09 116 .160	.29 118 .001	.13 108 .090	.11 120 .110
FCA_S	.01 106 .450	.44 99 .000	.56 101 .000	.16 103 .049	.28 102 .002	.54 106 .000	.51 106 .000	.55 106 .000

(r/cases/significance level)

TABLE 4-5 CONTINUED

PEARSON PRODUCT MOMENT CORRELATIONS

	CCA_Z	FCA_1	FCA_2	FCA_3	FCA_S
CCA_Z	1.00 135 ***				
FCA_1	.49 133 .000	1.00 133 ***			
FCA_2	.42 123 .000	.25 121 .003	1.00 123 ***		
FCA_3	.20 120 .010	.04 118 .320	.11 108 .140	1.00 120 ***	
FCA_S	.60 106 .000	.75 106 .000	.70 106 .000	.46 106 .000	1.00 106 ***

(r/cases/significance level)

Using the entire sample, age did not significantly correlate with any other variable. Since Pascual-Leone has postulated that M-power increases linearly up to an age of 15-16 and is "primarily dependent on factors such as maturation and general experience,"[6] the investigator examined the idea that the M-power scores of the sample's younger students might, in fact, be positively correlated with their ages. In order to explore this possibility, students starting the investigation at ages older than 15 years 6 months (186 months) were deleted and correlations recalculated.

Even though the oldest twenty students represented only fifteen percent of the 135 students in the sample, following their removal, age was found to significantly correlate with both the pretest and the posttest of M-power. The pretest correlation had a value of .214 (p = .01) and the posttest correlation, a value of .159 (p = .05). No other correlations were found with age at or below the .05 level.

The relationship between age and M-power scores is further illustrated by Figures 4-1 and 4-2, in which the sample's M-power scores are grouped by age intervals. It should be noted from Figures 4-1 and 4-2 that the age groups containing the youngest eighty-five percent of the student sample showed a linear increase in M-power throughout the duration of the investigation. This pattern also suggests that the oldest fifteen percent of the students were not typical of the sample as a whole, with regard to M-power scores, thus providing support for

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[6] Juan Pascual-Leone, "A Mathematical Model for the Transition Rule in Piaget's Developmental Stages," Acta Psychologica, Vol. 63, 1970, pp. 301-345.

FIGURE 4-1

MEAN M-POWER PRETEST SCORES

BY AGE INTERVALS

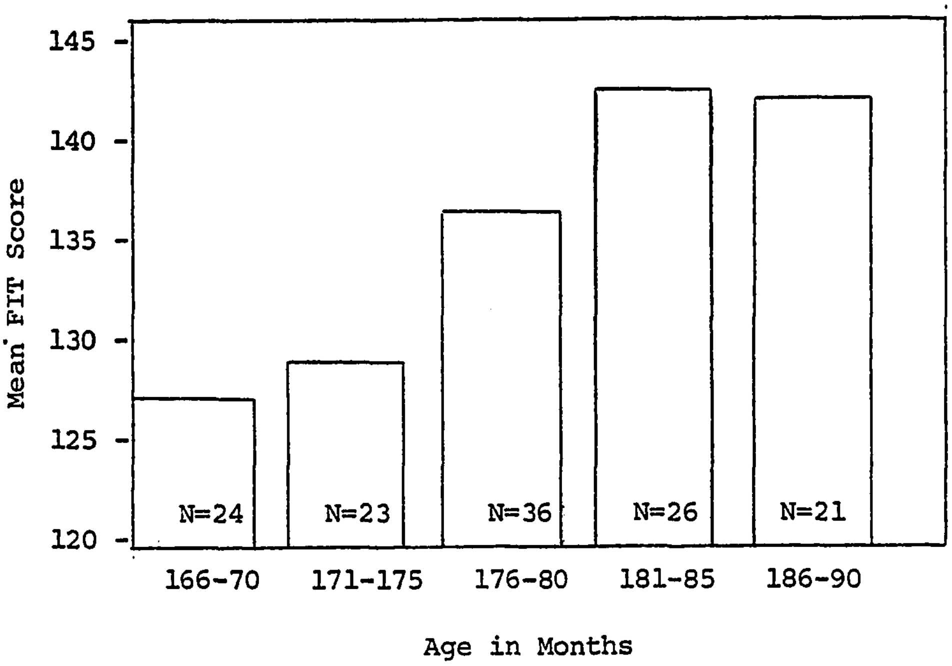
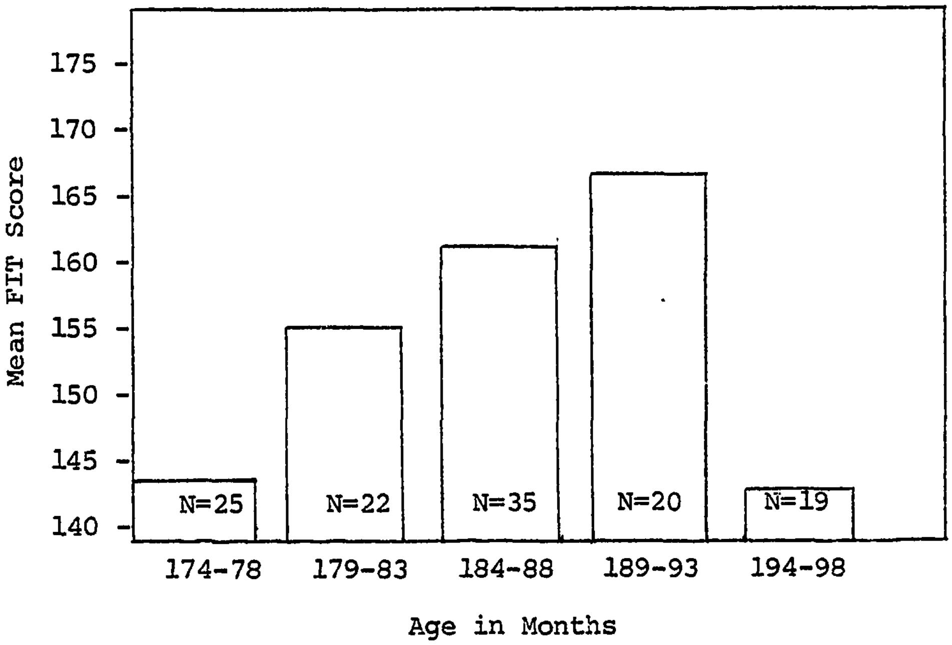


FIGURE 4-2

MEAN M-POWER POSTTEST SCORES

BY AGE INTERVALS



the existence of significant positive correlations between M-power and age.

Data Relating to the First Subproblem

The null hypothesis for the first subproblem of the investigation stated that no correlation exists between the students' scores on the CAP measure of cognitive development and the FIT measure of M-power. However, data gathered in this investigation showed positive correlations between M-power and cognitive development ranging from .36 to .49, all of which were significant below the .001 confidence level. These data therefore provide evidence supporting the rejection of null hypothesis number one.

Data Relating to the Second Subproblem

The second subproblem of the investigation was to determine whether correlations exist between M-power and achievement on examination questions involving concrete biology content. Of the eight correlations calculated between the students' M-power scores and their scores on various concrete content examinations, all eight were positive and seven were significant below the .05 confidence level. These correlations ranged from values of .12 to .34. These data provided evidence supporting the rejection of null hypothesis number two, that there is no correlation between M-power and achievement on concrete biology content.

Data were also gathered to determine whether correlations exist between M-power and achievement on formal biology content. Of the eight comparisons made between students' scores on measures of M-power and their respective scores on achievement on formal biology concepts, five positive correlations were found to be significant below the .05 confidence level. These correlations ranged in value from .16 to .28. This evidence supports the rejection of the null hypothesis that there is no correlation between

M-power and achievement on formal biology content. Nonetheless, the small correlation values obtained suggest a substantial part of the students' achievement on both concrete and formal concepts is determined by factors other than M-power alone.

Cognitive development, for example, was found in this investigation to correlate positively ($p < .001$) with all measures of the sample's achievement on concrete biology concepts. These correlations ranged in value from .31 to .69, suggesting a much stronger association than was found for M-power. Similarly, the correlations between cognitive development and achievement on formal biology concepts ranged from .35 to .56 for the six correlations out of eight which were found to be significant below the .05 level.

Data Comparing the Instruction Groups

Data were collected in this investigation with which to empirically compare the differential effects of formal instruction and concrete, learning cycle instruction on M-power growth, cognitive development, and achievement on selected concrete and formal biology content.

Testing the Third Hypothesis

Investigation Hypothesis Three specifically stated that the broad background of concrete experiences which would be provided by using learning cycle instruction over an extended period of time would accelerate the rate of M-power growth, if that factor were dependent on both maturation and general experience, as Pascual-Leone has suggested.[7]

The mean pretest and posttest scores on the FIT measure on M-power were compared for each instruction group by the Student's t-tests. Those

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[7] Ibid.

data are presented in Table 4-6.

It was previously noted from Table 4-2 that there were no significant differences in mean M-power pretest scores between the instructional groups. Although Table 4-6 used the smaller sample of only those students taking both the pretest and the posttest of M-power, this pretreatment t-ratio was also considered to be nonsignificant, especially since judging its p value of .053 to indicate significant pretest differences would increase the likelihood of a Type I error.

Although the concrete instruction group did show greater pretest to posttest gains in M-power than the formal instruction group, neither these gains nor the mean posttest scores were significantly different at the .05 level. Null hypothesis three, that there would be no differences between the mean M-power development scores of the two instruction groups, was therefore accepted. The parallel rate of M-power growth for the two instruction groups is illustrated in Figure 4-3.

Testing the Fourth Hypothesis

The fourth hypothesis of this investigation predicted that students taught Biology I concretely would have significantly greater cognitive development than students taught the same content formally. Mean pretest and posttest scores on the CAP measure of cognitive development were compared for each instruction group using Student's t-tests. These data are presented in Table 4-7 and illustrated by Figure 4-4.

As was previously noted, there were no significant differences between the two groups before instruction. An examination of Table 4-7 and Figure 4-4 does reveal, however, that the concrete instruction group did pretest at a lower level of mean cognitive development but then posttested

TABLE 4-6

M-POWER DATA
INCLUDING t-RATIO COMPARISONS
BETWEEN INSTRUCTION GROUPS

	Concrete Instruction			Formal Instruction					
	Mean	S. Dev.	N	Mean	S. Dev.	N	t	df.	p
Pretest	129.39	37.04	59	143.21	38.95	63	-1.96	120	.053
Posttest	151.49	49.48	59	158.73	37.38	63	-0.92	120	.361
Pretest to Posttest Change	22.10	31.69	59	15.52	25.57	63	1.27	120	.208

TABLE 4-7

COGNITIVE DEVELOPMENT DATA
INCLUDING t-RATIO COMPARISONS
BETWEEN INSTRUCTION GROUPS

	Concrete Instruction			Formal Instruction					
	Mean	S. Dev.	N	Mean	S. Dev.	N	t	df.	p
Pretest	9.11	1.25	60	9.31	1.59	56	-0.74	114	.462
Posttest	10.89	1.48	60	10.15	1.55	56	2.63	114	.010
Pretest to Posttest Change	1.78	0.97	60	0.85	1.01	56	5.07	114	<.001

FIGURE 4-3

M-POWER GROUP MEANS

PRETEST, POSTTEST

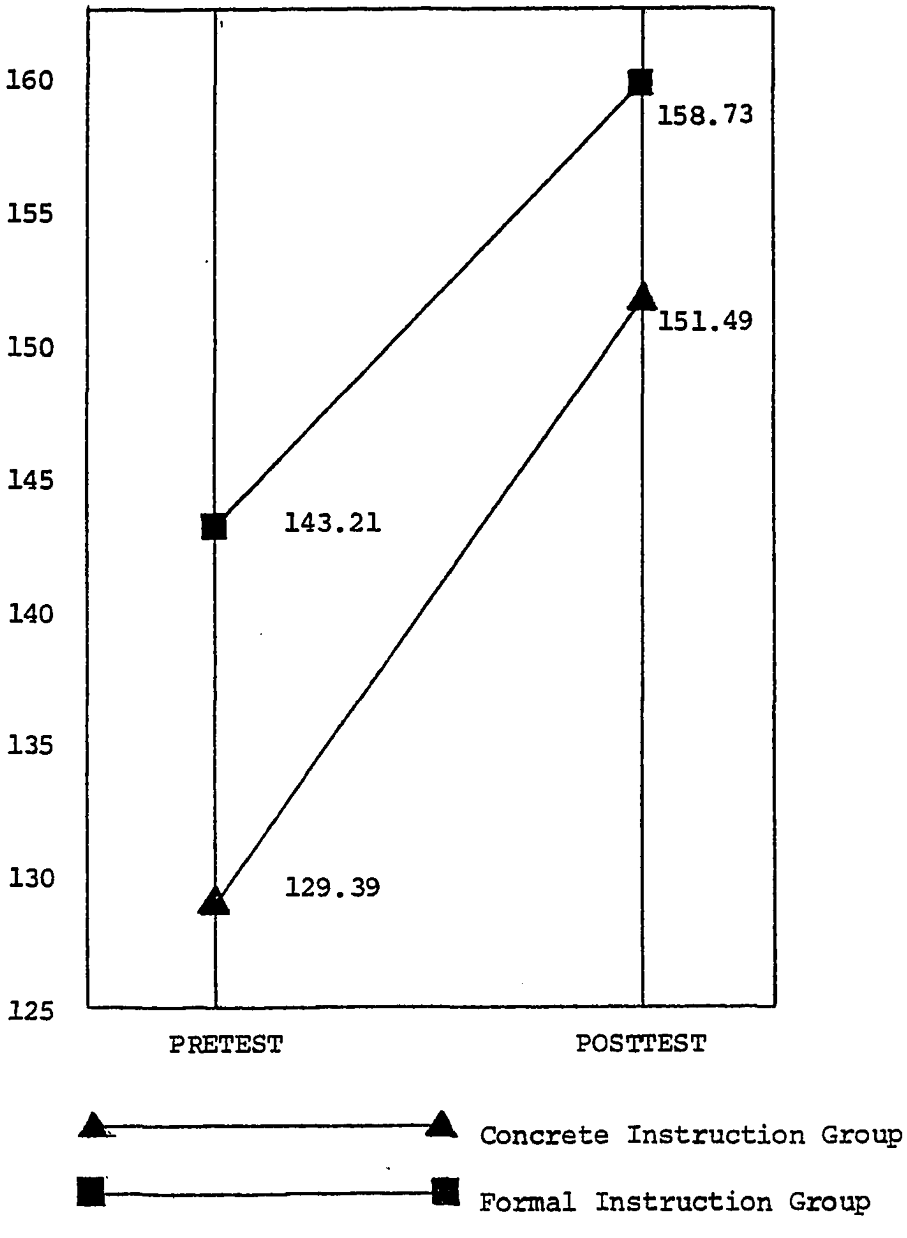
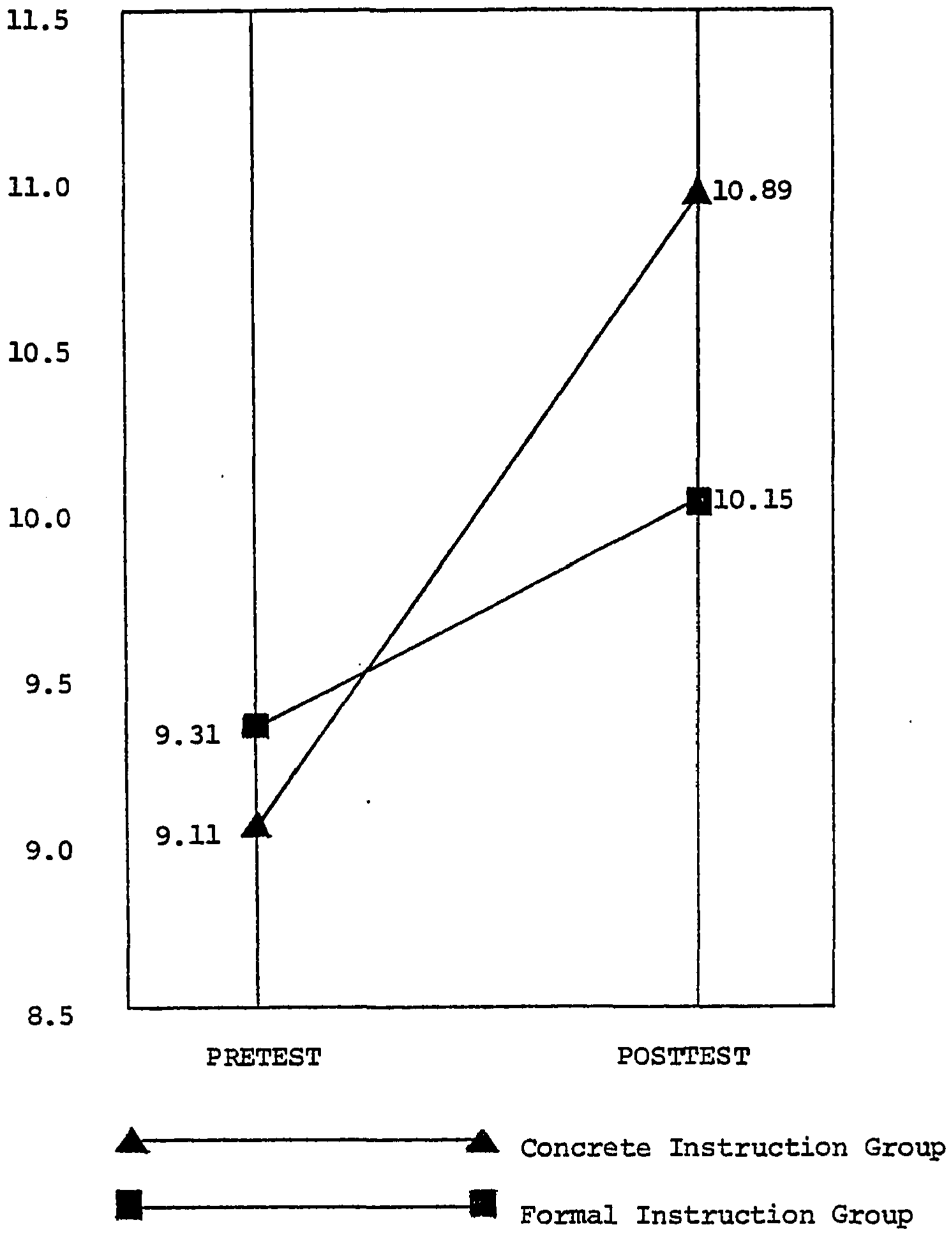


FIGURE 4-4

COGNITIVE DEVELOPMENT MEANS

PRETEST, POSTTEST



at a significantly higher level ($p = .010$) of mean cognitive development than the group receiving formal instruction. The pretest to posttest gains in cognitive development were significantly greater below the .001 level for the group receiving concrete instruction. These data support the rejection of null hypothesis number four, that there would be no differences between the cognitive development rates of students taught Biology I concretely and students taught Biology I formally.

Testing the Fifth Hypothesis

One premise of this investigation was that students experiencing concrete instruction would develop deeper understandings of concrete biology concepts than students receiving formal instruction of the same concepts. Student's t-tests were used to determine whether the means of the two instruction groups were significantly different on each test measuring concrete content achievement. Those data are presented in Table 4-8 and illustrated by Figure 4-5.

On every examination measuring concrete content achievement, the group experiencing concrete instruction performed significantly ($p \leq .001$) better than the formal instruction group. These data support rejection of the investigation's fifth null hypothesis that there would be no differences between the concrete content achievement means of the two instructional groups.

Data presented in Table 4-9 and illustrated in Figure 4-6 reflect a lack of achievement by either group on formal concepts. Although the concrete instruction group performed slightly better than the formal instruction group on that portion of each content examination which measured understanding of formal concepts, the obtained t-ratios were not significant at the .05 level. Even if the more generous significance level of .10

TABLE 4-8

CONCRETE BIOLOGY CONTENT ACHIEVEMENT DATA INCLUDING t-RATIO COMPARISONS BETWEEN INSTRUCTION GROUPS

Content	Concrete Instruction			Formal Instruction					
Examination	Mean	S. Dev.	N	Mean	S. Dev.	N	t	df.	p
1. Ecology	17.72	4.47	68	12.75	3.91	65	6.81	131	<.001
2. Energy Utilization	20.58	5.69	65	13.90	3.72	58	7.62	121	<.001
3. Energy Production	15.81	3.88	58	11.85	3.40	62	5.95	118	<.001
Average Z Scores	.49	.80	68	-.51	.61	67	8.15	133	<.001

TABLE 4-9

FORMAL BIOLOGY CONTENT ACHIEVEMENT DATA INCLUDING t-RATIO COMPARISONS BETWEEN INSTRUCTION GROUPS

Content	Concrete Instruction			Formal Instruction					
Examination	Mean	S. Dev.	N	Mean	S. Dev.	N	t	df.	p
1. Ecology	1.97	1.67	68	1.53	1.24	65	1.69	131	.093
2. Energy Utilization	1.71	1.40	65	1.33	1.13	58	1.64	121	.103
3. Energy Production	1.90	.99	58	1.74	.94	62	.88	118	.381
Sum of 1, 2, and 3	5.82	2.72	55	4.57	2.18	51	2.60	104	.011

FIGURE 4-5

COMPARISON OF INSTRUCTION GROUP MEAN Z SCORES

ON CONCRETE BIOLOGY CONTENT ACHIEVEMENT

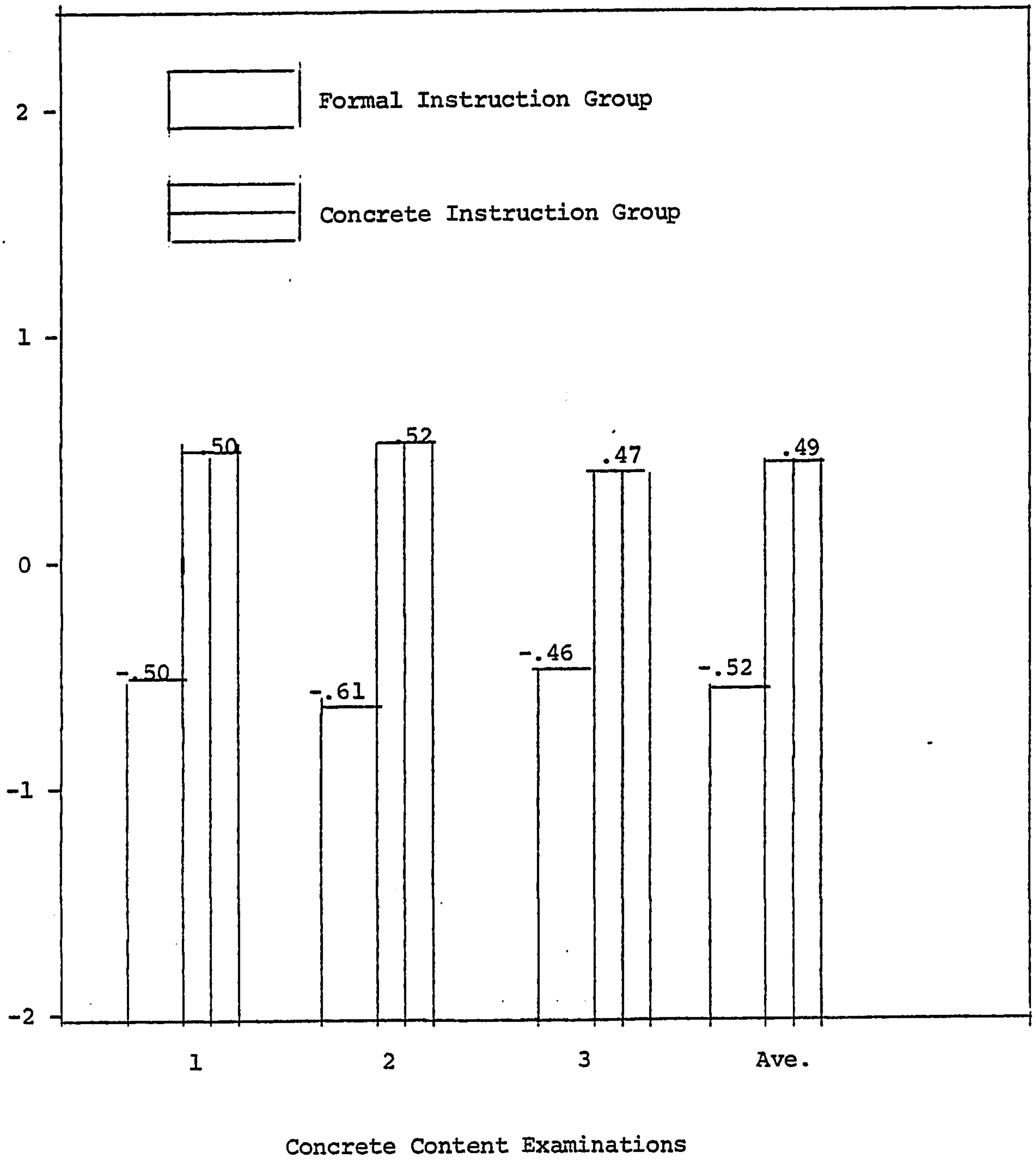
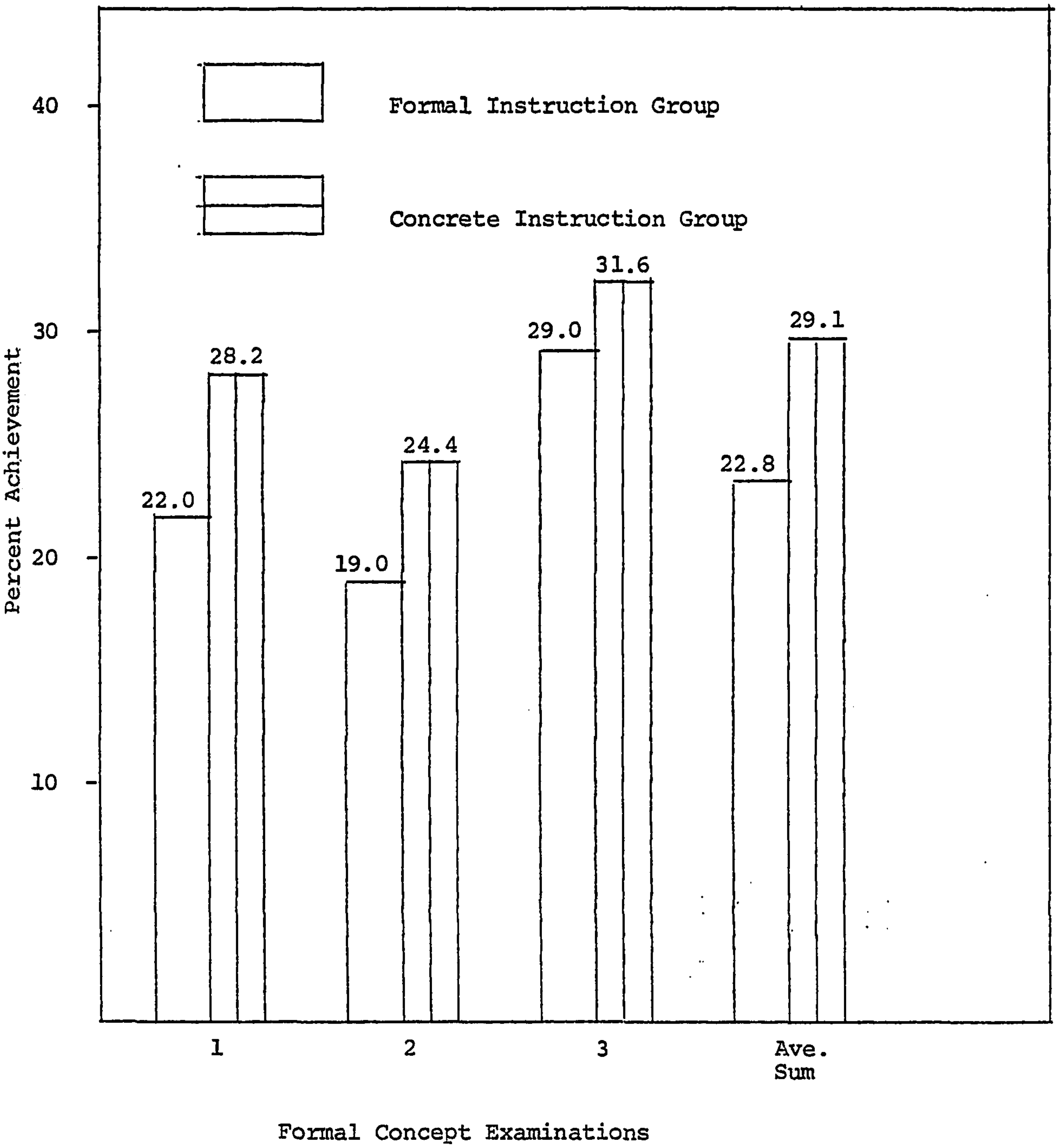


FIGURE 4-6

COMPARISON OF INSTRUCTION GROUP MEAN PERCENT SCORES
ON FORMAL BIOLOGY CONTENT ACHIEVEMENT



were adopted, only one of the three t-ratios would be significant. These t-ratios as well as the small percentages of formal content achievement suggest that neither concrete instruction nor formal instruction produces substantial understandings of formal content. This evidence supports the conclusion of Lawson and Renner[8] that concrete operational students cannot be taught to fully understand formal operational concepts.

Even if achievement on formal concepts were the only criterion for choosing between the two teaching treatments, however, the evidence from this investigation supports the supremacy of concrete instruction over formal instruction. Concrete instruction may not enable concrete operational students to completely understand formal operational concepts, but it does produce significantly greater cognitive development than formal instruction. Once the students become formal operational, they are then able to assimilate propositional data, define concepts in terms of other concepts, and fully understand formal concepts.

Tests of cognitive development showed the concrete instruction group to have had only two students with CAP pretest scores of almost twelve and no students beginning the year with CAP scores of twelve or more. Twelve was the lowest score which the CAP judged to indicate a formal operational classification.[9] However, the concrete group's post-test CAP scores showed that fourteen of the students achieved scores

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[8] Anton E. Lawson and John W. Renner, "Relationships of Science Subject Matter and Developmental Levels of Learners," Journal of Research in Science Teaching, 1975, Vol. 12, No. 4, p. 347.

[9] Renner, loc. cit.

higher than twelve with nine other students scoring just below twelve.

The formal instruction group had five students pretest at or above twelve. Posttesting of this group, however, showed only a total of five additional students who raised their Piagetian classification to being formal operational whereas one of those who was pretest classified being formal operational dropped to a posttest classification of being transitional from concrete to formal operations.

As a result of accelerated cognitive development, then, a concrete instructional group would eventually perform better on measures of achievement for formal biology concepts than a formal instruction group, even though individuals who were still concrete operational would not understand formal concepts with either instruction method. The consistently greater achievement on formal concepts exhibited by the concrete instruction group in this investigation gives evidence supporting the existence of such a trend.

This consistent difference in achievement is especially supportive in view of the fact that there was such a small number of formal concept questions on each one of the three content examinations. The judgment was previously expressed that concrete operational students should not be graded for their performances on questions requiring formal operational thought processes. For this reason, each content examination consisted of about thirty questions measuring understandings of concrete concepts, but only six or seven, non-graded questions measuring understandings of formal concepts. Because there were so few formal concept questions per examination, the group means on each examination were similar enough that the t-ratio significance levels actually increased by chance.

An accurate indication of each student's overall achievement on concrete concepts was obtained by averaging that student's Z scores from each separate test. Overall formal concept achievement, on the other hand, was better measured for this investigation by adding each student's formal concept scores on all three tests combined and then comparing those sums.

When the means of those sums were compared, the concrete instruction group was seen from Table 4-9 to achieve significantly higher ($p = .011$) totals on formal concepts than the formal instruction group, thus providing more evidence that concrete instruction is the preferred method for developing those formal thought processes necessary to understand specific formal concepts.

Analysis of Covariance Control of M-power Influence

The analysis of covariance is a procedure for statistically controlling one or more concomitant quantitative variables, thereby removing their influence from comparisons of groups with regard to the main treatment variable. According to Hays[10] this method first provides a more precise estimate of the dependent variable means by removing the linear effects or influences of the concomitant variable and then compares these adjusted means for evidence of treatment effects.

The assumptions which must be met in using this post-hoc statistical control are:

1. The usual Anova assumptions of normality, homogeneity of variance, and independence of errors.
2. Equality of slopes within treatment regression lines.
3. The covariate is assumed to be unaffected by the treatments.[11]

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[10] William L. Hays, Statistics for the Social Sciences, Second Edition, (Dallas, Texas: Holt, Rinehart, Winston, 1973), pp. 654-658.

[11] *Ibid.*

Even though experimental controls were achieved through the random assignment of subjects to teaching treatments, evidence presented in this investigation supports the judgment that analysis of covariance could be correctly used with the covariate M-power so as to more precisely control any influences M-power might have had on cognitive development and concrete content achievement. Since no statistically significant t-ratios were found between the instruction groups on formal content examinations, an analysis of covariance was not indicated for this dependent variable. Data from these analyses of covariance are presented in Table 4-10 and Table 4-11.

TABLE 4-10

ANALYSIS OF COVARIANCE, COGNITIVE DEVELOPMENT SCORES
BY INSTRUCTION TREATMENT WITH M-POWER CONTROLLED

Variable	F	df_A, df_{Error}	p
Cognitive Development Pretest	.261	(1,109)	.610
Cognitive Development Posttest	16.256	(1,109)	$<$ .001
Cognitive Development Change	24.274	(1,109)	$<$ .001

TABLE 4-11

ANALYSIS OF COVARIANCE, CONCRETE ACHIEVEMENT SCORES
BY INSTRUCTION TREATMENT WITH M-POWER CONTROLLED

Concrete Content Examination	F	df_A, df_{Error}	p
1 - Ecology	55.071	(1,100)	$<$ .001
2 - Energy Utilization	69.284	(1,100)	$<$ .001
3 - Energy Production	47.216	(1,100)	$<$ .001
Average Z Scores	82.909	(1,100)	$<$ .001

A comparison of the significance levels for the F values on Table 4-10 and the t-ratios on Table 4-7 reveals that cognitive development pretest differences between instruction groups are nonsignificant whether or not any influences of M-power are statistically removed with analysis of covariance. Similarly, both the t-test and the analysis of covariance comparisons on the cognitive development posttest scores were significantly higher in favor of concrete instruction. However, analysis of covariance did produce an F value with a significance level of less than .001 instead of the .010 significance level produced by the t-test comparison without statistical controls of M-power. Mean gains in cognitive development were also higher for the concrete instruction group and were significant at less than .001 levels on both the t-test and the analysis of covariance. Concrete instruction, then, was seen to effect significantly greater cognitive developement even when M-power influences were controlled.

By comparing the t-test results on Table 4-8 with the analysis of covariance results on Table 4-11, the reader may see that the concrete instruction group consistently showed greater achievement than the formal instruction group on all three examinations measuring understanding of concrete concepts. Further, these differences were always significant at less than the .001 level, whether or not M-power influences on concrete achievement were statistically removed.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER STUDY

The purpose of this investigation was to gather evidence with which to empirically evaluate proposed relationships among M-power, cognitive development, concrete and formal instruction methodologies, and achievement on selected concrete and formal biology concepts. Although the data presented in Chapter IV indicated statistically significant relationships among several of these variables, the practical significance of any research findings should be judged in view of the strengths of the relationships among variables. A very weak relationship could be statistically significant when based on a large sample yet have insufficient practical implications to justify its inclusion in most curricula. For this reason, the meanings of the following conclusions from this investigation have been inferred after giving due consideration to the appropriate strength-of-association (relationship) measures.

The strength of the relationship between a treatment variable and its effect on some dependent variable is measured for a t-test with the following computational equation:[1]

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[1] Marigold Linton and Philip Gallo, Jr., The Practical Statistician, (Monterey, California: Brooks/Cole Pub. Co., 1975), p. 334.

$$\eta^2 = \frac{t^2}{t^2 + df.}$$

where, η^2 = eta squared

t = the value of the t-ratio comparison between the groups

df.= degrees of freedom

Linton and Gallo[2] recently calculated strength-of-association measures on most of the published studies in American Psychological Association journals for the year 1964. Based on that survey, more than half of those published studies accounted for less than five percent of the variance in the dependent variables which was studied. According to Linton and Gallo, any study accounting for more than ten percent of the variance on the dependent variable was "doing better than the vast majority of studies."[3] With this statement in mind, the investigator considered the following conclusions to be especially noteworthy:

1. With reference to Table 4-7, concrete, learning cycle instruction does promote significantly greater cognitive development than formal instruction. Based on a t value of 5.07 and 114 degrees of freedom, the eta squared value of 0.184 means that more than eighteen percent of the variance in cognitive development pretest to posttest change scores is accounted for by factors associated with the concrete instruction treatment. Thus, the strength of the relationship between concrete instruction and gains in the cognitive development scores in this study was strong.

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[2] Ibid, p. 330.

[3] Ibid, p. 331.

As previously described, the concrete instruction treatment primarily differs from formal instruction in that concrete instruction provides a wide background of concrete, hands-on assimilations for each student and encourages each student to take an active role in accommodating the meanings of his/her own assimilations. It may thus be inferred from the findings of this research that a substantial and important portion of each student's cognitive development may be attributed to his/her personal interactions with selected concrete objects and experiences.

2. With reference to Tables 4-8 and 4-9, concrete, learning cycle instruction does promote significantly greater achievement on measures of understanding of concrete biology concepts than that achievement which is produced by formal instruction of the same concepts. Neither method of instruction regularly produces significantly greater achievement on measures of the understanding of formal biology content; however, observed differences in achievement on formal concepts are consistently in favor of concrete instruction.

Using each student's average Z score, an eta squared value of 0.333 was obtained for the t-test comparing the instruction groups' average concrete content achievement. This value means that, in this investigation, more than thirty three percent of the variance on average concrete concept achievement is accounted for by factors associated with concrete instruction. In light of the effects typically produced in those studies surveyed by Linton and Gallo, concrete instruction may be inferred to exert very powerful influences on concrete content achievement as well as cognitive development.

As explained in Chapter IV, overall student achievement on formal content was best indicated in this investigation by each student's total score of the formal questions on all three examinations. Using these data, an eta squared value of 0.061 was obtained for the t-test comparing the instruction groups' overall formal content achievement. This value means that only six percent of the variance in achievement on all twenty of the formal concept questions is due to factors associated with the more effective teaching treatment, i.e. concrete instruction. These findings may be interpreted as providing further support of the findings of Lawson and Renner[4] and Cantu and Herron[5] that concrete operational students cannot understand formal operational concepts, but that concrete instruction is still preferable to formal instruction, especially since concrete instruction promotes superior cognitive development.

3. With reference to Table 4-6, concrete, learning cycle instruction does not produce a pattern of M-power development which is significantly different from the pattern produced by formal instruction. This finding suggests that M-power development is not a sufficient cause for the accelerated cognitive development and greater content achievement associated with concrete instruction.

4. With reference to Table 4-5, M-power scores correlate positively with both cognitive development levels and achievement scores

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[4] Anton E. Lawson and John W. Renner, "Relationships of Science Subject Matter and Developmental Levels of Learners," <u>Journal of Research in Science Teaching</u>, Vol. 12, No. 4, 1975.

[5] Luis L. Cantu and J. Dudley Herron, "Concrete and Formal Piagetian Stages and Science Concept Attainment," <u>Journal of Research in Science Teaching</u>, Vol. 15, No. 2, March, 1978, pp. 135-143.

on concrete and formal biology concepts. Evidence also suggests the existence of positive correlations between M-power scores and age for subjects up to at least fifteen and a half years of age.

The appropriate strength-of-association measure of the Pearson r is called the coefficient of determination[6] and is calculated as r squared (r^2). According to Linton and Gallo, this measure tells "the proportion of variance on one set of scores which can be accounted for from the other set of scores."[7] These coefficients of determination range in value from 0.130 to 0.240 for the strength of the association between this sample's M-power scores on the FIT and their cognitive development scores on the CAP instruments. Such values indicate a relatively large thirteen percent to twenty four percent of the variance in cognitive development scores for the entire sample can be accounted for by the M-power scores. Any interpretation of the strength of the relationship between M-power scores and cognitive development scores, however, must also take into account this investigation's previous conclusion that concrete instruction did not significantly affect M-power development but did produce significantly greater cognitive development.

Although it is not reasonable to infer that nonsignificant M-power differences caused significant cognitive development differences, it is reasonable to suggest that minimum M-power scores may be necessary before cognitive development can proceed beyond certain levels.

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[6] Linton and Gallo, *op. cit.*, p. 344.

[7] *Ibid*, p. 329.

Assuming that most students in this investigation had reached or exceeded any such M-power constraints, the rate of cognitive development would then be influenced by other factors, in particular the quality and amounts of those concrete experiences provided by the instruction method.

As a case in point, one student (Ss No. 2) was seen on Table 4-3 to achieve a Piagetian classification of transitional to formal operations with an FIT score of only thirty three of the possible 232 points. However, the lowest FIT score of any student entering the formal operations classification (Ss No. 20) was 108 points. The disparity between these two M-power scores suggests the need for higher M-power in order to be successful with formal operations. More conclusive data on this possibility await further research.

5. With reference to Table 4-5, both cognitive development scores on the CAP and M-power scores on the FIT correlate positively with achievement scores on measures of both concrete and formal biology concepts.

By correlating average achievement Z scores on concrete biology concepts with M-power pretest and posttest scores, the coefficient of determination for the average r of 0.285 is 0.081. However, by correlating average achievement Z scores on concrete biology concepts with cognitive development pretest and posttest scores, the coefficient of determination for this average r of 0.614 is 0.377. These data indicate that almost forty percent of the variance in average achievement on concrete biology content is explained by cognitive development, with less than one-fourth as much of the variance being explained by M-power.

The pattern above is similar to that which is found on achievement with formal biology concepts. By correlating the sums of the achievement tests on formal biology concepts with M-power pretest and posttest scores, the coefficient of determination for the average r of 0.220 is 0.048. Again, by correlating the sums of achievement tests on formal biology concepts with cognitive development pretest and posttest scores, the average r of 0.530 yielded the much higher coefficient of determination of 0.281. In this case, cognitive development accounted for more than five times as much of the variance on the sums of the formal content achievement tests than that portion of the variance which was attributed to M-power.

These patterns of association among M-power, cognitive development, and content achievement are better understood in relation to the investigator's judgment that understandings of concepts are best measured with questions that deemphasize the simple recall of information and emphasize the transfer of learnings to new situations.

As previously defined, M-power is simply the maximum number of independent schemes that can be attended to at any one moment in the absence of direct support from the perceptual field. M-power thus places constraints on understanding only when the task demands exceed the available M-power.

A more general constraint on understanding, however, is insufficient cognitive development for subjects who normally do have sufficient M-power. Since cognitive development has been viewed as a succession of increasingly more comprehensive executive strategies,[8] two subjects with different levels of cognitive development would be expected to use different mental strategies to resolve some cognitive conflict, even though they might have identical M-powers and might have also been taught with the same method. On a test question which requires the application of learnings in new situations, the student with the greater cognitive development would be more likely to successfully organize the data needed to transfer his/her understandings and identify the correct answer choice.

The strength-of-association between M-power and success on these content instruments thus reflects that relatively small portion of achievement variance which is accounted for by the size of one's memory. The large strength-of-association between cognitive development and success on these content instruments shows the much more powerful influence of the comprehensiveness of one's thinking strategies.

The conclusions from this research all lend support to the investigator's judgment that concrete instruction is a superior tool for promoting both cognitive development and content achievement significantly and importantly beyond those levels resulting from formal instruction. Furthermore, these same research findings strongly support the philosophy that the time and money used in providing each student with numerous concrete experiences is well spent. The suggestion that verbal teaching strategies which reduce M-power demands may be used to supplant concrete

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[8] H.A. Simon, "An Information Processing Theory of Intellectual Development," Thought in the Young Child, W. Kessen & C. Kohlman, ed., Society for Research in Child Development Monographs, 1962, pp. 150-155.

experiences seems dubious. However, proposed interactions between M-power and sensory assimilations during the resolution of conflicts between incompatible schemes suggest the need for further research into how and when to best use concrete experiences to achieve educational goals.

This research and the conclusions drawn from it have revealed the need for additional research with which to answer the following questions:

1. What factors besides instruction method and M-power affect the rate of cognitive development? Marek[9] has found I.Q. to be one additional factor which correlates with cognitive development and which changes with concrete instruction. Are there others as well?

2. Are there minimum levels of M-power which are necessary before a student can enter each qualitative stage of thought processes? If so, at what ages are these minimums usually reached?

3. Are there any experiences or logical strategies which can be used to accelerate M-power development?

4. To what extent can teaching strategies which reduce M-power demands assist concrete assimilations in promoting cognitive development and in helping students to accommodate specific concepts?

The conclusions drawn from this investigation and subsequent investigations of M-power and cognitive development could have a profound influence on the quality, quantity, and sequencing of the concrete experiences conscientious teachers should be regularly providing for their students.

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[9] Edmund A. Marek and John W. Renner, "Intellectual Development, IQ, Achievement, and Teaching Methodology," The American Biology Teacher, 1979, Vol. 41, No. 3, pp. 145-150.

BIBLIOGRAPHY

Books

Bruner, Jerome S. *The Process of Education*. Cambridge, Massachusetts: Harvard University Press, 1960.

________. "The Process of Education--Reconsidered," *Dare to Care/ Dare to Act: Racism and Education*, Robert R. Leeper, ed., Washington, D.C.: Association for Supervision and Curriculum Development, 1971.

________. *Toward a Theory of Instruction*. Cambridge, Massachusetts: Harvard University Press, 1966.

Bybee, Rodger W. *Personalizing Science Teaching*. Washington, D.C.: National Science Teachers Association, 1974.

Case, Robbie, "Piaget and Beyond: Toward a Developmentally Based Theory and Technology of Instruction," *Advances in Instructional Psychology*, Vol. 1, Robert Glaser, ed., Hillsdale, New Jersey: Lawrence Erlbaum Associates, 1978.

________. *The Process of Stage Transition in Cognitive Development*. Berkely, California: University of California, 1977.

Downie, N.M. and Heath, R.W. *Basic Statistical Methods*. New York: Harper & Row, 1970.

Flavell, J.H. *The Developmental Psychology of Jean Piaget*. New York: Van Nostrand Reinhold, 1963.

Hays, William L. *Statistics for the Social Sciences*, Second Edition, Dallas, Texas: Holt, Rinehart, Winston, 1973.

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

________, Sinclair, H, and Bovet, M. *Learning and the Development of Cognition*. Cambridge, Massachusetts: Harvard University Press, 1974.

Linton, Marigold and Gallo, Philip, Jr. The Practical Statistician, Monterey, California: Brooks/Cole Pub. Co., 1975.

Magnusson, David. Test Theory. Reading, Massachusetts: Addison-Wesley Pub. Co., 1967.

Phillips, John L., Jr. The Origin of Intellect: Piaget's Theory, Second Edition. San Francisco, California: W.H. Freeman & Co., 1975.

Piaget, Jean. The Child and Reality. New York: Grossman Publishers, 1972.

_________. The Psychology of Intelligence. Paterson, New Jersey: Ligglefield, Adams, 1963.

Posner, M.I. "Short Term Memory Systems in Human Information Processing," Attention and Performance I, A.F. Sanders, ed., Amsterdam: North Holland, 1970.

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

_________, Stafford, Don G., and Ragan, William B. Teaching Science in the Elementary School, Second Edition. New York: Harper & Row, 1973.

_________ and Stafford, Don G. Teaching Science in the Elementary School, Third Edition. New York: Harper & Row, 1979.

_________, et. al. Research, Teaching, and Learning with the Piaget Model. Norman, Oklahoma: University of Oklahoma Press, 1976.

Silberman, Charles. Crisis in the Classroom. New York: Random House, 1970.

Simon, H.A. "An Information Processing Theory of Intellectual Development," Thought in the Young Child, Kessen, W. and Kohlman, C., ed., Society for Research in Child Development Monographs, 1962.

Articles

Ausubel, David P. "Some Psychological Considerations in the Objectives and Design of an Elementary-School Science Program," Science Education, Vol, 47, Issue 3, 1963.

Cantu, Luis L. and Herron, J. Dudley, "Concrete and Formal Piagetian Stages and Science Concept Attainment," Journal of Research in Science Teaching, Vol. 15, No. 2, 1978.

Case, Robbie. "Validation of a neo-Piagetian Capacity Construct," Journal of Experimental Child Psychology, Vol. 14, 1972.

__________. "Responsiveness to Conservation Training as a Function of Induced Subjective Uncertainty, M-space, and Cognitive Style," *Canadian Journal of Behavioral Science*, Vol. 9, 1977.

Kohlberg, Lawrence and Gilligan, Carol. "The Adolescent as Philosopher: The Discovery of the Self in a Postconventional World," *Daedalus: Journal of the American Academy of Arts and Sciences*, Vol. 100, No. 4, Fall, 1971.

Lawson, Anton E. "M-Space: Is it a Constraint on Conservation Reasoning Ability?" *Journal of Experimental Child Psychology*, Vol. 22, 1976.

__________ and Renner, John W. "Relationships of Science Subject Matter and Developmental Levels of Learners," *Journal of Research in Science Teaching*, Vol. 12, No. 4, 1975.

Marek, Edmund A. and Renner, John W. "Intellectual Development, IQ, Achievement, and Teaching Methodology," *The American Biology Teacher*, Vol. 41, No. 3, 1979.

McKinnon, Joe W. and Renner, John W. "Are Colleges Concerned with Intellectual Development?" *American Journal of Physics*, Vol. 39, No. 9, 1971.

Pascual-Leone, Juan. "A Mathematical Model for the Transition Rule in Piaget's Developmental Stages," *Acta Psychologica*, Vol. 63, 1970.

Piaget, Jean. "Genetic Epistemology," *Columbia Forum*, Fall, 1969.

__________. "Development and Learning," *The Journal of Research in Science Teaching*, Vol. 2, Issue 3, 1964.

Renner, John W. "Learning, Motivation, and Piaget," *Engineering Education*, March, 1974.

__________. "The Relationships Between Intellectual Development and Written Responses to Science Questions," *Journal of Research in Science Teaching*, Vol. 16, No. 4, 1979.

Stafford, Don G. and Renner, John W. "SCIS Helps the First Grader to Use Logic in Problem Solving," *School Science and Mathematics*, February, 1971.

Pamphlets

Educational Policies Commission. *The Central Purpose of American Education*. Washington, D.C.: National Education Association, 1961.

Oklahoma Curriculum Improvement Commission. *The Improvement of Science Instruction in Oklahoma, Grades K-6*. Oklahoma City: Oklahoma State Department of Education, 1968.

Oltman, Philip ., Raskin, Evelyn, and Witkin, Herman A. Group Embedded Figures Test. Palo Alto, Calif.: Consulting Psychological Press, 1971.

Pascual-Leone, Juan. Figural Intersection Test: A Group Measure of M-space. Downsview, Canada: York University, 1977.

Unpublished Materials

Bautista, Leticia B. The Relationship Between Intellectual Levels and Achievement in the Comprehension of Concepts Classified According to a Scheme Derived from the Piagetian Model. Unpublished Doctoral Dissertation, University of Oklahoma, 1974.

Grant, Norris. The Validity of Objective Testing as a Process of Appraising the Thinking Ability of Students in High School Biology and Physics. Unpublished Doctoral Dissertation, University of Oklahoma, 1974.

Grant, Rosalie M. Group and Individual Problem Solving High School Students. Unpublished Doctoral Dissertation, University of Oklahoma, 1978.

Johnson, Linda M. Biology Concepts Taught Compared to the Intellectual Level of the Biology Student. Unpublished Masters Thesis, University of Oklahoma, 1975.

Lawson, Anton Eric. Relationships Between Concrete and Formal Operational Science Subject Matter and the Intellectual Level of the Learner. Unpublished Doctoral Dissertation, University of Oklahoma, 1973.

Marek, Edmund A. The Influence of Inquiry Learning on Intellectual Development, Achievement, and IQ. Unpublished Doctoral Dissertation, University of Oklahoma, 1977.

Pascual-Leone, Juan. Cognitive Development and Cognitive Style. Unpublished Doctoral Dissertation, University of Geneva, 1969.

Schneider, Livingston S. Relationships Between Concrete and Formal Instructional Procedures and Content-Achievement, Intellectual Development, and Learner IQ. Unpublished Doctoral Dissertation, University of Oklahoma, 1977.

APPENDIX A

SAMPLES OF CONCRETE INSTRUCTION

LEARNING CYCLES

Name________________________

Chapter 2

GOAL: You will gain an understanding of how a scientist conducts an investigation and the features of the system he uses to make measurements.

A FACT can be defined as an observed phenomenon agreed on by a number of people. A scientist must be a good observer to determine the facts.

The following activity is devoted entirely to improving your ability to describe. You will gain most from doing the activity yourself or with the members of your group. Record your data in the space provided.

ACTIVITY: DESCRIPTION OF A BURNING CANDLE

Materials needed:
- 1 white candle, 8 to 10 inches long
- 1 box of matches
- metric ruler

Describe the unlighted candle as accurately as possible without destroying the candle, and make a record in the space provided below of each separate description. After you have had about 15 minutes to do this, then light the candle and continue making and recording your description of this event.

Pool your descriptions with those of the other members of your group. Compare the number, variety, and quality of your description with those of the others in your group. Decide who has the best description and discuss why it was so good. Why would a group's description be even better than that one?

Your Description:

The following very detailed description of a candle is taken from the text Chemistry, An Experimental Science. Compare the data (descriptions) which follow with your own.

"A drawing of a burning candle is shown in the accompanying figure. The candle is cylindrical in shape and has a diameter of about 3/4 inch. The length of the candle was initially about 8 inches and it changed slowly during the observation, decreasing about 1/2 inch in one hour. The candle is made of a translucent, white solid which has a slight odor and no taste. It is soft enough to be scratched with the fingernail. There is a wick which extends from top to bottom of the candle along its central axis and protrudes about half an inch above the top of the candle. The wick is made of three strands of string braided together.

A candle is lit by holding a source of flame close to the wick for a few seconds. Thereafter the source of flame can be removed and the flame sustains itself at the wick. The burning candle makes no sound. While burning, the body of the candle remains cool to the touch except near the top. Within about 1/2 inch from the top, the candle is warm (but not hot) and sufficiently soft to mold easily.

The flame flickers in response to air currents and tends to become quite smoky while flickering. In the absence of air currents, the flame is of the form shown in the figure though it retains some movement at all times. The flame begins about 1/8 inch above the top of the candle and at its base the flame has a blue tint. Immediately around the wick in a region about 1/4 inch wide and extending about 1/2 inch above the top of the wick, the flame is dark. This dark region is roughly conical in shape. Around this zone and extending about half an inch above the dark zone is a region which emits yellow light, bright but not blinding. The flame has rather sharply defined sides, but a ragged top.

The wick is white where it emerges from the candle, but from the base of the flame to the end of the wick it is black, appearing burnt, except for the last 1/16 inch where it glows red. The wick curls over about 1/4 inch from its end. As the candle becomes shorter, the wick shortens too, so as to extend roughly a constant length above the top of the candle. Heat is emitted by the flame, enough so that it becomes uncomfortable in ten or twenty seconds if one holds his finger 1/4 inch to the side of the quiet flame or 3 or 4 inches above the flame.

The top of a quietly burning candle becomes wet with a colorless liquid and becomes bowl shaped. If the flame is blown, one side of this bowl-shaped top may become liquid, and the liquid trapped in the bowl may drain down the candle's side. As it courses down, the colorless liquid cools, becomes translucent, and gradually solidifies from the outside, attaching itself to the side of the candle. In the absence of a draft, the candle can burn for hours without such dripping. Under these conditions, a stable pool of clear liquid remains in the bowl-shaped top of the candle. The liquid rises slightly around the wick, wetting the base of the wick as high as the base of the flame."

Several aspects of this description deserve specific mention. Compare your own description in each of the following characteristics:

1. The description is full of sensory details. They checked all the five senses and recorded those observations too. When you described the candle, did you remember to include its smell, taste, feel, and sound in addition to its appearance?
   (NOTE: A chemist quickly becomes reluctant to taste or smell an unknown chemical. A chemical should be considered to be poisonous unless it is known not to be!)

2. Wherever possible, the description uses measurements. This means that the question "How much?" is answered. Notice how many times the description uses number measurements of the various parts of the candle. Also, the remark that the flame emits yellow light is made more meaningful by the "how much" expression, "bright but not blinding." They even included the distance and time factors to describe "how much" heat was emitted by the flame.

3. The description does not presume that any aspect of the observation is less important than the others. Thus the observation that a burning candle does not make any sound deserves to be mentioned just as much as the observation that it does emit light.

4. The description sticks to observable facts and avoids making any interpretations. It is an observation that the top of the burning candle is wet with a colorless liquid. It would be an interpretation to state what you think or presume is the composition of that liquid.

Investigation 1

You will be given a piece of string and a measuring stick which has the length units of the metric system on one side and the length units of the English system on the opposite side. Study these two unit systems carefully.

Measure the following items in both centimeters and inches and record these values in the proper blanks below:

	centimeters	inches
Height of your desk top	________ cm.	________ in.
Length of your desk top	________	________
Length of your foot (from heel to tip of big toe)	________	________
Length of your lower arm (from elbow to tip of middle finger)	________	________
Neck size (at your Adam's apple)	________	________

Compare the measurements you have collected and determine how centimeters are related to inches. Use the information that you personally collected to figure out this relationship.

Getting the Idea:

In the space below, describe how centimeters are related to inches.

Expanding the Idea:

Convert 73 inches to feet. 73 in. = ________ feet

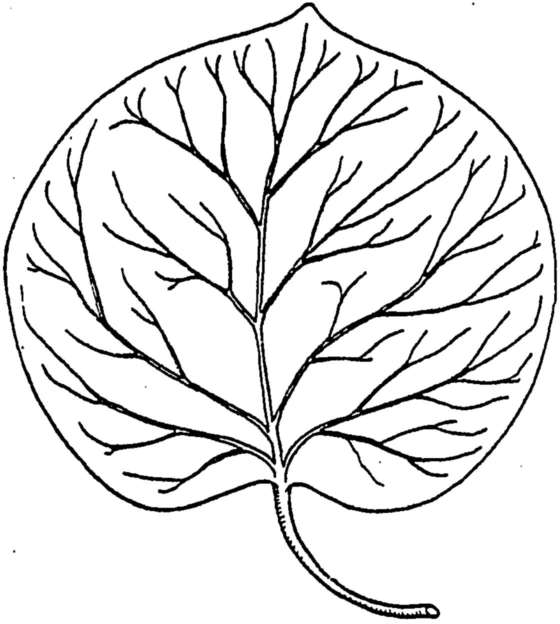
There are one hundred centimeters in a meter. Convert 646 centimeters to meters.

646 centimeters = __________ meters

Why do you think that scientists prefer to work with metric lengths rather than English system units of lengths? Write your answer in the space below.

Investigation 2

Using the centimeter side of your ruler, determine the approximate area of this leaf drawing. (HINT: Rule it off in 1 centimeter squares.)



_____ sq. cm.= area of the leaf

The tall, thin measuring cup used in the science class is called a "graduated cylinder." It is marked off in metric units of volume. A liter is about a quart; however, since scientists usually use less than a quart, they have divided the liter into 1000 smaller parts, each of which is called a milliliter (ml.).

What should you call a unit of length that is 1/1000 of a meter?

Use your metric ruler and draw a straight line exactly 5 of those units long in this circle.

Obtain a graduated cylinder, an overflow tray, and a beaker completely full of water. How could you use this equipment to find the volume of your hand?

First, ask the teacher whether your method would work. Then use your water overflow method to find the volume of your hand in milliters.

____________ml._____ = volume of my hand

What part of a liter is the volume of your hand? Write this answer as a decimal if you know how.

____

Using the enclosed handout, cut out, fold, and tape together a cubic centimeter. So as to avoid leaks, or spills, quickly transfer 10 cubic centimeters full of water to a small graduated cylinder.

1 cc. of water = ______ ml. of water

Getting the Idea:

What is the relationship between one cubic centimeter (cc.) and one milliliter (ml.)?
(HINT: If you aren't sure, transfer 10 more cc. of water to the graduated cylinder and compare again.
20 cc. of water = ______ml. of water)

Expanding the idea:

The weight of a volume of liquid is figured indirectly. To do this....

1. weigh the empty container
2. weigh the container, plus the desired amount of liquid
3. subtract the value of step 1. from the value in step 2.

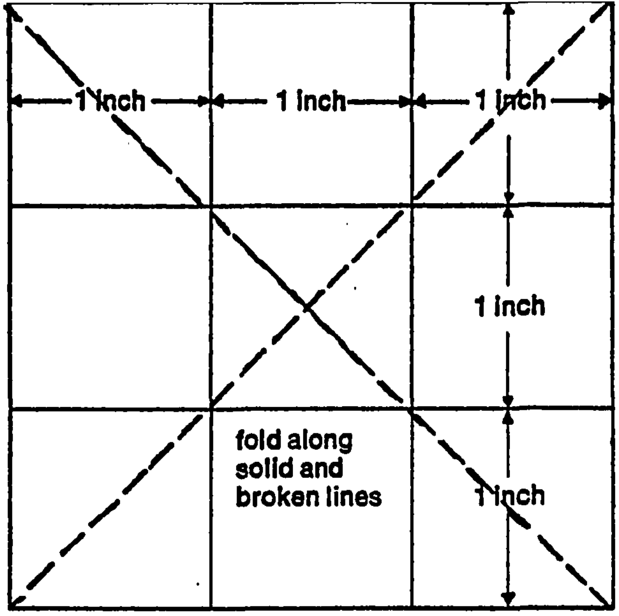
After learning the procedure for weighing items on a pan balance, determine the weight of exactly 50 ml. of pure (distilled) water in the metric unit for small weights which is grams (g.).

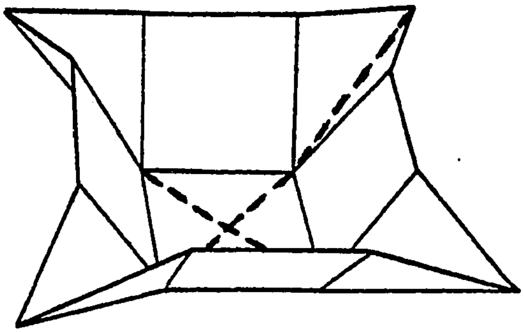
50 ml. of water = ______ g. of water

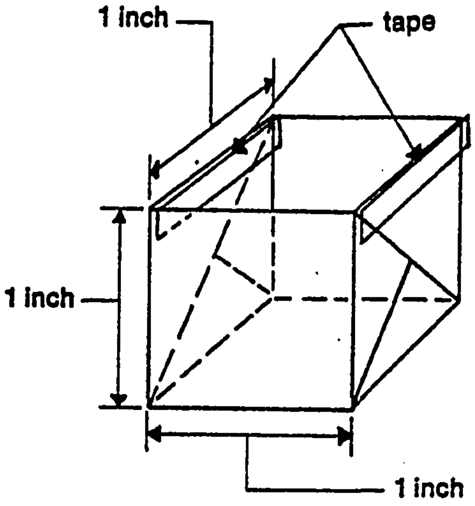
What is the weight of one ml. of pure water? _____________

Earlier in this investigation, you measured the volume of your hand. If your hand weighed the same as water (which it doesn't), predict how much it would weigh in grams.

_________ g. = wt. of the same volume of water as my hand



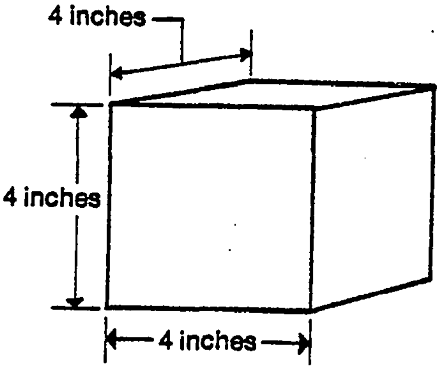




F. Things to Do

1. Construct a paper container with the volume of 1 cubic inch. Use this container to measure a cubic inch of such substances as granulated sugar, table salt, dry sand, and iron filings or iron powder. Fill the container with the substance you are measuring. Then gently tap the container to settle its contents. Add more of the substance, if necessary. The measure should be full and its contents level with the top of the container. Weigh each substance you measure on a pan balance. Make a chart to show the density of each substance you measure and weigh.

2. Cut out a square of paper 1 foot on each edge. Draw lines to divide the square foot into one-inch squares. How many inches are in a square foot? Cut the square into at least five pieces. Make some cuts straight and some curved. Fit all the pieces together in different ways. What is the area of each shape you produce?



Measuring a Volume

How can we measure the volume of a solid block that is not a cube? Suppose a block of wood is 8 inches long, 4 inches wide, and 2 inches high. To measure its volume, we multiply the length times the width times the height; 4 inches x 8 inches x 2 inches is 64 cubic inches. The block has the same volume as a solid cube 4 inches long, 4 inches wide, and 4 inches high. Objects with different shapes may have the same volume.

Investigation 3

Get a container of freshly drawn tap water and set it on your desk. Obtain an ice cube and paper towel. Watch for drips as you hold the ice cube on your fingertips for three minutes.

Immediately remove your fingers from the ice cube and plunge them into the tap water.

How does the tap water feel compared to the ice cube?

Repeat the above procedure using some rather hot water that the teacher has prepared in place of the ice cube.

How does the tap water feel compared to the hot water?

Why is there any difference in your sensation of the tap water?

By touch, arrange the five jars of water labeled A - E from the coolest to the warmest. Do not actually move the jars into their "proper" places, but list them in order below.

Coolest __________

____

____

____

Warmest __________

How could you test your hypothesis that this is the right order of the jars?

Remember that facts are observations upon which many people can agree. Observations which are recorded as <u>numbers</u> are called DATA.

Scientists usually use the metric system's Celsius degrees when measuring temperature.

Gathering Data:

Take the temperature of jars A - E with a Celsius thermometer and record those temperatures below.

A - ________°C

B - ________°C

C - ________°C

D - ________°C

E - ________°C

How do these data compare to your arrangement by touch?

Explain how it might be possible for your senses to have been "fooled" into getting the wrong arrangement.

Measure the temperatures of the following items in both Celsius degrees and Fahrenheit degrees. Record your observations below.

	°C	°F
Boiling water	_____	_____
Ice cube	_____	_____
Running tap water	_____	_____
Cold water from hall drinking fountain (One at a time in the hall)	_____	_____
Room temperature	_____	_____

How many degrees between the temperature of ice and boiling water on the

Celsius scale? __________ and the Fahrenheit scale? ___________

If you rounded off the above numbers to the nearest 10°, which measuring system would seem more logical?

Obtain one of the body temperature thermometers from your teacher and be sure it is disinfected with alcohol before you put it under your tongue.

After 3 - 5 minutes, remove this thermometer from your mouth and record your body temperature below.

__________°C __________°F

Is this number exactly what you expected? ________ Explain.

Using a different body temperature thermometer, again take your body temperature. (Be sure to disinfect this thermometer, too!)

__________°C __________°F

Why take your body temperature with two different thermometers?

What is your average body temperature? ________°C ________°F

Is this number what you expected? ______ Why or why not?

Record the average body temperature of 20 other students by name in the data table below.

	Name	°C	°F
1.			
2.			
3.			
4.			
5.			
6.			
7.			
8.			
9.			
10.			
11.			
12.			
13.			
14.			
15.			
16.			
17.			
18.			
19.			
20.			

How do the numbers in each column compare to one another?

What is the average body temperature of the first 5 students? __________
How does this number compare to the standard you expected?

What is the average body temperature for all twenty students? __________
How does this number compare to the standard of 37°C or 98.6°F ?

Explain how you think text books came up with the figure of 98.6°F as the standard body temperature for humans?

Getting the Idea:

A VARIABLE is an observation that can have different values. Individuals vary in many ways, including their body temperatures.

Expanding the Idea:

A kilogram is 1000 grams. Keeping your shoes on, weigh yourself on the bathroom scale marked in kilograms. Record your weight below and also on the the chalkboard.

_____._____ kg.

Using the class data, record the total number of people in each weight interval listed below.

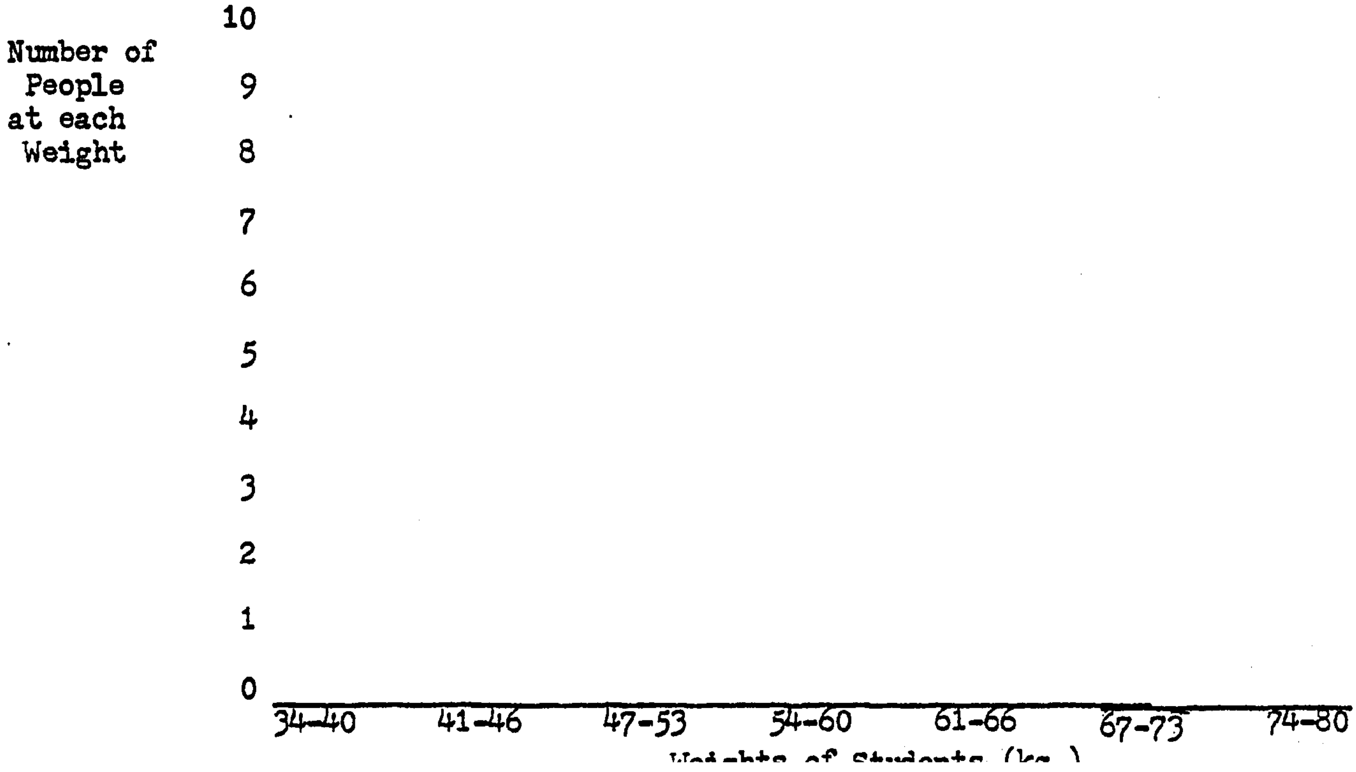
34 - 40 kg. ______ people
41 - 46 kg. ______
47 - 53 kg. ______
54 - 60 kg. ______
61 - 66 kg. ______
67 - 73 kg. ______
74 - 80 kg. ______

Compare the "data table" arrangement above to the "raw data" listed on the chalkboard. In what way is the data table arrangement better?

Use either the raw data list on the chalkboard or your data table to finish the bar graph started below. *

* NOTE: Don't let the final height of each bar go above the totals listed in your data table. You already have a headstart on some of the bars.

Bar Graph of Student Weights



What is the lightest weight interval with anyone in it?___________

What is the heaviest?__________

Which one weight interval best represents all the people in this class? __________

Compare your bar graph (called a histogram) to your data table. How is the bar graph better?

Does your weight vary from that weight? _______ If so, how?

What are three human variables other than weight and body temperature?

An EXPERIMENT is a time when facts are gathered to help us find out something or to solve a problem.

Gathering Data:

Obtain a "stopper popper" from the teacher and determine how it works. SAFETY NOTE: Do not point it at anyone, however, even if you think they are out of range!

List all of the <u>variables</u> you can think of which might affect the range of the stopper popper:

In order to answer the question "How does the angle of the stopper popper affect its range?" we are going to do a series of experiments.

Which variable will have a different value for each try? ____________________

Explain in detail how you will keep each of your other variables the <u>same</u> for each try.

Why is it necessary to keep all of the variables but one the same for each try of the series?

Record the flight distance you measure for each angle to the nearest 1/10 of a meter. Test each angle at least <u>two</u> times. Then figure the <u>average</u> flight distance for that angle.

Stopper popper angle	Flight Distance (to the nearest 1/10 of a meter)			Average Flight Distance
Example - ?? degrees	3.4	3.7		3.6
0 degrees				
20 degrees				
40 degrees				
70 degrees				
80 degrees				

Report your results to the teacher <u>if</u> he asks for them and observe the board as he demonstrates the procedure for making a line graph.

On the graph squares below, construct a line graph of the results of your experiments.

One of the best benefits of drawing a graph to summarize an experiment is that it allows us to PREDICT the results on experimental trials that we have not yet done.

From your line graph, predict the distance the stopper would travel if the angle were...

30 degrees _____

55 degrees _____

90 degrees _____

Put a target box at the predicted range for 55 degrees and see if your stopper hits it, as predicted.

How well did this work?

Can you predict what angle you would need to hit a box ______ meters away? (HINT: Use your graph.)

Now try it. How well did you do?

Getting the Idea:

A CONTROLLED EXPERIMENT is one in which all factors are identical, except the one being tested.

The factor which the experimentor chooses to vary is the INDEPENDENT VARIABLE or treatment.

The effect of the independent variable (which must be measured) is called the DEPENDENT VARIABLE.

What was the independent variable in your stopper popper experiment?

What is an example of a variable which was "controlled" (kept the same) throughout the stopper popper experiment?

What was the dependent variable in the stopper experiment?

Why do you think it would be almost impossible to have 100% accuracy in predicting events from a controlled experiment?

Expanding the Idea:

A scientist is often compared to a detective solving a mystery. However, guessing alone is not enough. Scientific guesses must begin with the facts and must then be confirmed by testing (or EXPERIMENTING). In other words, a scientist must always back up his guesses with evidence.

For example, you recently weighed yourself using the metric system's unit of weight, the gram. (Because there were thousands of these, you recorded your weight in kilograms.)

Based on your past experiences you should already have an idea of how a person's height relates to his or her weight. Write down what you think that relationship is.

To get more specific, is that relationship also affected by the sex of the person?

In what way? (HINT: How will you expect a gro up of teen-aged boys to compare to a group of girls of about the same height?)

A good scientific guess or HYPOTHESIS is testable with an experiment.

Describe what needs to be done to test your hypothesis above, using our class for your data.

What are some of the variables that you need to control in your suggested experiment?

In order to test your hypothesis about height and weight, we are going to have your lab partner use pencil (not pen) to put a small mark on the wall, making it even with the top of your head. Keep your shoes on as he or she does the measuring.

Have your lab partner measure this height in centimeters. Also have him subtract the thickness of one of you r shoe heels before you record your height below.

_______ cm. = height without shoes
(as measured by partner)

From the same pencil mark on the wall, you measure your own height in centimeters and again subtract your heel thickness as you record your result below.

_______ cm. = height without shoes
(as measured by me)

Compare these two height values.

Why might there be differences between them?

Average the two height values and record this average (rounded to the nearest cm.) as well as your sex and weight (in kg.) on the "Class Data Table" portion of the chalkboard and also below.

_______ = height in cm. (average)

_______ = weight in kg. (from previous lesson)

_______ = sex

Describe which variable was controlled in the instructions above and how it was kept the same.

Suggest any ways you might put in controls which weren't mentioned.

Observe the procedure the teacher uses for making a line graph which has two lines on the same graph.

Following his instructions and using the Class Data Table, make a graph for males and then use the same graph squares to make a graph for females.

The average lines you were told where to draw are based on <u>all</u> the people in each group.

How does your weight compare to the average line for your sex? (NOTE: Be sure to compare at only your height!)

How much heavier or lighter than that average are you?

How does the average boy who is 150 cm. tall compare to the average girl of the same height?

Based on the average line for females, predict the weight of the average girl who is 4 cm. taller than anyone in your class.

Predict the <u>height</u> of the average male who weighs 55 kg.

How do boys' weights compare <u>in general</u> to girls of the same height? Be specific and base your answer on the <u>evidence</u> of your graph.

How does this evidence go along with the hypothesis you wrote before the experiment?

Observing Fresh Water Cultures

In this exercise, your class will begin several small water cultures. With these cultures you should be able to find out many biological principles. Try to keep the culture going as long as the teacher suggests. If you make careful observations and keep a record of them, you will learn many new ideas in biology.

Materials

One-gallon wide-mouth jar
Cover for jar
Masking tape for label

Procedure

Clean the jar thoroughly. Wash it with soap, or a detergent, and then rinse it several times with tap water. After drying the outside of the jar thoroughly, place a label on it. On the label put your name, the date, and the information about where the material in the jar came from.

Prepare the contents of the jar using one of the methods listed below. When completed, the jar should be about two-thirds full. Remember to record what you have done on the label.

A. Place three handfuls of grass and leaves from a dried-up ditch into the jar. Add water from a pond, river, or lake.

B. Put material directly from the pond, river, or lake in the jar. This might include plants, snails, mud, decaying matter, or floating materials. Add water from a pond, river or lake.

C. Place three handfuls of grass or leaves from different places in the jar. Add tap water that has been allowed to stand in the open air for at least 24 hours.

Cover the jar with a loose-fitting cover. A piece of glass will work well. You may use the jar's cover, but be sure that it is not screwed on tightly. Place the jar in a well-lighted place, but not in the direct sunlight.

You will be using your water culture at different times. Discuss with your lab partners how you will keep records of all your observations. Prepare a special sheet in your notebook on which you can keep all of your observations.

Examine the jars for a few minutes during each class period that the teacher requests. Record any changes you observe in your notebook. Also, remember to record the date on which you observed these changes.

Here are just a few examples of some of the things you should be looking for: Does a scum appear on the surface of the water? Or is the scum on the sides of the jar? Does the water become cloudy? Does the material in the jar change appearance? Do you notice any animals in the jar? Do these animals move?

Chapter 15

As an activity for the entire class, the teacher has brought an assortment of objects for you to study. There are many similarities (or likenesses) and differences between the objects.

After the teacher has divided the objects into two smaller groups, see if you can determine what characteristic is common among all the objects in each group.

Next, see if you can suggest a different way of organizing these objects into two groups. Do <u>not</u> tell the class your system. Have them figure it out by looking at which objects you put together.

Investigation 1

BIOLOGY is the study of life. Make a list of 20 things and then sit down with your lab partners and put these things into categories of living and nonliving. Write this on your own sheet of notebook paper.

Make a list of all the reasons for putting the objects into the categories. Remember, if you put any object into the living category for a particular reason, you cannot put any other object into the nonliving category for that same reason. Now, recopy your items and reasons into the appropriate spaces below.

Living		Nonliving	
Item	Reason	Item	Reason

At the end of this investigation, your explorations should have led you to have invented a CLASSIFICATION for living and nonliving objects.

Next, pick any object in the room and, using your classification system, explain why it is one of the categories, living or nonliving.

Investigation 2

The science of classifying living things is called TAXONOMY. A famous Greek named Aristotle is often called the "father of biology." One of his many contributions to biology was to invent one of the first classifications of animals.

Study each of the lists of animals below.

Group 1	Group 2	Group 3
bass	bat	ostrich
clam	hawk	garden snail
penguin	mosquito	salamander
tadpole	flying fish	bear
whale		ant

For what reason are all the animals in Group 1 together?

What is the same about all the animals in Group 2?

What property do the animals in Group 3 share?

What is the basis for Aristotle's taxonomy of all the animals?

* * *

Over two thousand years after Aristotle, a Swedish scientist named Carolus Linnaeus decided to classify animals in a different way.

Someone familiar with Linnaeus' classification system would separate this same list of animals into the following categories:

1	2	3	4	5	6
garden snail	ant	bass	salamander	ostrich	whale
clam	mosquito	flying fish	tadpole	hawk	bear
				penquin	bat

What is one common property that the animals in group 5 share?

What are some of the properties that made gro up 2 distinct and separate from the other groups?

How is Linnaeus' way of separating groups different from Aristotle's?

Linnaeus considered his animal taxonomy to be more helpful for studying the animals than Aristotle's classification system. Explain why his system is better.

Getting the Idea:

Modern biological classification systems are based on similarities of body structure. Two body parts which are similar in structure, shape, and origin are said to be HOMOLOGOUS.

Expanding the Idea:

(Do lab work in groups of three.)

Obtain a tray of various kinds of sea shells. Label each sea shell with a numbered piece of masking tape.

As you did earlier with the assorted objects, divide the shells into two distinct groups on the basis of some homologous characteristics that they have in common.

On the blanks below, list the numbers of the sea shells in each group. Then in the space below each group, describe what characteristic(s) group A had that group B did not have - and vice versa.

Sea Shells

Group A: ____________________ Group B: ____________________

Unique characteristics: Unique characteristics:
( ) ( )
( ) ( )
( ) ( )

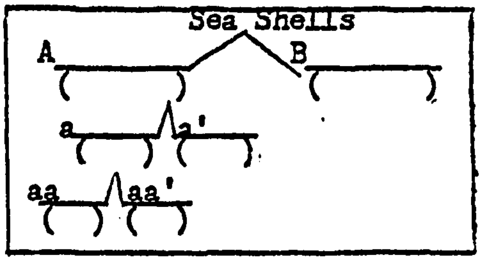
Now subdivide group A into two smaller groups, each of which must have at least <u>one</u> distinct feature. Again list the numbers of the shells in each group, but note that your sea shell choices are limited to those in that one group (A in this case). Also record the unique group feature(s).

Group A : ____________________
( )

Group (a): ____________________ Group (a'): ____________________

Unique features: Unique features:
( ) ( )

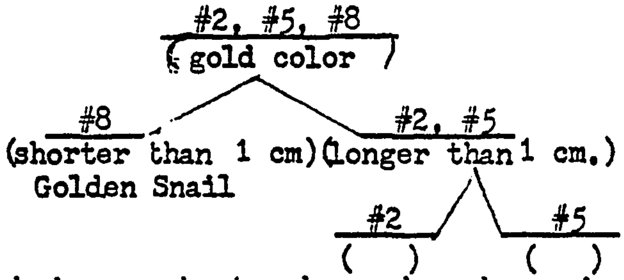
Obtain a clean sheet of typing paper from your teacher. Turn it lengthways on your desk so that you will have room for your the information, set up your chart as sketched below. Copy the information you put on page 15.3 onto your chart.



Now, continue the subdividing process for each group with 2 or more sea shells in it. Do this for the B group too after you have finished completely subdividing the A group.

When you only have 1 sea shell in a "group", it is no longer a group of different kinds of sea shells. It is, however, a representative of that one kind of sea shell. One biologic kind of plant or animal is called a SPECIES.

On your chart, give each species an imaginary name when it is the only sea shell in its group. Here is an example:



Once you have finished your chart and named each species, take the number labels off each sea shell. Trade your sea shell tray and your shell classification chart with a neighboring group of students. Use their classification chart to determine (without asking them) which name matches each shell. Then ask them to check your answers to see how well you did at using their classification chart. Tell them any ideas you have for improving their chart.

Trade with at least 2 other groups and identify their shells as best you can.

What are some of the features of a poorly-made classification system?

How could your classification chart be improved, based on the suggestions of the other students who used it?

Homework Assignment

In this activity you will use a classification system that has already been prepared by a biologist. Its purpose will be to help you identify unfamiliar specimens.

Why do you think such charts are usually called "keys" by the biologists?

You will need to choose whether to collect leaves or insects. Your object is to have representatives from eight of the ten groups shown on the key, whether insects or plants.

To use either of the keys to identify your specimens, start at the top with a specimen you have collected. Work your way down through the choices by comparing them to your specimen. If you collect insects, you will soon arrive at a scientific name for the group to which that insect belongs. If you collect leaves, You will arrive at a short list of common names, one of which probably is the name of that plant. If you wish, you may use other, more detailed keys to search out the actual name for that specimen. This will be optional, however.

You must then follow more detailed instructions from the teacher on preserving and displaying your specimens. On each display, you will need to label the specimen, identifying it by name (as well as you can) and describing when and where you found it.

APPENDIX B

SAMPLES OF FORMAL INSTRUCTION

WORKSHEETS AND EXAMS

Name____________________

Chapter Two Worksheet

1. The main concern of early biology was mainly what?____________________

2. What Greek scientist and physician contributed much to the area of anatomy?________________________

3. The study of the structure of organisms is __________________.

4. Anatomy had its beginning as humans tried to treat what?_________________

5. An especially exciting period for biology was the late ___________.

6. All things (living) are composed of tiny units called ____________.

7. Louis Pasteur discovered tiny living things he called _______________.

8. An Austrian Monk discovered the basic laws of heredity. His name was ________________________.

9. The findings of Pasteur and Mendel were expecially important because ____(9 words)

10. Name three dreaded diseases.
(1)___________________ (2)____________________ (3)__________________

11. Who prevented polio? ____________________ When? ______________

12. Who discovered the chemical structure of the genetic message?
_________________________ & ________________________.

13. One of the most important factors in good science is what?______________ ______________________________(4 words)

14. A scientist also has to be a good ______________________.

15. What 3 things must a scientist and a detective do?
(1)__________________________(2 words) (2)_______________________(2 words)
(3)____(10 words)

16. What produces a body of organized knowledge about nature? _______________

17. Science, along with art, music, history, all involve what?_________________

18. Name the four elements of scientific investigation.
(1)_________________________________ (2)__________________________
(3)_________________________________ (4)__________________________

19. A fact comes from ____________________.

20. An observed phenomenon agreed upon by a number of people is a _______.

21. Numerical facts are called ___________.

22. What type of bacteria was Sir Alexander Fleming studying?____________

23. What is a jelly-like substance used in a culture dish? ______________

24. What mold grew in Fleming's culture dish? __________________

25. What two things are important in order to obtain a final answer to any scientific problem? (1)_______________ (2)___________________

26. Name 3 creative activities used in the book. (1)____________________
(2)__________________________ (3)______________________

27. When a scientist develops an idea from the facts, this statement is called an ___________________.

28. A good hypothesis does two things. They are:
(1)___________________(2 words) (2)____________________(3 words)

29. A good hypothesis must undergo what? ______________

30. Scientific teasting is known as what? ______________________

31. An experiment in which all the factors are identical except for one is what type of experiment? ___________________________

32. In a controlled experiment, the factor tested is called?_____________
____

33. The group which receives the variable factor is called the ___________
________________.

34. When a fundamental hypothesis has survived the test of time, it is called? ________________

35. What is the universal language of numbers and measurement called?
____

36. Which is more logical, the metric system or the English system?
____

37. The metric system is what type of system?___________________________

38. What is the basic unit of length in the metric system? _____________

39. One meter equals ______________ inches.

40. Which is longer, a meter or a yard? ____________

41. A rod equals haw many yards? ___________

42. Name the four major prefixes of the metric system?
(1)__________ (2)__________ (3)______________ (4)______________

43. What is the measurement of gravitational attraction?___________(metric)

44. What is the amount of material in an object? ________

45. What instrument is used to measure mass? ___________________

46. The basic unit of mass in the metric system is the ___________________.

47. One kilogram equals how many pounds? _________

48. The unit of liquid volume in the metric system is ___________.

49. One liter equals how many quarts? _____________

50. Scientists use what scale to measure temperature? ___________

51. Write the formula to convert Fahrenheit to Celsius.

____

52. What is the formula to convert Celsius to Fahrenheit?

____

53. Does the metric system have a unit for time? _________

Converting Temperatures from Fahrenheit (F) to Celsius (C) and C° to F°

Activity (1) Complete the following using the formulas below or using the comparison thermometer on page 2 of this section.

1. 205° C = ________°F
2. 11° C = ________°F
3. 115° C = ________°F
4. 45° C = ________°F
5. 0° C = ________°F
6. 140° F = ________°C
7. 95° F = ________°C
8. 104° F = ________°C
9. 131° F = ________°C
10. 77° F = ________°C

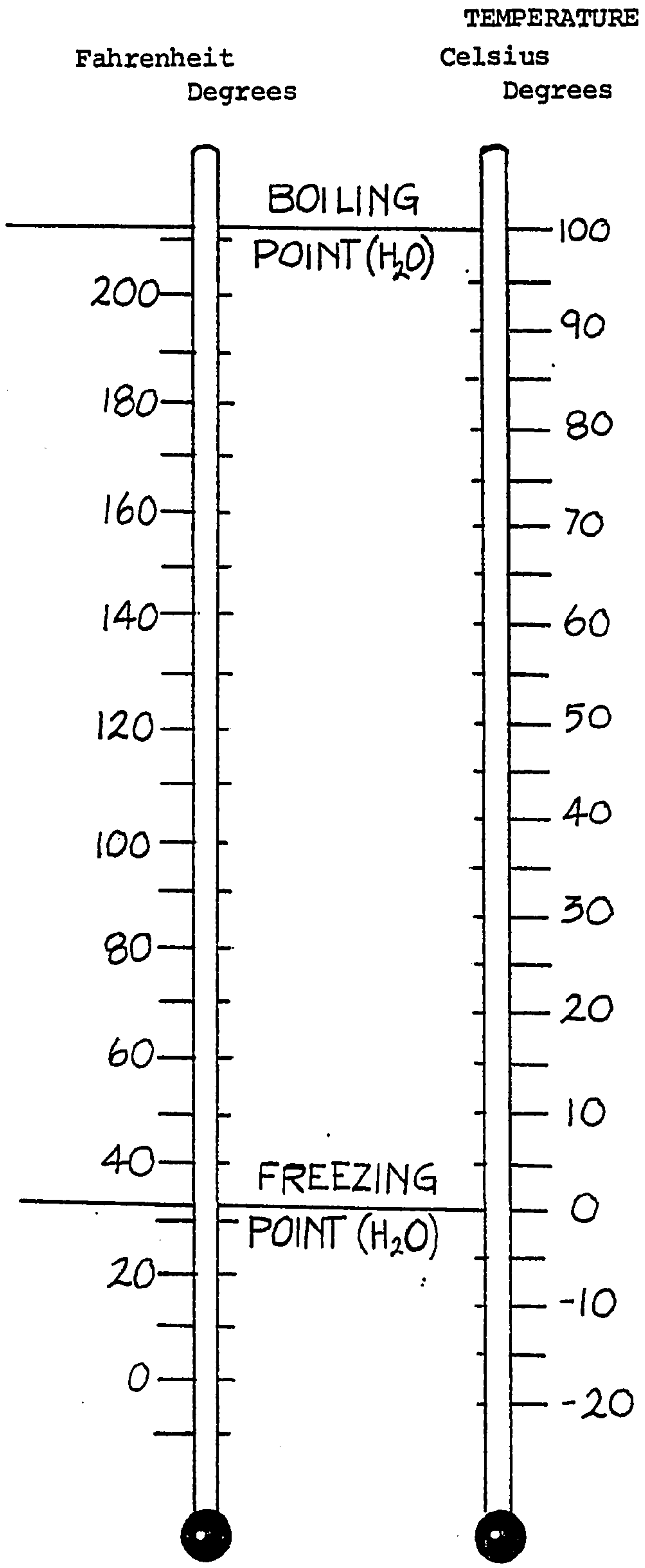
$$F = 9/5\ C + 32$$

$$C = 5/9\ (F - 32)$$

Activity (2) Match the following temperatures with the appropriate terms.

_____1. 100°C
_____2. 2°C
_____3. 39°C
_____4. 98°C
_____5. -18°C
_____6. 175°C
_____7. 0°C
_____8. 37°C

A. Normal body temperature
B. Boiling temperature of water
C. Freezing temperature of water
D. Almost freezing temperature
E. Almost boiling temperature
F. Temperature of a sixk person
G. Skiing temperature
H. Temperature to bake a cake



To change F° to C°

C = 5/9 X (F-32)

Example: Change 75° F to C°

1. C = 5/9 X (F-32)
2. C = 5/9 X (75-32)

$$\begin{array}{r} 75 \\ -32 \\ \hline 43 \end{array}$$

3. C = 5/9 X 43

$$\begin{array}{r} 43 \\ \times\ 5 \\ \hline 215 \end{array}$$

4. C = 215/9

$$\begin{array}{r} 23.88 \\ 9\overline{)215.00} \\ \underline{18} \\ 35 \\ \underline{27} \\ 80 \\ \underline{72} \\ 80 \end{array}$$

5. C = 23.9°
6. 75°F = 23.9°C

To change F° to C°

F = 9/5 X C + 32

Example: Change 100°C to F°

1. F = 9/5 X C + 32
2. F = 9/5 X 100 + 32
3. $F = 9/\underset{1}{\cancel{5}} \times \overset{20}{\cancel{100}}/1 + 32$
4. F = 180 + 32
5. F = 212°C
6. 100°F = 212°C

Temperature Unit

Answer the following questions.

1. The thermometer reads 15°C. Will the outdoor swimming pool be open? ____
2. A cup of hot chocolate is 50°C. Will it burn your tongue? _____
3. Your body temperature is 40°C. Are you sick? _____
4. The temperature outside is 0°C. Is it safe to skate on the pond? _____
5. The temperature is 35°C. Would you go sledding or swimming? ____________

Select the appropriate temperatures.

6. o°C is the same as A. 32°F B. 0°F
7. A hot cup of apple cider would be A. 55°C B. 105°C
8. The temperature of a popsicle is A. -6°C B. -70°C
9. Water polo is played at A. 30°C B. 10°C
10. Water boils at A. 200°C B. 100°C
11. Your normal body temperature is A. 37°C B. 98°C
12. You would water your lawn at A. 7°C B. 25°C
13. Water freezes at A. 32°C B. 0°C
14. You would wear a heavy coat at A. 15°C B. 1°C
15. A comfortable room temperature is A. 20°C B. -20°C

Name___________________

Chapter Two Test

1. Name the 4 elements of scientific investigation: (1)________________
(2)____________________ (3)__________________ (4)________________

2. What is a body of organized knowledge about nature? _________

3. What is the study of the structure of organisms? ______________

4. Who prevented polio? ________

5. Anatomy had its beginning as humans tried to treat what? ____________

6. Name the three dreaded diseases (from the worksheet)
(1)_____________________ (2)____________________ (3)_______________

7. What two people discovered the chemical structure of the genetic message?
(1)_______________ (2)_____________

8. The most important factor in good science is what? __________________

9. In a controlled experiment, the factor being tested is __________________

10. The basic unit of mass in the metric system ? ________

11. What is a jelly-like substance used for the growth of organisms? __________

12. Pasteur discovered tiny living things called? _______________

13. What 2 things are important in order to obtain a final answer to any scientific problem? (1)_____________________ (2)_____________________

14. The group that receives the variable factor is called? __________________
____

15. What two things does a good hypothesis do?
(1)______________________________ (2)____________________________

16. Name 3 creative activities used on the worksheet: (1)_________________
(2)____________________________ (3)______________________________

17. A fact comes from what? _________________

18. When a fundamental hypothesis has survived the test of time, it is called? ____________________

19. The metric system is what type of system? __________

20. One kilogram equals how many pounds? _______

21. Write the formula to convert Celsius to Fahrenheit: ________________________________

22. Write the formula to convert Fahrenheit to Celsius: ________________________________

23. What is the basic unit of length in the metric system? ___________

24. What is the amount of material in an object called? __________

25. A good hypothesis must undergo what? ______________________

26. An observed phenomenon agreed upon by a number of people is called?

____

27. When a scientist develops an idea from the facts, this statement is called? ________________________

28. Scientific testing is known as what? ______________________

29. What mold grew in Fleming's culture dish? __________________

30. Name the 4 major prefixes of the metric system?
(1)___________ (2)______________ (3)_______________ (4)____________

31. What is the universal language of numbers and measurements called?

____

32. What are numerical facts called? ___________

33. Who discovered the basic laws of heredity? ___________

34. Name a type of bacteria. ______________

35. What is the basic unit of time? __________________

Name________________

Chapter Fifteen Worksheet

1. What is the science of classifying living things called? ____________

2. How did Aristotle classify animals? ________________________

3. How did Aristotle classify plants? _________________________

4. Can common names be used in classification (yes or no)________

5. What two major groups did Aristotle break all living things into?
(1)___________________ (2)________________

6. Each major group was subdivided into how many subgroups? ___________

7. How were plants classified, what groups? (1)________________
(2)________________ (3)________________

8. In what class were plants with a single woody stem? ____________

9. In what class were plants with soft stems? ___________

10. In what class were plants with several small, woody stems? ___________

11. How were animals grouped? _________________________

12. What was the one major criticism of Aristotle's system of classification?
____

13. What method of grouping organisms do biologists use today? _____________
____

14. Linnaeus' system of classification was based on what? _________________

15. What was Linnaeus' system of classification called? ____________________

16. Linnaeus system used how many terms? ___________

17. What language did Linnaeus use? ____________

18. A noun is used to identify what? ___________________

19. An adjective is used to identify what? _____________________

20. Is the first letter of the noun or admective capitalized? _________

21. Each organism is named by what two things? (1) _______________
(2) _____________________

22. Most cats belong to what genus? ____________

23. What theory also plays a part in classification of organisms?__________
____

24. The major basis of classification is what? ________________

25. Besides homologous structures, what else can help identify an organism?
____

26. What is becoming increasingly useful in taxonomy? ______________

27. Which name is most specific? ___________________________

28. Name the groups of complete classification, going from general to more specific? (1)______________ (2)____________ (3)__________________
(4)_______________ (5)______________ (6)______________ (7)______________

29. Name the third kingdom?

30. What organisms are placed in the third kingdom? _______________

31. What is the fourth kingdom? ________________

32. What organisms are placed in this kingdom? _______________

33. Classify a dog and a human in the space below:

Division	Dog	Human

Name_______________

Chapter Fifteen Test

1. Most cats belong to what genus? ________

2. What theory also plays a part in classification of organisms?

3. Linnaeus' system of classification is based on what? ____________

4. What language did Linnaeus use in his system of classification?

5. What two major groups did Aristotle break all living things into?
(1)___________________ (2)_______________

6. Aristotle's two major groups can then be divided into how many subgroups? _________

7. Classify plants into 3 groups: (1)________ (2)_______ (3)_______

8. Each organism is named by what two things? (1)______________
(2)____________________

9. What is the fourth kingdom? ________

10. The major basis of classification is what? ______________

11. An adjective is used to identify genus or species? ________

12. Linnaeus' system of classification uses how many terms? _________

13. In what class are plants with single woody stems? ______

14. Each organism is named by what two things? (1)________ (2)_______

15. What is the science of classifying living things called? _____________

16. In what class are plants with several small, woody stems? __________

17. What is the third kingdom? _____________

18. Name the groups of complete classific ation, going from general to more specific: (1)_____________ (2)_______________ (3)______________
(4)_________________ (5)____________ (6)____________ (7)__________

19. In what class are plants with soft stems? ___________

APPENDIX C

CONTENT EXAMINATIONS

FORM ______

BIOLOGY I TEST

#1

Answer the questions on your answer sheet which has been provided. Do NOT write on the test, please.

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

   A. ecosystems
   B. food chains
   C. individuals
   D. populations

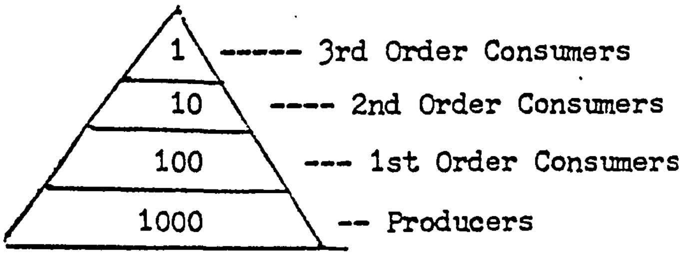
2. You go to a field and mark off an area of 100 square feet. Next you capture and weigh every living plant or animal in that area. What have you measured about the area?

   A. biomass
   B. biotic potential
   C. productivity
   D. biology

3. Which of the following are *not* organisms?

   A. human beings
   B. *Felis concolor*
   C. granite rocks
   D. sunflower plants

Use the diagram below to help answer the following 5 questions.



4. The energy pyramid above maintains its shape only by *excluding*

   A. plants
   B. decomposers
   C. carnivores
   D. herbivores

5. What is on the first <u>consumer</u> level in the pyramid?

   A. carnivores
   B. herbivores
   C. decomposers
   D. omnivores
   E. scavengers

6. What is the ratio of 2nd order consumers to producers?
   (Put your answer on the blank provided on the answer key)

7. Weasels eat mice. If 60 mice weigh 25 grams each, how many grams of energy could they supply to a weasel?
   (Put your answer on the blank provided on the answer key)

8. What do we call an animal that regularly eats both plants and animals?

   A. herbivores
   B. carnivores
   C. scavengers
   D. omnivores
   E. parasites

9. How does <u>new</u> energy enter an ecosystem?

   A. scavenger organisms
   B. reproduction of organisms
   C. digestion in consumers
   D. parasitic bacteria
   E. photosynthesis of green plants

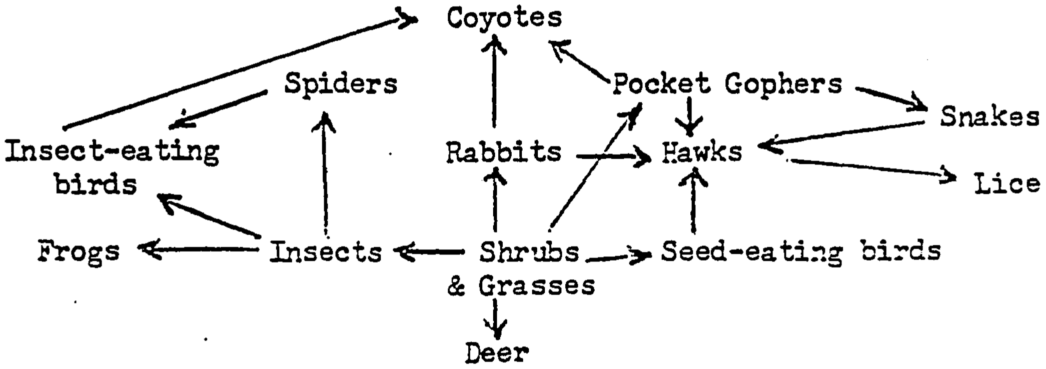
10. Members of the clover population are consumed by members of the mouse population. Some of the mice are eaten by members of a weasel population. Some of the weasels are in turn consumed by eagles. This represents

    A. biomass inversion
    B. food web
    C. population dispersion
    D. food chain

11. Which of the following is an example of a 1st order consumer?

A. a mold growing on a log
B. a hawk eating a mouse
C. a mouse eating a leaf
D. a bacteria eating a dead hawk

The next six questions are based on the following diagram:



12. In this diagram, the hawk would be a <u>3rd order</u> consumer if he ate

A. a grasshopper
B. a snake
C. a rabbit
D. a pocket gopher
E. none of the above

13. Spiders and snakes are <u>best</u> classified as

A. producers
B. primary consumers
C. secondary consumers
D. tertiary consumers

14. The role of the shrubs and grasses in the diagram is best described as

A. an animal shelter
B. a source of seeds
C. a source of energy
D. a place for nests
E. a source of shade

15. In terms of numbers of individuals, you would expect to find more

A. rabbits than shrubs
B. frogs than insects
C. coyotes than rabbits
D. gophers than snakes
E. hawks than deer

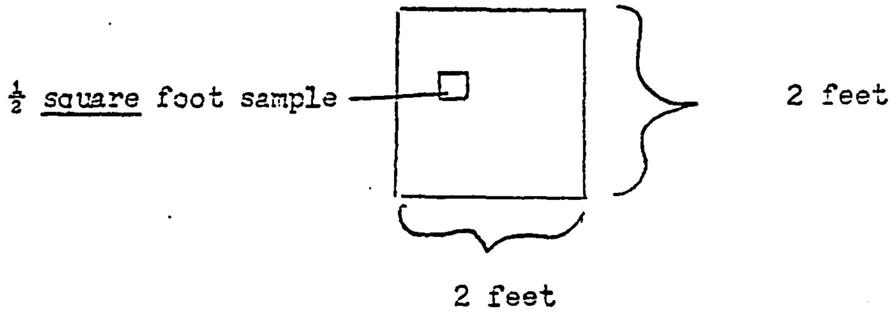
16. If a drought occurs, which of the following pairs of animal populations would probably decline <u>first</u>?

A. rabbits and deer
B. lice and coyotes
C. frogs and hawks
D. insect-eating birds and snakes
E. snakes and lice

17. Which of the following ends a food chain?

A. carnivores
B. herbivores
C. omnivores
D. parasites
E. decomposers

The next two questions use this diagram:



18. In the sample area above, 15 earthworms were counted. The area sampled is

A. one half (1/2) of the total area
B. one fourth (1/4) of the total area
C. one eighth (1/8) of the total area
D. one sixteenth (1/16) of the total area

19. The number of worms in the total area is about

A.	30	D.	80
B.	45	E.	120
C.	60	F.	240

20. A one acre area can only support 10 healthy rabbits, assuming there are no predators or parasites. Which term best describes this idea?

A. carrying capacity
B. population density
C. natality
D. climax community

21. Rats transported by ships to Krakatoa have, at times, overrun the island. This is because

A. the plants on this volcanic soil are especially nourishing
B. rats have a low biotic potential
C. the volcanic gases are poisonous to other animals
D. ships introduce large numbers of new rats each year
D. there are no natural enemies to control the rat population

22. What will most likely happen if two different species of animals are competing for the same food?

A. the least adapted species will eliminate the other
B. the most adapted species will eliminate the other
C. a single, new species will be produced from the two original species
D. both species will survive in small numbers

23. Which of the following could be considered as the only <u>unnecessary</u> part of a biological community?

A. green plants
B. sunlight
C. decomposers
D. animals

24. In a few decades, the offspring from just one pair of elephants could produce thousands of elephants. Which term describes this possibility?

A. carrying capacity
B. ecologic succession
C. biotic potential
D. biologic diversity

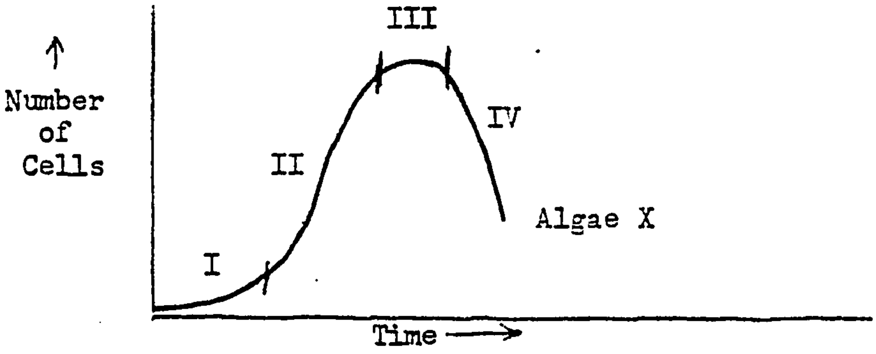
25. In the early spring, some chemical wastes were dumped into a pond. It killed all the mold, bacteria, yeasts, and other types of decomposers. By the end of the summer, members of the bass population of the pond began to die. What is the most likely reason for the bass deaths?

A. The chemical 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 recycle nutrients, so the productivity of the pond dropped to near zero.

26. A physical principle states that energy conversions always involved an overall change from concentrated to dispersed form. In other words, changing one kind of energy into another is never 100% efficient. Best <u>evidence</u> of this is that

A. Small organisms use food faster than large ones.
B. Food chains are usually limited to four or five links.
C. Old people put on weight.
D. Dead animals decay into minerals.

The next four questions are based on the following diagram that plots the growth of algae type X. They were placed in a single flask containing pond water. The flask was then maintained in normal light at room temperature.



27. At what stage in the population curve is there a balancing of the birth rate and the death rate?

A. I
B. II
C. III
D. IV

28. At what stage in the population curve are the conditions best for the maximum amount of growth?

A. I
B. II
C. III
D. IV

29. If some fertilizer was added at the end of Phase IV, what would most probably happen to the size of the population?

A. all algae would die
B. nothing
C. level off
D. increase
E. decrease

30. What could account for the slowing down of the growth rate at the beginning of Phase III?

A. a decrease in available water
B. a decrease in waste materials present
C. an increase in available space
D. an increase in available light

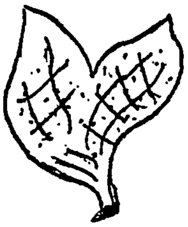
31. An area of ground was completely stripped of life by a fire. Six months later, only small grass-like plants were covering the ground. In two years, small bushes were common. After ten years, poplar trees were covering the area. Thirty years later, the poplar trees were being crowded by pine trees.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

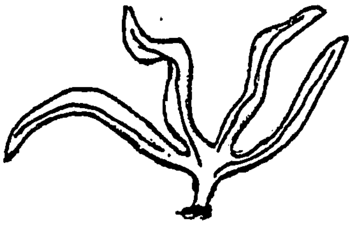
A. the life cycle
B. biotic potential
C. ecological regression
D. ecologic succession

32. What do we call an interdependent system of plants and animals which remain relatively unchanged over a long period of time?

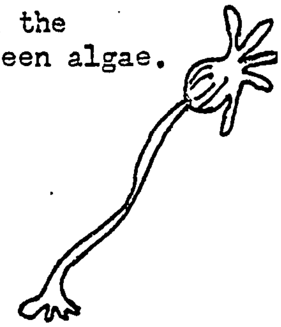
A. a montane zone
B. a climax community
C. a biomass
D. an ecological succession
E. a convergent community

33. A population of crabs which eats 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 lists all the different combinations of algae it is possible to find in their stomachs. List <u>all</u> of those possible combinations of algae diets (in the space provided on your answer sheet). Use the letters Y, R, G, and B to save space.

Form ______

BIOLOGY I TEST

#2

Answer all questions on the answer sheet provided. Do NOT write on this test!

1. What is the original source of all our food?

   A. one-celled animals
   B. green plants
   C. domestic animals
   D. bacteria

2. What do we call the unit we use to measure the heat energy values in food?

3. Which of the foods listed below would have the most energy in a one gram sample?

   A. lean meat (mostly protein)
   B. marshmallow (mostly starch)
   C. sugar cube
   D. peanut (mostly oil)

4. Several people each weigh the same amount. Which one typically uses the most energy on an average day?

   A. 16 year old male
   B. 16 year old female
   C. 25 year old male
   D. 25 year old female

5. Bacteria can cause a sore throat. A home remedy for treating a sore throat is to gargle with salt water. How does this treatment help?

   A. Bacteria cells lose water until they die.
   B. Salt pickles bacteria cells.
   C. Salt coats the throat so the bacteria can't breathe.
   D. Salt water stops reproduction processes in bacteria.
   E. Salt water neutralizes the poisons from the germs.

6. Aquarium plants may die if the aquarium is not tested. Which is the best explanation for this?

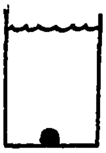
   A. Plants soon overpopulate and use the available food.
   B. Evaporating water leaves salt behind which makes the remaining water too salty.
   C. Aquarium fish produce wastes which are poisonous to water plants.
   D. Carbon dioxide is necessary for plants but does not spread evenly through the aquarium.

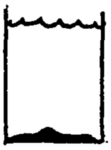
7. What is the movement of water across a cell membrane from an area of high water concentration to an area of low water concentration called?

   A. active transport
   B. diffusion
   C. osmosis
   D. phagocytosis

8. A dye particle is placed on the bottom of a tall column of water. Which will most likely be the final condition within the beaker?

A. 

B. 

C. 

D. 

9. If drops of blood are added to a 6 percent salt solution, what happens to the blood cells?

A. bursting
B. swelling
C. shrinking
D. nothing
E. hemolysis

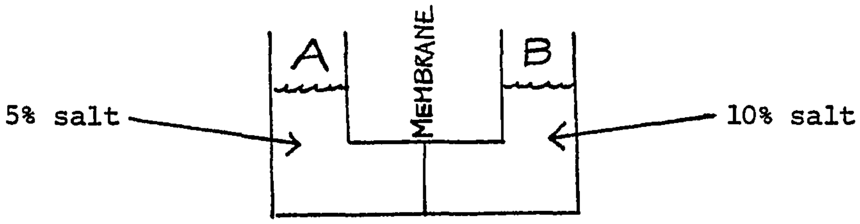
10. Osmosis is a form of

A. active transport
B. phagocytosis
C. diffusion
D. hydrolysis

11. An artificial cell is made by filling a cellophane bag with solutions of food nutrients. Which of those below is most likely to get out of the bag without any digestion?

A. starch
B. sugar
C. fat
D. protein

The U-shaped tube below contains solutions of salt water separated by a membrane which salt cannot go through.



12. What will happen to the water level in side A?

A. It will rise.
B. It will fall.
C. It will rise, then fall.
D. It will fall, then rise.

13. When will the water level remain constant on both sides of the tube?

A. when all the water is on side A
B. when all the water is on side B
C. when the water concentration becomes the same on each side
D. when the water concentration becomes 90% on side A and 95% on side B

14. What is the effect of a slight fever on enzymes within the stomach?

A. causes them to work faster
B. causes them to work slower
C. causes them to stop working
D. does not affect the enzymes

15. Sucrase is an enzyme that causes table sugar molecuels to break into simple sugars. Which term best describes the table sugar in this process?

A. substrate
B. enzyme
C. product
D. nutrient

16. What enzyme does saliva contain?

A. pepsin
B. maltase
C. glycogen
D. amylase

17. What is the final product resulting from the digestion of starch?

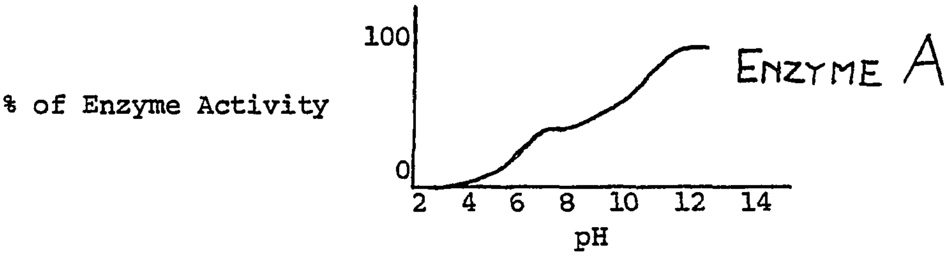
A. amino acids
B. simple sugars
C. glycerol
D. polysaccharides

18. A substance with a pH of 2 is a

A. neutral solution
B. strong base
C. weak base
D. strong acid
E. weak acid

19. About what should the pH of pure water be?

A. 1
B. 7
C. 10
D. 14

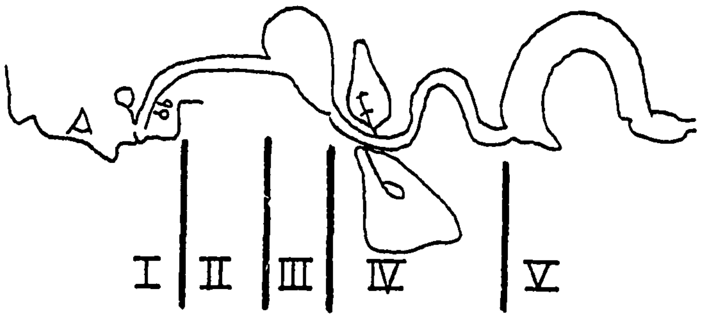


20. Enzyme A above works best under what conditions?

A. acid
B. base
C. neutral
D. none of these

21. Where is enzyme A most likely found?

A. mouth
B. esophagus
C. stomach
D. small intestine
E. large intestine



22. The absorption of the digested food takes place almost entirely in

A.	II	C.	IV
B.	III	D.	V

23. Two parts of the digestive tract which secrete carbohydrate-digesting enzymes are

A.	I and III	C.	II and IV
B.	I and IV	D.	III and V

24. Enzyme action on fat begins in

A.	I	C.	III
B.	II	D.	IV

25. An acid is normally found in

A.	I	C.	I and III
B.	III	D.	II and IV

26. Enzymes from region III

A.	are digested by low pH's	C.	work best in small amounts
B.	digest both carbohydrates and proteins	D.	work faster during sleep

27. What is the correct order of food passage through the digestive tract?

A. appendix, small intestine, colon, rectum
B. large intestine, small intestine, colon, rectum
C. small intestine, colon, large intestine, rectum
D. small intestine, colon, rectum, anus
E. small intestine, colon, duodenum, rectum

28. Villi are projections in the

A. large intestine which absorb nutrients
B. small intestine which absorb nutrients
C. small intestine which move chyme through the pyloric sphincter
D. small intestine which secrete enzymes
E. colon which absorb water

On the right is a list of nutrients:
On the answer sheet, enter the letter from this list of nutrients which corresponds to each item below.

A. sugars
B. starches
C. fats and oils
D. proteins

29. Gives a blue-black color with iodine
30. Most plentiful nutrient in white bread
31. Gives a red color with hot Benedict's solution
32. Easy to burn by lighting with a match
33. Leaves a spot on paper

34. The movement of materials across the cell membrane against a concentration influence best describes which of the following?

A. active transport
B. osmosis
C. passive transport
D. diffusion
E. phagocytosis

35. Which of the following is an organic molecule?

A. $NaOH$
B. HCl
C. CCl_4
D. H_2O
E. None of the above

36. Which of the following is a substrate for a disaccharidase?

A. sucrose
B. cellulose
C. glucose
D. fructose

37. One winter seven sailors were shipwrecked on a barren arctic island which had water but neither soil nor vegetation. A crate of corn flakes and another containing seven hens were also cast ashore. In order to get the most energy from the food they have, the sailors should...

A. feed the corn flakes to the hens, then kill and eat the hens
B. kill and eat the hens, then eat the corn flakes
C. feed the corn flakes to the hens, then eat the eggs from the hens
D. eat the corn flakes, then eat the hens when they die of starvation

38. In which of the nuts below are the Calories most concentrated?

	Type	Total Calories	Weight of Sample (grams)
A.	walnut	110	4.0
B.	peanut	200	7.1
C.	pecan	55	2.1
D.	almond	80	2.8

39. If a 2/3 cup portion of spaghetti has 100 Calories, how many Calories are there in a 1½ cup portion?

40. Explain why molecules diffuse from an area of high concentration to an area of low concentration.

Form ________

BIOLOGY I TEST

#3

Answer the questions on your answer sheet which has been provided. Do <u>NOT</u> write on the test, please.

1. What is the process in which green plants use CO_2 and H_2O to produce food and oxygen called?

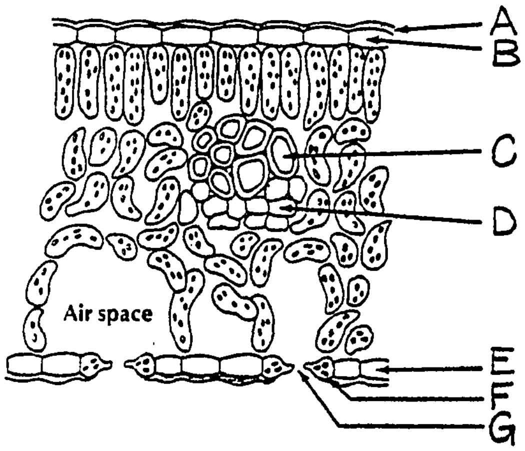
2. In which process is oxygen combined with food to release useful energy and CO_2?

A. Hydrolysis
B. Digestion
C. Transpiration
D. Respiration
E. Inspiration

3. What is the best term for the movement of water entirely through a plant?

A. Respiration
B. Transpiration
C. Expiration
D. Evaporation
E. Hydrolysis

Questions 4 through 8 refer to the following diagram of a magnified cross-section of a leaf.



4. What does the arrow labeled G represent?

A. food conducting openings
B. water storage locations
C. areas of gas exchange
D. protective areas

5. What kind of structures is indicated by arrow A?

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

6. What is the best term for the cells indicated by arrow B?

A. Epidermis
B. Endoderm
C. Phloem cells
D. Spongy cells
E. Palisade cells

7. What structures are most likely represented by the small dots within many of the cells?

A. chromosomes
B. chlorophyll
C. chloroplasts
D. nuclei
E. mitochondria

8. The cells indicated by arrow C are called xylem cells. What substance is most likely found in the center of these cells?

A. chlorophyll
B. CO_2
C. O_2
D. H_2O
E. sugar

9. In photosynthesis, the function of stomata is that of

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

10. In photosynthesis, the function of chlorophyll is that of

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

11. In which color of light would a bean plant grow most efficiently?

A. red light
B. white light
C. green light
D. color makes no difference

Questions 12 through 15 refer to the following facts:

BTB is a harmless chemical that is blue in room air but turns to green when extra CO_2 is dissolved in it. If the extra CO_2 is then removed, the BTB turns back to blue.

12. What would most likely happen to a jar of blue BTB if a fish spent the day in it?

A. It would stay blue.
B. It would turn blue-green.
C. It would turn green.

13. What would happen to a jar of green BTB if a fish spent the night in it?

A. It would stay green.
B. It would turn blue-green.
C. It would turn blue.

14. What would most likely happen to a jar of blue BTB if a water plant spent the night in it?

A. It would stay blue.
B. It would turn blue-green.
C. It would turn green.

15. What would most likely happen to a jar of blue BTB if a small fish and a large water plant spent the night in it?

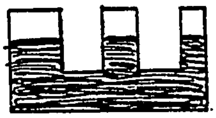
A. It would stay blue.
B. It would turn blue-green.
C. It would turn green.

16. When would the stem of a plant have its smallest diameter?

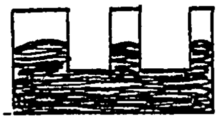
A. at dawn
B. shortly after dawn
D. shortly after sundown
E. midnight

17. A device used for demonstrating the adhesion forces involved in capillary action is partially filled with water. Which drawing below best predicts its appearance?

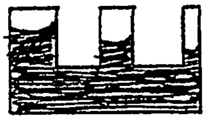
A.



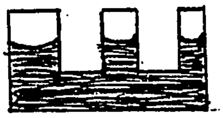
C.



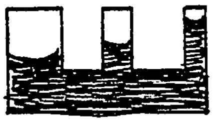
E.



B.



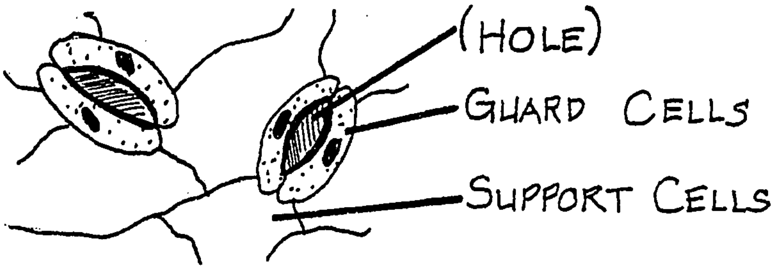
D.



18. By which process would rain water enter the root hairs of a growing plant?

A. Osmosis
B. Capillary action
C. Active transport
D. Inspiration
E. Digestion

Questions 19 and 20 on the next page refer to this close-up sketch of the cells of a leaf:



19. By which action is the hole between the guard cells opened?

A. a decrease in the water pressure in the guard cells
B. an increase in the water pressure in the guard cells
C. an increase in the water pressure in support cells
D. a decrease in the water pressure in support cells

20. What will result from the guard cells' production of sugar?

A. The hole will open.
B. The hole will partly close.
C. The hole will entirely close.
D. The hole will stay the same.

21. Grasshoppers have a series of small holes down the sides of their bodies. Which of these plant parts has the most similar function?

A. vacuoles
B. chloroplasts
C. veins
D. stomata
E. leaves

22. Insects and leaves both have a waxy outer coating to prevent excess water loss. Which term would best apply to this coating?

A. epidermis
B. endodermis
C. cutin
D. axon
E. alveoli

23. Which of the following has a major function in the human respiratory system?

A. diaphragm
B. phloem
C. xiphoid
D. vacuoles
E. nitrogen

24. There are about 1/2 million microscopic sacks in each lung of a human. If each air sack has 1/10 sq. in. of surface area, how many sq. feet of surface area are there in both lungs?

A. 7 sq. ft.
B. 70 sq. ft.
C. 700 sq. ft.
D. 7,000 sq. ft.
E. 70,000 sq. ft.

Questions 25 through 31 on the next page refer to the following experiment:

A student wants to determine whether different amounts of exercise will cause him to produce different amounts of CO_2 in his breath. He obtains a pink chemical which gets lighter in shade as CO_2 is dissolved in it. He then sets four partly filled beakers side by side and, after running three different distances, uses a drinking straw to exhale for 15 seconds into beakers #2, #3, and #4.

The following list of experimental variables is the answer key for questions 25 through 30. You may use a selection more than once.

A. independent variable
B. dependent variable
C. controlled variable
D. uncontrolled variable
E. not a variable

25. What variable is represented by the use of a single straw for each exhale?

26. What variable is represented by the investigator selecting different distances to run?

27. What variable is represented by the exhale being timed at 15 seconds each try?

28. What variable is represented by the final color shade of the pink liquid in beakers #2, #3, and #4?

29. What variable is represented by the investigator exhaling with different amounts of force each try?

30. What variable is represented by putting some test chemical into each beaker?

31. In the previous experiment, what purpose does beaker #1 best serve?

A. an experimental control for comparing color changes in #2, #3, and #4
B. a mixing container for equalizing the colors in #2, #3, and #4.
C. a reserve set-up in case #2, #3, or #4 need to be repeated
D. an independent variable for testing other, related hypotheses

32. What is characteristic of the circulatory system of insects?

A. The blood is filled with dissolved hemoglobin.
B. The blood vessels circulate oxygen but not CO_2.
C. The size of the vessels is controlled by spiracles.
D. The blood vessels do not make a complete circle.

33. Which of the choices below is always true of arteries?

A. They carry oxygenated blood.
B. They carry deoxygenated blood.
C. They lead away from the heart.
D. They lead towards the heart.
E. Both A and D are true.
F. Both B and C are true.

34. In which type of blood vessel does the blood not pulsate?

A. arteries
B. veins
C. capillaries
D. both B and C
E. both A and C
F. It pulsates in all of the vessels.

APPENDIX D

COGNITIVE ANALYSIS PROJECT INCIDENTS AND GRADING SCALES

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THE UNIVERSITY OF OKLAHOMA

EVALUATING INTELLECTUAL DEVELOPMENT
USING WRITTEN RESPONSES
TO SELECTED SCIENCE PROBLEMS

by

JOHN W. RENNER

The Cognitive Analysis Project Incidents

The Geranium Problem

You have an unlimited supply of geranium plants. They are exactly alike. All are in the same kind of pots and have been planted in the same kind of soil. You are told that such factors as fertilizer, the amount of water, and the amount of sunlight affect the way the plants will grow. Describe the experiments you need to do in order to test whether or not each of those factors is important to the growth of geranium plants. Be sure to include reasons why you do the experiment the way you do.

The Frog Problem

An ecologist conducted an experiment to find out how many frogs lived in a pond. He could not catch all of the frogs and count them. The first day he caught 55 frogs and put a band on one of the legs of each frog. He waited a week to give the banded frogs a chance to distribute themselves evenly throughout the pond. He then caught 72 frogs, and 12 of them had bands on one leg.

Using all of this information, what could the ecologist conclude about the number of frogs in the pond? Show any calculations you make, and then write a paragraph to explain how you arrived at your answer.

The Shadow Problem

The lengths of the shadow of a building and the shadow of a post are measured at the same time of day.

The building shadow's length is 50 meters.
The height of the post is 3 meters.
The post shadow's length is 2 meters.

How many meters tall is the building? Show your calculations. Write a paragraph to explain why you computed the height of the building the way you did.

COMBINATORIAL REASONING INCIDENT

"The Geranium Problem"
Grading Scale

1. No response.
   Example: Blank paper.
   Example: "I don't know," or "I can't do it."

2. There is reiteration of the problem, with irrelevant procedures and conclusions which are concerned with "good growth conditions." The student in this category may be more concerned with growing good geraniums than with providing experiments to determine factors important to plant growth as the problem asks. Sophisticated answers may be found in this response category, and the subject may bring in outside information which in and of itself is correct but which still does not directly deal with problem variables.
   Example: "First I'd water them just enough to keep moisture in the roots so the plants get nourishment."
   Example: "I would take all the different plants and put them in different environments. The reason is to see which environment is best for growing geranium plants."

3. The response is a description of conditions and the activities performed on the system using problem variables. An off-on variable supply is suggested ("I'll water some and I'll leave some without; I'll fertilize some and not others") or the subject may supply two quantity extremes, such as "a lot" versus "a little." If three situations are supplied (for example, "none," "a little," and "a lot") this is considered to be the first genuine attempt at control and the individual is judged to belong in category #4. Some of the responses in this category are elaborate, in that they provide multiple sets of conditions, but if they go no further than "a lot of water in one pot and a little in another," they cannot move higher than this category. (One exception has been made for the student who can produce a <u>complete</u> combinatorial scheme yet does not quantify.)
   Example: "Put water in one group; water and fertilizer in the second group; water, fertilizer and sunlight in the next one; and nothing in the last one."
   Example: "Put a geranium plant in soil that is fertilized, one that has nothing but water and one with just sunlight."
   Example: "Give each group a certain amount of sunlight, water and fertilizer."
   Example: "Have plants with different combinations of the 3 elements and some without, (I'm too lazy to write it all out.)"
   Example: "Put more fertilizer in one than the other."

4. An obvious attempt is made to control the quantity of the variables. The subject shows that problem variables need to be arranged to construct an experimental procedure that will result in the isolation of each variable from the rest of the variables, but fails to control, or the subject may provide all valid combinations without quantities. Demonstration of the complete combinatory system in terms of structure was determined sufficient to rate these individuals without quantity control higher than category #3. A student may mention that he would "use all combinations," but this is not sufficient merit for him to be placed in this category without quantification. Since fertilizer, water, and sunlight are the immediate variables, a complete system should include:
   (1) one plant with fertilizer and water
   (2) one plant with fertilizer and sun
   (3) one plant with water and sun
   (4) one plant with fertilizer, water, and sun

   In relation to quantification, the student may fulfill this criterion with an answer such as, "Put one in a bright spot, another in a real dark spot, but even others in dimmer places."

5. There is valid control of at least one variable, with inclusion of what the subject did to insure control. The student may list all combinations, but this does not necessarily mean he has controlled the variables. Students in this category often attempt more than one set of experiments but fail to control in all cases, either by omission of a needed test or by failure to describe how control was maintained. However, at least one variable is in fact controlled.
   Example: "Fertilize another group of plants and don't fertilize the other. Put both groups in direct sun and water both the same."
   Example: "You could put different types of fertilizer in the pots, and then grow under the same conditions."

6. There is control of all variables. Again, as in category #5, the subject explains how the controls are achieved. A student may be classified in category #6 instead of #7 because he fails to tell which variable he is testing with which test. A statement such as, "I did these things to test the variables," does not specify which variable is being tested by which experiment.
   Example: "Do this on a different plant to each variable--next increasing fertilizer, then water."
   Example: "Take 6 plants;
      1. Fertilize and water two plants the same, but vary the sunlight.
      2. Fertilizer and sunlight the same on two, but vary the sunlight.
      3. Water and give the same amount of sunlight to the last two, but put different kinds of fertilizer on them."

7. There is control of all variables, complete with an explanation as to why the control of each variable was necessary.
   Example: "I did this to see if differing amounts of water made any difference in the growth of geraniums."
   Example: "The last experiment should include plants with the same amount of water and sunlight but with different amounts of fertilizer to show the effect of fertilizer on plant growth."

PROPORTIONAL REASONING INCIDENTS

"The Shadows Problem" and "The Frog Problem"
Grading Scale

1. No response. No mathematical attempt.
   Example: "I don't know," "I can't think of anything," or "I can't do it."

2. There is mathematical manipulation without a class inclusion concept, or confused explanations with or without the use or manipulation of irrelevant numbers or factors which were invented by the student.
   Example (Shadows): "The post is 3 meters tall and the shadow is 2 meters tall. The building would be 60 meters tall."
   Example (Frogs): "It mattered how well he drained the pond. If he did a good job there are not many frogs over 72. If he didn't there are more than 72."

3. The student realizes that certain quantities given in the problem are subsets of other quantities within the problem and has a grasp of the relationships between those quantities. (Realization of only one relationship where two exist does not constitute inclusion.) Addition and/or subtraction are carried out with that class inclusion in mind. If class inclusion is employed in a mathematical solution, relevant and irrelevant asides will be ignored.
   Example (Shadows): "It would be 51 meters tall. The shadow is only one meter shorter than the post. The building's shadow is 50 meters long. Add one meter and it would make it 51 meters tall."
   Example (Frogs): "115 frogs. There must be more than a hundred frogs in the pond."

4. The student indicates ratio recognition but does not show the relationship of the ratio to the rest of the problem. The student sets up a ratio (or indicates one) and then stops.
   Example (Shadows): "The ratio of 3:2 of the post."
   Example (Frogs): " $\begin{array}{r}6\\12\overline{)72}\end{array}$ One out of every 6 that he found had bands."

5. The student goes beyond simple ratio recognition. A solution may not necessarily be obtained, but it is essential for the student to go beyond simply recognizing that the problem involves a ratio. The student may apply the ratio in attempting to find a solution by any method short of a true proportion, or the student may establish a proportional relationship involving all the elements of the problem which fails because the proportional relationship is improperly established or irrationally solved.

Example (Shadows): "I figured that the post shadow was 2/3 the height. So I took 2/3 of fifty. 2/3/50 16 2/3 X 2 = 33 1/3"

Example (Frogs): "

$$72\overline{)12.000}^{\;0.165}$$

$$\begin{array}{r} 55 \\ \underline{\times 16.5} \\ 275 \\ 230 \\ \underline{55} \\ 907.5 \end{array}$$

Approximately 907 frogs in the pond."

6. There is proper use of the correct proportion, demonstrating either correct solution of the problem, or use of sound logic with an incorrect solution.

Example (Shadows): "If the post is longer than its shadow then the building is going to be longer than its shadow. You had to put 3 over 2 to get a larger number than 50. 3 halves of 50 is 75 so the building is 75 meters."

$$\frac{\text{post } 3}{\text{shadows } 2} + 50 = 75$$

Example (Frogs): "He could conclude that there are roughly 330 frogs in the pond. If 1/6 of the second group were already banded then 6 times the original amount were in the pond."

$$\frac{12}{72} = \frac{55}{X}$$

$$12X = 72(55)$$

$$X = 330$$

7. There is proper use of a proportion <u>with</u> a discussion of implications of the problem or other relevenat variables. For example, statements such as "evenly distributed" or "same time of day" must be abstracted in order to apply to this category. Casual mention of problem variables without discussion or generalization does not constitute an abstraction.

Example (Shadows): "The building is 75 meters tall. If the shadows are measured at the same time of day then the sun cannot mess it up."

Example (Frogs): "Within the week the banded frogs were evenly spread out. By catching in any area of the pond (of the equivalent size) of the first day's venture, he found that he had caught 1/6 of the population, the first day. There are about 330 frogs in the pond."