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RELATIONSHIP BETWEEN LEVELS OF MATURITY AND LEVELS OF UNDERSTANDING OF SELECTED CONCEPTS OF THE PARTICLE NATURE OF MATTER. TECHNICAL REPORT NO. 36.

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INVESTIGATED WERE THE LEVELS OF UNDERSTANDING OF SELECTED CONCEPTS CONCERNING THE PARTICLE NATURE OF MATTER AND THE RELATIONSHIP OF THE STUDENTS' MATURITY AND CONCEPTUAL UNDERSTANDING. THE STUDENTS SAMPLED WERE OF HIGH AND AVERAGE IQ, AND IN GRADES 2-5. ALL GROUPS RECEIVED COMPARABLE INSTRUCTION. USED WERE ALTERNATE RESPONSE TAXONOMY-TYPE OBJECTIVE TESTS CONSISTING OF EQUAL NUMBERS OF QUESTIONS OF THREE TYPES--(1) KNOWLEDGE, (2) COMPREHENSION, AND (3) APPLICATION. CRITERIA FOR DETERMINING LEVELS OF UNDERSTANDING WERE (1) THE EARNED MEAN SCORE IS SIGNIFICANTLY DIFFERENT FROM GUESSING, AND (2) MORE THAN HALF OF THE MEMBERS EARN A SCORE OF 65 PER CENT OR HIGHER. BOTH GRADE LEVEL AND IQ WERE POSITIVELY CORRELATED WITH THE LEVEL OF ACHIEVEMENT IN (1) KNOWLEDGE, (2) COMPREHENSION, AND (3) APPLICATION. THE APPENDIX INCLUDES A LIST OF TEXTBOOKS THAT WERE ANALYZED FOR BASIC CONCEPTS IN THE STUDY, AND A BIBLIOGRAPHY. THE LESSONS AND TESTS WHICH WERE DEVELOPED ARE PUBLISHED IN A COMPANION VOLUME, "PRACTICAL PAPER NO. 1 OF THE CENTER FOR COGNITIVE LEARNING." (DH)

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By RUSSELL L. CAREY

REPORT FROM THE SCIENCE CONCEPT LEARNING PROJECT

Milton O. Pella and George T. O'Hearn,
Principal Investigators

WISCONSIN RESEARCH AND DEVELOPMENT
CENTER FOR
COGNITIVE LEARNING

THE UNIVERSITY OF WISCONSIN
Madison, Wisconsin

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By Russell L. Carey

Report from the Science Concept Learning Project

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PREFACE

Contributing to an understanding of cognitive learning by children and youth—and improving related educational practices—is the goal of the Wisconsin R & D Center. Activities of the Center stem from three major research and development programs, one of which, Processes and Programs of Instruction, is directed toward the development of instructional programs based on research on teaching and learning and on the evaluation of concepts in subject fields. The staff of the science project, initiated in the first year of the Center, has developed and tested instructional programs dealing with major conceptual schemes in science to determine the level of understanding children of varying experience and ability can attain.

In the study reported here instruction dealing with the concepts related to the particle nature of matter was given to students of high and average IQ in Grades 2, 3, 4 and 5. Both IQ and grade level were positively correlated with the level of understanding—knowledge, comprehension, or application—children were able to attain. Many of the concepts can be successfully taught in the elementary school, particularly in Grades 4 and 5. The lessons and tests developed for this study are available in Practical Paper No. 1 of the Center.

Herbert J. Klausmeier
Director

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ABSTRACT

The purpose of the study is to determine the relative levels of understanding of certain concepts, within the conceptual scheme the particle nature of matter, achieved by pupils in Grades 2-5.

The following concepts were selected and ordered with reference to the logic of the discipline.

1. Matter is made up of particles.
2. The particles which make up matter have spaces between them.
3. The particles which make up matter are in motion.
4. Some matter is composed of molecules.
5. Molecules are composed of atoms.
6. Atoms may be composed of protons, neutrons, and electrons.
7. The nature and the amount of charge on an electron is a negative one.
8. The nature and the amount of charge on a proton is a positive one.
9. A neutron does not have a charge.
10. Atoms have the same number of protons as electrons.
11. All atoms of the same element have the same number of protons.
12. Some matter is composed of ions.
13. An ion is a particle or group of particles which has more electrons than protons or more protons than electrons.
14. Ions can differ in the nature and magnitude of the net unbalanced charge.
15. Ions are formed from atoms when the atoms lose or gain electrons.
16. Atoms may be formed when ions gain or lose electrons.

Experimental groups consisted of nine subjects from each of the average (IQ 90-110) and high (IQ 115-135) ability groups in Grades 2-5 in Oregon, Wisconsin. All groups received comparable instruction. The outcomes of the instruction were assessed by using alternate response taxonomy-type objective tests consisting of equal numbers of questions of three types: knowledge, comprehension, and application.

The levels of understanding of a concept by a given grade group were determined by utilizing two criteria: (1) the earned mean score is significantly different from guessing and (2) more than 50 percent of the members earn a score of 65 percent or higher.

The conclusions are as follows:

1. Pupils of average ability in Grade 2 mastered Concept 1 at the knowledge level.
2. Pupils of high ability in Grade 2 mastered Concepts 1 and 3 at the knowledge level.
3. Pupils of average or high ability in Grade 3 mastered Concept 3 at the knowledge level and Concepts 1, 6, and 10 at the knowledge and comprehension levels.

4. Pupils of average ability in Grade 4 mastered Concepts 2, 3, 5, 8, and 12 at the knowledge level and Concepts 1, 6, and 10 at the knowledge and comprehension levels.
5. Pupils of high ability in Grade 4 mastered Concepts 3, 5, 8, 11 and 12 at the knowledge level; Concepts 1, 6, and 10 at the knowledge and comprehension levels; and Concepts 2, 4, and 14 at the knowledge, comprehension, and application levels.
6. Pupils of average ability in Grade 5 mastered Concepts 2, 3, 5, 8, and 11 at the knowledge level; Concepts 1 and 6 at the knowledge and comprehension levels; and Concept 10 at the knowledge, comprehension, and application levels.
7. Pupils of high ability in Grade 5 mastered Concept 11 at the knowledge level; Concepts 1, 3, 5, 8, 12, and 13 at the knowledge and comprehension levels; and Concepts 2, 4, 6, 9, 10, 14, and 15 at the knowledge, comprehension, and application levels.

I

THE PROBLEM AND ITS SIGNIFICANCE

INTRODUCTION

> Concepts have been cited as the products of scientific processes, as the basis for further scientific studies, and at times the knowledge that is applied by the technologist. Concepts are important not only because they are the warp and woof of science, but also because they provide the possessor with a means of coping with the development of knowledge in the future. It seems that one way known to provide maximum coverage of old and new knowledge is through the development of a classification system. The formation of concepts or conceptual schemes is one method of classification which results in such economical use of human intelligence [Pella, 1966, p. 31].

A concept or conceptual scheme is man's "means of getting a lot into the narrow compass of his attention at one time [Bruner, 1965, p. 21]."

"Concept formation results in a simplification of past, present, and future experiences because individual facts become parts of the ideas [Pella, 1966, pp. 31-32]." A number of facts may be combined by their relationships to produce an idea. The idea may be a "mental image of an action or thing, a generalization about related data [Kranzer, 1963, p. 180]." It may be "an image of a thing formed by a generalization from particulars; also, an idea of what a thing in general is to be [Hunt, 1962, p. viii]." A "summary of the essential characteristics of a group of ideas and/or facts that epitomize important common features or factors from a larger number of ideas" is viewed as a concept (Pella, 1966, p. 32).

Concepts may be categorized as classificational, correlational, and theoretical. Science concepts in these three categories have the following common characteristics.

1. Concepts are ideas possessed by individuals or groups. They are a type of symbolism.
2. Concepts of any particular object, phenomenon, or process exist in a continuum from simple to complex.
3. Concepts emerge as a result of experience with more than one object, phenomenon, or fact. They are generalizations.
4. Concepts are the result of abstract thinking that embraces the many experiences.
5. Concepts involve the relating of facts or supposed facts to each other by the individual.
6. Concepts are not always based upon a physical encounter.
7. Concepts are not inherent in nature or reality.
8. Concepts are not photographic images of reality.
9. Concepts are neither true nor false; they are, rather, adequate or inadequate.
10. Concepts have five primary relationships: relations to people, relations to things, relations to other concepts, relations within conceptual systems, and relations to processes.
11. Concepts are useful in making predictions and interpretations.
12. The individual concepts formed in any area may be determined by the sequence of the sensory experiences received or available.
13. The individual concepts formed in any area may be determined by the cultural pattern at the time of formulation. As the culture changes, the meaning and value of a given concept may change.
14. The nature of a concept may be determined by the procedure that led to its formulation.
15. Concepts and conceptual schemes are rendered inadequate as a result of new knowledge and must undergo constant revision [Pella, 1966, p. 33-34].

This study is concerned with theoretical concepts, within the conceptual scheme the particle nature of matter, that facilitate the explanation of phenomena.

THE PROBLEM

To determine the relative levels of understanding of certain concepts, within the conceptual scheme the particle nature of matter, achieved by pupils in Grades 2-5 as indicated by objective test scores when all pupils receive comparable instruction.

Several subproblems are part of the problem.

1. To determine the relative levels of achievement, as indicated by mean test scores, attained by the high and average ability groups in Grades 2-5 on each of the 16 selected concepts.
2. To determine whether the mean scores attained by pupils in the experimental population on each of the tests are significantly different from guessing.
3. To identify those groups in Grades 2-5 in which more than 50 percent of the members attained a score of 65 percent or higher on individual concept tests.

BACKGROUND OF THE PROBLEM

Concepts have been discussed for many years. In 1920, Hull performed what was probably the first controlled experiment on concept formation (Woodruff, 1964, p. 84). In the early studies on the nature of concepts and concept formation there was

> . . . a constant inference that concepts have a significant place in man's thinking processes, but not until recently has anyone drawn a clear picture of the nature of a concept or of its actual relationship to behavior. The relationship of concepts to subject matter has been equally vague but has been consistently inferred [Woodruff, 1964, p. 81].

In the 31st Yearbook it is mentioned that the major generalizations are seen as of such importance that an understanding of them should be made one of the objectives of science teaching. It was

> . . . proposed that the curriculum in science for a program of general education be organized about large objectives, that understanding and enlargement of these objectives shall constitute the contribution of science teaching to the ultimate aim of education, and that the course of study be so organized that each succeeding grade level shall present an increasingly enlarged and increasingly mature development of the objectives [NSSE 31st Yearbook, 1932, p. 44].

Also, there was the suggestion

> . . . that we may expect to accomplish a grade placement of the material relating to this objective by analyzing the major generalization into the smaller generalizations, principles, and concepts from which it has been synthesized and by subsequent subdivision of these until they are reduced to elements which are appropriate for the different grades [NSSE 31st Yearbook, 1932, p. 49].

The teaching of concepts is mentioned in the 46th Yearbook. It was stated:

> Science concepts and principles must also be taught so that they will be functional. It is one thing to be able to repeat Boyle's Law of gases. It may be quite another thing to be able to identify the operation of the law under new conditions or to be able to control phenomena through the use of the law. It is one thing to be able to recite a neat statement covering a concept. It may be something else to be able to use the concept correctly in thinking, speaking, or writing about a relatively unfamiliar situation in which the concept properly plays a part [NSSE 46th Yearbook, 1947, pp. 26-27].
>
> For the kinds of concepts and principles which are properly science objectives there must be many and varied experiences in which the same idea, large or small, occurs in differing situations. Moreover, for the most fruitful learning these experiences must be arranged and graded with respect to complexity and difficulty, so that the pupil may be guided to organize his meanings at higher and higher levels. Meaningful learning is spiral. Each experience adds a new loop in the spiral of meaning [NSSE 46th Yearbook, 1947, p. 27].

In the 59th Yearbook (1960), it was considered that:

> Recent theories and new knowledge should have priority in science-teaching when they are significant and can be made

understandable at a specified grade level. The generalized concepts selected for teaching should be those which tend to explain or involve many science facts [p. 35].

Significance to the Philosophy of Science

The invention of ideas plays an important role in science. Scientific ideas are attempts to establish relationships between discovered facts. These relationships are steps toward making "our sense-experience correspond to a logically uniform system [Einstein, 1940, p. 487]."

A relationship between facts is a construction of the mind, as a result of a composite of individual facts and emotional experiences, which may be called a concept. Concepts "are not found as such in nature; they are evoked in the human mind by nature [Nash, 1963, p. 17]." "Science is an ever-unfinished quest to discover facts and establish relationships between them [Holton and Roller, 1958, p. 214]." These concepts are brought together according to their relationships to each other into conceptual schemes. Concepts and conceptual schemes are ideas that are the products of science. Shamos (1966) states:

> There is no magic formula for discovering the great ideas. They are man's response to the challenge of nature; he devises models or schemes which seek to account for his experience with nature and which are intellectually satisfying to his scientific peers. This is the nature of science, and any science course or curriculum which fails to make crystal-clear this aspect of science cannot possibly have a lasting impact on its students [p. 29].

Science is "an interconnected series of concepts and conceptual schemes that have developed as the result of experimentation and observation and are fruitful of further experimentation and observations [Conant, 1951, p. 25]." Learning science includes learning some of the concepts accepted by the scientific community.

Significance of Concepts

The fact that the body of scientific knowledge is in a constant state of flux results in the problem of selection of content for instruction in schools. Some comments relative to criteria to be utilized in making selections for instructional programs are given by Hurd and Shamos.

> Because our culture is characterized by change and progress, the greatest threat to either individual or national security is obsolescence. This means that an education in the sciences must be based upon the kind of information that has survival value and upon strategies of inquiry that facilitate the adaptation of knowledge to new demands [Hurd, 1964, p. 7].

> To make science education meaningful to the average man throughout his lifetime, it must be based upon the kind of ideas that have survival value—not upon trivia [Shamos, 1966, p. 28].

> The conceptual structure ties past experience to the present and serves as a guide for the comprehension and assimilation of new facts and concepts. It serves as a basis for prediction of what will happen in a new problem or situation. While the significant facts in science change at a bewildering rate, the conceptual structures are more stable. However, we need to recognize that conceptual frameworks also change. The problem is to produce learners with the concepts and modes of inquiry that will permit them to understand these changes [Hurd, 1964, p. 9].

Concepts are ideas

> . . . which organize the world of objects and events into a smaller number of categories. These, in turn, can be organized into hierarchical systems, thus extending organized knowledge [NSSE 59th Yearbook, 1960, p. 39].

Concepts are important in interpreting natural phenomena. The same concept is often used in the description of many different phenomena.

> What makes certain concepts important, therefore, is their recurrence in a great many successful descriptions and laws, often in areas very far removed from the context of their initial formulation. The electron, first discovered in attempts to explain phenomena in discharge tubes similar to those now used as "neon" signs, later reappeared prominently in the explanations for electric current in wires and liquids, for photoelectricity, for thermionic phenomena

(as in today's radio and television tubes), for radioactivity, for the emission of light from hot bodies, and much besides. Here we have the only reason and full meaning behind the statement that scientists "believe in the reality" of electrons: the concept is needed so often and in so many ways [Holton and Roller, 1958, p. 233].

Significance of Theoretical Concepts

Theoretical concepts are inventions of men. They are invented in order to explain observed phenomena. "Such ideas as the gene, the atom, and the electron . . . were invented to explain observations. . . . [NSSE Yearbook, 1960, p. 40]." Science is concerned with these ideas which are theoretical concepts.

> Science is not concerned with things; it is concerned with ideas, although those ideas often are ideas about things. And those ideas are created by men's mind [Roller, 1960, p. 16].

Theoretical concepts may be used to give direction to inquiry.

> It is the existing conceptual scheme that gives direction to inquiry, it represents the initial "common sense" from which the scientist may draw or perhaps eventually break away [Holton and Roller, 1958, p. 253].

Examples of theoretical notions guiding inquiry are given by Toulmin and Nagel.

> The whole of theoretical physics and chemistry in the nineteenth century was developed round the notions of atoms and molecules: both the kinetic theory of matter, whose contribution to physics was spectacular, and the theory of chemical combinations and reactions, which turned chemistry into an exact science, made use of these notions, and could hardly have been expounded except in terms of them . . . . So, paradoxically, one finds that the major triumphs of the atomic theory were achieved at a time when even the greatest scientists could regard the idea of atoms as hardly more than a useful fiction. . . . [Toulmin, 1960, pp. 137-138].
>
> Many physicists have therefore concluded that quantum theory cannot be viewed as a statement about an "objectively existing" domain of things and processes, as a map that outlines even approximately the microscopic constitution of matter. On the contrary, the theory must be regarded simply as a conceptual schema or a policy for guiding and coordinating experiments [Nagel, 1961, p. 144].

Significance of Concepts in the Particle Nature of Matter

Conceptual Scheme

The theoretical concepts of the particles that make up matter are important.

> From the time of Dalton the atomic hypothesis has played an increasingly important role in science, first in chemistry and later in physics. It is true that a few scientists, some of them men of influence like the German physical chemist Wilhelm Ostwald, doubted the existence of atoms, but by the early years of the present century even these objectors were converted. Today the arguments in favor of the atomic structure of matter are so numerous and convincing that the concept is universally accepted as an established fact rather than a theory [Glasstone, 1958, pp. 2-3].

The theoretical concepts of the particle nature of matter have value in the understanding of many different natural phenomena. These concepts are considered to have important survival value. Feynman, Leighton, and Sands (1963), stated:

> If, in some cataclysm, all of scientific knowledge were to be destroyed, and only one sentence passed on to the next generation of creatures, what statement would contain the most information in the fewest words ? I believe it is the atomic hypothesis (or the atomic fact, or whatever you wish to call it) that all things are made of atoms—little particles that move around in perpetual motion, attracting each other when they are a little distance apart, but repelling upon being squeezed into one another. In that one sentence, you will see, there is an enormous amount of information about the world, if just a little imagination and thinking are applied [pp. 1-2].

The principal achievements of science identified as "major conceptual schemes" or "big ideas" by NSTA included conceptual schemes of the particle nature of matter. Two conceptual schemes that the scientists making the selection considered important for understanding science were:

> I. All matter is composed of units called fundamental particles; under certain conditions these particles can be transformed into energy and vice versa.
> II. Matter exists in the form of units which can be classified into hierarchies of organizational levels [NSTA, 1964, p. 20].

Significance for Psychological Reasons

"Experience is fundamental in the learning process [Thorpe and Schmuller, 1954, p. 410]." In learning there is an interaction of the student with "the phenomena of experience [Butts, 1963, p. 82]." Concepts perform an important role in this interaction. "The chief function of concepts is to relate learning to current situations arising within the subject's present experience [Thomson, 1959, p. 66]."

Learning "depends, not only upon the learner, but also upon the orderly presentation of that which is to be learned [Thorpe and Schmuller, 1954, p. 441]." Conceptual inventions order present experiences and open up new realms of experience. "For it is structure, the great conceptual inventions that bring order to the congeries of disconnected observations, that give meaning to what we may learn and makes possible the opening up of new realms of experience [Bruner, 1965, p. 120]."

An orderly sequence of concepts is desirable in science instruction. Kranzer (1963) emphasizes an important aspect of an orderly sequence of challenging science experiences in his statement:

> There is no argument about the desirability of providing an orderly sequence of challenging science experiences in the elementary grades in order to overcome some of the deadening repetition and poor choice of material that is too commonplace today. However, there may be cause to argue about the kind, level, and importance of topics selected [p. 179].

Concepts not only play an important role in learning but also in thinking.

> One agreement among all psychologists concerns the importance of concepts in the child's and the adult's thinking [Russell, 1956, p. 120].

> It seems difficult to overestimate the importance of concepts in any thinking done by children or adults. More than anything else they are the premises, the foundations, and the structural steel of thinking [Russell, 1956, p. 122].

Thomson (1959) also mentions the essential factor of concepts in thinking in his statements:

> In human thinking the use of concepts is one essential factor [p. 63].

> . . . we quickly catalogue what we perceive in a matter of seconds—using a ready-made set of concepts [p. 63].

> If we did not categorize or classify automatically we would be faced with the exhausting and complicated task of relating every particular item in our experiences to every other item in the context of their occurrence. We would flounder in the immediate concrete situation and be unable to interpret it [p. 65].

Concepts taught to elementary children must be adapted to the child's degree of readiness. The readiness is "both in terms of his capacity for understanding and in terms of his interests and needs [Tannenbaum and Stillman, 19·0, p. 14]." "It also is a matter of record that learning does not take place adequately until the organism is sufficiently mature to grasp whatever problem or activity is involved, which is individually determined [Thorpe and Schmuller, 1954, p. 442]."

Just how the development of concepts is linked to age and environment is not very clear.

> . . . there seems to be a serial order development of children's concepts that may be a function of their rate of organismic maturation. . . there is a wide range of understanding of different concepts among children of the same chronological age while at the same time knowledge of concepts seems to be related to chronological age, mental age, cultural-environment influences, and sometimes sex [Kranzer, 1963, p. 181].

Piaget (1964) has conducted many studies on the relationship of development and learning. He believes

> . . . that development explains learning, and this opinion is contrary to the widely held opinion that development is a sum of

discrete learning experiences . . . . In reality, development is the essential process and each element of learning occurs as a function of total development, rather than being an element which explains development [p. 176].

The range of understanding of concepts is not always the same for the same chronological age group.

Although the growth of knowledge is orderly, any group of children of the same chronological age shows a wide range in their understanding of different types of concepts. In school, the amount of overlapping between grades and the range of achievement within any one grade is considerable. This range usually increases as children grow older [Russell, 1956, p. 162].

The unclear relationship between age, mental ability, etc., and concept development gives rise to the consideration of

. . . the consequences of teaching "adult" science to elementary youngsters prematurely. It does not seem too much to expect that programs can be developed that are in phase with normal growth processes, in contrast to our proclivity for imposing various science disciplines because of the importance we attach to them [Kranzer, 1963, p. 182].

There is a need for determining when certain concepts can be taught to different children. Brandwein said,

We stress the need for determining, in some valid way, when children in the course of their schooling come to significant concepts—and how early comprehension of a concept is possible for different children, with different gifts [1962, p. 141].

Significance to Curricula

Curricula can be organized by using concepts. Such an organization will aid in eliminating the teaching of isolated facts.

It is wasteful to teach facts divorced from a meaningful concept. When facts, which have meaning for the learner, are tied into a logically related conceptual pattern, retention is improved and insight is more likely to occur. After learning one pattern, a student tends to respond more systematically to the alternatives in a new situation. An understanding of conceptual structure and training in inquiry help him select what is pertinent in a new situation [Hurd, 1964, p. 10].

The task of the curriculum-maker is to extract the essence of scientific knowledge and define the significant concepts in terms of their usefulness for understanding the structure of science. This is a process that begins with the "big picture" of science, not with bits of information, bodies of facts, or concepts in isolation. Thus it is the conceptual schemes and the inquiry processes that provide the framework for curriculum design and for developing courses at each grade level [Hurd, 1964, p. 11].

Conceptual schemes can be the goal of science and provide the structure for the curriculum.

They represent the pinnacle of explanation in science, and must be classed among the greatest of man's pure intellectual achievements. Such unifying theories are the main goal of science and should be at the focal point of a science curriculum [Shamos, 1966, p. 29].

Concepts and conceptual schemes contribute to the stability of a science curriculum.

Conceptual schemes remain recognizable at least within the span of formal education of the young and adolescent child; hence they can serve as moorings for a somewhat stable science curriculum [Brandwein, 1962 p. 110].

Concepts can form the framework for a curriculum, but there is need to know which concepts should make up a curriculum. The National Science Teachers Association (1961) emphasizes the need for basic research in the area of science curriculum in the statements:

The entire area of the science curriculum is one in which basic research is sorely needed. Too little is known about the readiness of students for different concepts. More must be learned about the dependence of readiness on age, on background, and on the type of presentation employed.

In designing a course or a sequence of

courses, science educators must select concepts that explain much, concepts that make further learning easier. Science experiences should be developed to help students learn how to learn. But very little research (in comparison with the need) has been done to identify the methods and examples that promote this important kind of transfer [p. 49].

Concepts in the particle nature of matter conceptual scheme occupy an important position in a science curriculum. The concepts to be presented in a particular grade need to be determined.

II

REVIEW OF RELATED STUDIES

Piaget, believing that "each element of learning occurs as a function of total development" (1964, p. 176), is interested in the development of intellectual structures. He postulated the existence of cognitive structures that change with age and these developmental changes constitute the major object of his study (Flavell, 1963, p. 17). Defining Piaget's research concern Flavell stated:

> It is possible to give a rough definition of Piaget's principal concerns in a single sentence; he is primarily interested in the theoretical and experimental investigations of the qualitative development of intellectual structures [p. 15].

Utilizing a clinical method Piaget (1964) distinguished four main stages in the development of intellectual structures.

> 1. Sensory-motor, pre-verbal (0-2 years): During this stage is developed the practical knowledge which constitutes the substructure of later representational knowledge [p. 177].
>
> 2. Pre-operational (2-7 years): The beginnings of language, of the symbolic function, and therefore of thought, or representation. But at the level of representational thought, there must now be a reconstruction of all that was developed on the sensory-motor level [p. 177].
>
> 3. Concrete operations (7-11) years: They operate on objects, and not yet verbally expressed hypotheses [p. 177].
>
> 4. Formal or hypothetic-deductive operations (11-15 years): The child can now reason on hypotheses, and not only on objects. He constructs new operations, operations of propositional logic, and not simply the operations of classes, relations, and numbers [p. 177-178].

Oakes (1947) analyzed the answers given by children from grade levels K, 2, 4, and 6 and a group of adults to direct questions regarding natural phenomena and concluded that children can learn correct explanations of natural phenomena. However, he did not find evidence "to corroborate Piaget's interpretation that there is a definite stage in the child's thinking which is characteristic of a given age [p. 93]."

An analysis of 20 research studies, in an attempt to find out whether mental age and grade level are factors in learning some basic principles of physical science, was made by Read (1958). It was concluded that grade level and intelligence were factors in learning the principles.

Research into the nature of children's scientific concepts was reported by King (1960). The study included 1,235 children ages six to eleven. A schedule of 70 questions arranged into five categories and a follow-up of the answers by interview were used. The questions were presented by the regular teacher under normal classroom procedures. King concluded that 24 questions could be correctly answered by experience without formal teaching. But topics like length, weight, direction, and volume cannot be understood solely by experience. He found "no evidence of Piaget's stages of development but only a gradual development of the reasoning processes by more systematic organization of concepts [p. 275]."

Inbody (1963) examined 50 kindergarten children to ascertain the nature of their understandings of physical phenomena. The subjects' chronological ages ranged from 64 months to 80 months. He concluded:

> There seems to be little doubt that the nature of children's thinking changes with maturity and experience. It also seems that the kind of thinking a child can do at any given time places limitations on the type of instruction he can profitably utilize [p. 275-276].

In 1960, Nelson investigated how children acquire science concepts, the level of their understanding and the relationship between socio-economic background and intelligence to this learning. The classroom teachers taught 118 boys and girls from the intermediate elementary grades two areas of light and sound. In the conclusions Nelson stated:

> Instruction produced a significant increment in the understanding of principles related to Light and Sound.
>
> The Sound Test showed a significant improvement directly related to the grade of the pupil.
>
> Grade and social status are not related to the amount of improvement on the various tests, but they are directly related to the level of performance, both before and after instruction [1960, p. 143].

Haupt (1952) attempted to determine what experiences with magnetism elementary school children have encountered and what the grade and age differences are in their experiences. The subjects were 25 children in Grades 1 through 7. The children were permitted to play with two bar magnets, a steel knitting needle, a piece of paper, a splinter of wood, and a dipping needle while they were asked basic questions on magnetism. Haupt stated:

> This particular array of data seems to indicate that the children in the lower grades have attained to concepts that are equivalent in complexity and maturity to those from the children in the higher grades [p. 166].

Weaver and Coleman (1963) studied the relationship of mental abilities to the development of meaningful understandings and formation of the concepts of time, change, and variety. A selected group of 26 first-grade pupils was taught using a problem-solving approach. Weaver and Coleman concluded that average and below average mental ability first-grade children can develop science concepts when taught by a problem-solving method.

In 1954, Reid investigated the levels of understanding of certain atomic energy concepts achieved by pupils in Grades 4, 5, and 6 when the pupils received instructions about the concepts. It was found that the pupils in each grade made significant gains in their understanding of the concepts. Also, Grade 6 pupils, generally, achieved the highest scores.

A study to examine the relationships between intelligence, reading ability, and concept development in terms of a hierarchy of understanding defined as knowledge, comprehension, and application was performed by Pollach (1963). The science content was presented to an experimental group of 117 fifth-grade students by means of a film. Pollach found little evidence to support the notion that the application level of concept development was related more to intelligence than the knowledge level of concept development. It was found that knowledge of subject matter was a predictor of the achievement on the test of comprehension and application.

McNeil and Keislar (1962) investigated the ability of first-grade children to form and use particular concepts related to molecular theory. The second phase of the investigation was a study of children's learning of certain molecular concepts. Six first-graders were taught utilizing 500 picture cards each with a written passage which was read to pupils. It was concluded that children in the first grade can correctly respond in theoretical terms to oral questions about molecular theory.

Ashbaugh (1964), in an attempt to arrange in order of difficulty a series of concepts in geology for intermediate grades, instructed 256 pupils. The pupils were grouped according to high and low achievement determined by intelligence quotients and previous science achievement. Thirty demonstrations were used in the instruction. Ashbaugh stated in the conclusions:

> Socio-economic status, age, and intelligence were not significantly related to post-test achievement on the geological concepts test at the fourth, fifth, or sixth grade levels.
>
> The post-test score for each group indicated that scores of the high experimental group were significantly different from those of the low experimental group and the control group scores.
>
> The number of acceptable concepts at each grade level was higher for the high experimental group than for the low experimental group [p. 5776].

Oxendine and Read (1953) were interested in the grade placement of the principle "Sound is produced by vibrating material." Fourth and sixth graders were instructed by a lecture demonstration method. It was concluded that fourth-grade pupils were not ready for this instruction. Also, pupils with a mental age level of 11-12 years could attain mastery of the test.

A study to determine where certain facts and principles concerning work can best be introduced into the curriculum was performed by McCarthy (1952). Children in Grades K, 1, 2, 3, and 4 performed three experiments utilizing the lever, the pulley, and the inclined plane. McCarthy stated, "The conclusion is that these three experiments, giving concepts concerning Work as defined in physics, are suitable for the second grade [p. 253]."

Harris (1964) sought to obtain evidence concerning the ability of pupils in Grades 4, 5, and 6 to understand some of the concepts basic to the molecular or kinetic theory of heat. The 74 subjects were instructed by the utilization of tapes and were orally tested. In the conclusions Harris stated:

> The fifth and the sixth graders were found to be appropriate levels for the placement of certain concepts of the molecular or kinetic theory, insofar as these children were involved.
>
> The grade-placement of most concepts of the molecular-kinetic theory at the fourth grade level was found to be inappropriate for the particular fourth grade class involved in this investigation [1964, p. 49].

III

PROCEDURE

The concepts to be developed were selected from among the many that make up the conceptual scheme the particle nature of matter. The conceptual scheme was analyzed beginning with the level of the ion concept since the desire was to terminate instruction at the level "ions are formed from atoms when the atoms lose or gain electrons."

METHOD OF ANALYSIS OF CONCEPTUAL SCHEME

A list of concepts prerequisite to and including the desired terminal concept concerned with the particle nature of matter was prepared. The individual concepts selected were included within one or more of the following textbooks (See Appendix).

- 6 high school chemistry
- 4 college general chemistry
- 2 advanced inorganic chemistry
- 1 radiochemistry
- 2 high school physics
- 2 college general physics

The list of concepts was ordered with reference to the logic of the discipline; the sequence that would make the achievement of the goal most probable. This list was then examined by scholars in chemistry and revised and reordered. The five concepts that follow served as the content for the pilot study.

1. An ion is an atom or a group of atoms with a net unbalanced electrostatic charge.
2. Ions can be different in nature and magnitude of net unbalanced charge.
3. Ions are formed from atoms when the atoms lose or gain electrons.
4. Ions gain or lose electrons, depending on the nature of their charge, to form neutral atoms or molecules.
5. Free ions are formed in water from ionic crystals as a result of the crystals dissociating.

The population utilized for the pilot study consisted of six sixth-grade pupils equally representing high, average, and low ability groups based on the criteria of IQ. These pupils were treated as clinical cases on a one-to-one basis for both teaching and testing and all sessions were recorded on tape. Analysis of the results revealed that the five concepts related to various aspects of ions were not gained by the pupils. It was evident that the assumed prerequisite knowledge was not included in the backgrounds of the pupils in the sixth-grade group.

The five concepts and the pupil responses and reactions were examined as a part of the attempt to ascertain the nature of the prerequisite knowledges for this level of conceptualization of an ion. A tentative list of difficulties was identified and submitted to a panel of science educators for consideration. This resulted in an expanded list of prerequisite concepts. The expanded list was then resubmitted to a scholar in chemistry for reaction and no modifications were suggested. This expanded list then became the basis for this study.

POPULATION SELECTION

The population from which the experimental subjects were selected consisted of the pupils in Grades 2-5 from the Oregon Elementary School, Oregon, Wisconsin: 140—second grade, 152—third grade, 150—fourth grade, and 136—fifth grade. The roles for each class were arranged according to the rank IQ scores of the pupils on the Kuhlmann—Finch test. The names of pupils with IQ scores of 90—110 and those with IQ scores of 115—135 were rank ordered according to grade level into two groups. These groups were referred to as average ability (A) and high ability (H) groups respectively. The ability levels according to grades were considered the levels of maturity.

The numbers in each group according to grade level are given in Table 1.

Table 1

Numbers of Pupils in Average and High Ability Groups According to Grade Level

Ability Level	Grade 2	3	4	5
A	67	75	89	53
H	48	40	25	61

Because the design of the experiment required a minimum of six subjects per group per grade and the fact that absences are frequent within the elementary grades, a sample of 15 subjects was drawn at random from each of the ability groups at each grade level. It was decided that the maximum number per group per grade to be included in the statistical treatment would be equal to the number of subjects within the group in a single grade having the minimum number of subjects that completed all lessons and all tests but in no case would the number fall below six per group per grade. Random exclusion would be utilized to obtain an equal number of members per group per grade for the statistical treatment.

INSTRUCTIONAL PROCEDURE

The 16 concepts identified were arranged to be the content of twelve 30-minute instructional and eight 30-minute testing periods per class. Lesson plans (Carey, 1967) including oral narration, demonstration, and model and pictorial visualization were prepared with the cooperation of four other science educators competent in chemistry and/or physics and one chemist.

Instruction proceeded as is traditional with 30 pupils per class at each grade level. The instructional procedures employed for any one concept and the sequence and rate of progress from concept to concept was uniform for all groups and grades. The sequence was:

1. Two 30-minute periods of instruction.
2. Two 30-minute periods of testing.
3. Three 30-minute periods of instruction.
4. Two 30-minute periods of testing.
5. Seven 30-minute periods of instruction.
6. Two 30-minute periods of testing.

The testing period was conducted within 24 hours following the last instructional period on each unit.

EVALUATION

A sequence of three 60-minute alternate response taxonomy-type objective unit tests, each administered in two 30-minute sessions, were used to assess the outcomes of the instruction. Each test included equal numbers of questions of three types: knowledge, comprehension, and application. The criteria guiding the preparation of the instruments were:

1. The questions should be appropriate to pupils in Grades 2-5.
2. The number of items per concept of each taxonomic type should be the same within any one test instrument.
3. The items should be of the objective multiple choice multiple response type.
4. The vocabulary, other than technical terms taught, must come from one of four lists:
   a. Words Which Are Common to the International Kindergarten Union List and to the First Thousand of Thorndike's List (Dale, 1931)
   b. Words in the First Thousand of the Thorndike List Which Are Not Found in the International Kindergarten Union List (Dale, 1931)
   c. Dale's List of 3000 Familiar Words (Dale and Chall, 1948)
   d. The First Thousand Words For Children's Reading (Dolch, 1950)
5. All test items must be approved by at least three of four other science education research students. The guidelines for the test construction were:
   a. Taxonomy of Educational Objectives (Bloom, 1956)
   b. Testing and Evaluation for Sciences (Hedges, 1966)
   c. The Construction and Validation of Tests of the Cognitive Processes as Described in the Taxonomy of Educational Objectives (Kropp and Stoker, 1966)

Because of noted reading problems encountered by pupils, especially in Grades 2 and 3, all items included on the tests were read aloud to the pupils. Those who could read at grade level could read along with the instructor. Each pupil indicated his response on his own test instrument and was asked not to skip items.

TREATMENT OF DATA

Since the desire was to ascertain relative levels of achievement of understanding of the conceptual scheme the particle nature of matter up to and including the level of sophistication "ions are formed from atoms when the atoms lose or gain electrons" it was necessary to analyze the data for each concept separately according to groups within grade levels. The score on the items related to a given concept within a unit test is referred to as the score on a concept test. The data related to each of the 16 concepts were treated as described below.

Sub Problem 1

The relative levels of achievement of the groups are indicated by the rank order of the group mean scores on each concept test.

The probability of the existence of any significant differences among the mean scores was tested through the use of the ONE WAY 1-ANOVA program prepared by G. Minch for use on a CDC 1604 computer. If the results indicated a significant difference when the alpha is .05, the Newman-Keuls post hoc test was applied (Alpha .05).

Sub Problem 2

To determine whether the mean scores on the concept tests were significantly higher than those which could be earned by random guessing, the mean scores attained by the groups by grade level were compared with the population mean (μ) of theoretical normal distribution of random guessing scores. The comparison was based on the formula $z_{.95} = \frac{\bar{X} - \mu}{\sigma/\sqrt{N}}$ where μ is the population mean of the theoretical random guessing distribution, σ is the standard deviation of the random guessing scores, $z_{.95}$ is the standard score for means with confidence coefficient of .95, and $\bar{X}$ is the critical guessing mean score which the group mean must exceed to be significantly higher than the theoretical guessing mean.

Sub Problem 3

The portions of the groups meeting the criteria were computed in terms of percent of group by grade level.

Criteria for Minimum Acceptable Achievement

A group by grade level was considered to have been achieving at a particular level of understanding on a concept when the following two arbitrarily selected criteria were met.

1. The earned mean score is significantly different from guessing.
2. More than 50 percent of the members earn a score of 65 percent or higher.

Variations in relative levels of performance were also taken into consideration.

IV

RESULTS

INTRODUCTION

The results of this investigation are presented in three sections: 1. selected concepts and their order, 2. population sample, and 3. test results and analysis. The test results for each concept will be stated and analyzed according to taxonomic types of questions.

SELECTED CONCEPTS AND THEIR ORDER

The 16 concepts selected from the conceptual scheme the particle nature of matter are listed along with the unit (lesson) of which they are a part.

Unit I

1. Matter is made up of particles.
2. The particles which make up matter have spaces between them.
3. The particles which make up matter are in motion.

Unit II

4. Some matter is composed of molecules.
5. Molecules are composed of atoms.
6. Atoms may be composed of protons, neutrons, and electrons.
7. The nature and the amount of charge on an electron is a negative one.
8. The nature and the amount of charge on a proton is a positive one.
9. A neutron does not have a charge.
10. Atoms have the same number of protons as electrons.
11. All atoms of the same element have the same number of protons.

Unit III

12. Some matter is composed of ions.
13. An ion is a particle or group of particles which has more electrons than protons or more protons than electrons.
14. Ions can differ in the nature and magnitude of the net unbalanced charge.
15. Ions are formed from atoms when the atoms lose or gain electrons.
16. Atoms may be formed when ions gain or lose electrons.

POPULATION SAMPLE

The number of pupils in each of the groups of 15 completing all lessons and all tests is given in Table 2.

Table 2

Numbers of Pupils in Average and High Groups According to Grade Level Completing All Lessons and All Tests

Ability	Grade			
Level	2	3	4	5
A	9	9	9	12
H	12	10	12	9

Since the smallest number in any group completing the entire treatment sequence is nine, this number was selected as the number of subjects per group per grade included in the statistical treatment.

TEST RESULTS AND ANALYSIS

Concept I: Matter is made up of particles.

It is noted from Table 3 that the numerical sequence based upon group mean scores most closely parallels the grade levels from two through five on the knowledge type questions. The relative position of a particular grade group in the order, when application and comprehen-

Table 3

Rank Order of Groups by Grade Level According to Mean Scores Attained on the Three Taxonomic Test Forms, Concept 1

Knowledge		Comprehension		Application	
Group	Mean (%)	Group	Mean (%)	Group	Mean (%)
5H	89.4	5H	81.9	5H	60.0
4H	85.0	4H	76.9	3H	56.2
5A	75.0	3H	70.0	3A	53.8
4A	70.6	3A	68.1	5A	51.9
3A	69.4	5A	67.5	4H	50.6
3H	68.8	4A	64.4	2H	50.0
2A	66.9	2H	57.5	2A	48.1
2H	63.1	2A	56.9	4A	45.0

sion type questions are considered, appears to be best described as chance. The only group that consistently performs at a high level is the 5H.

A comparison of mean scores reveals that: (a) at the knowledge level (Tables 4, 5, and 6), the mean scores earned by groups 2H, 2A, 3H, 3A, and 4A are significantly lower than the mean score earned by group 5H and that the mean score earned by the 2H group is significantly lower than that earned by group 4H; (b) at the comprehension level, only groups 2A and 2H attained mean scores significantly lower than those earned by groups 5H and 4H (Tables 7, 8, and 9); and (c) statistically significant differences were not found among the mean scores earned on the application type questions (Table 10).

The mean scores that exceed the critical guessing mean score (Table 11) are (a) those attained by all groups at the knowledge and comprehension levels and (b) that earned by the 5H group at the application level.

When the performance of individuals is considered it is found that the groups in which more than 50 percent of their members earned a score of 65 percent or higher (Table 12) are (a) 5H, 5A, 4H, 4A, 3A, 2H, and 2A at the knowledge level and (b) 5H, 5A, 4H, 4A, 3H, and 3A at the comprehension level.

Table 4

Analysis of Variance Among Groups—Knowledge Level, Concept 1

Source	SS	df	MS	F	F*Critical
Between Groups	134.99	7	19.28	4.14	2.17
Within	298.00	64	4.66		
Total	432.99	71			

*Alpha of .05

Table 5

Differences Between Mean Scores — Knowledge Level, Concept 1

Groups		2H	2A	3H	3A	4A	5A	4H	5H
	Means	10.11	10.67	11.00	11.11	11.33	12.00	11.56	14.33
2H	10.11	0	.56	.89	1.00	1.22	1.89	3.45*	4.22*
2A	10.67		0	.33	.44	.66	1.33	2.89	3.66*
3H	11.00			0	.11	.33	1.00	2.56	3.33*
3A	11.11				0	.22	.89	2.45	3.22*
4A	11.33					0	.67	2.23	3.00*
5A	12.00						0	1.56	2.33
4H	11.56							0	.77
5H	14.33								0

*$p < .05$

Table 6

Critical Values — Knowledge Level, Concept 1 (Newman-Keuls Test)

r	2	3	4	5	6	7	8
$q_{.95}(r, 60)$	2.83	3.40	3.74	3.98	4.16	4.31	4.44
$\sqrt{\frac{MS\ error}{n}}\ (q_{.95}[r, 60])$	2.04	2.45	2.69	2.87	2.99	3.10	3.20

Table 7

Analysis of Variance Among Groups — Comprehension Level, Concept 1

Source	SS	df	MS	F	F* (critical)
Between Groups	120.54	7	17.22	4.32	2.17
Within	255.33	64	3.99		
Total	375.87	71			

*Alpha of .05

Table 8

Differences Between Mean Scores — Comprehension Level, Concept 1

Groups	Means	2A 9.11	2H 9.22	4A 10.33	5A 10.78	3A 10.89	3H 11.22	4H 12.33	5H 13.11
2A	9.11	0	.11	1.22	1.67	1.78	2.11	3.22*	4.00*
2H	9.22		0	1.11	1.56	1.67	2.00	3.11*	3.89*
4A	10.33			0	.45	.56	.89	2.00	2.78
5A	10.78				0	.1	.44	1.55	2.33
3A	10.89					0	.33	1.44	2.22
3H	11.22						0	1.11	1.89
4H	12.33							0	.78
5H	13.11								0

*p < .05

Table 9

Critical Values — Comprehension Level, Concept 1, (Newman-Keuls Test)

r	2	3	4	5	6	7	8
q .95 (r, 60)	2.83	3.40	3.74	3.98	4.16	4.31	4.44
$\sqrt{\frac{\text{MS error}}{n}}$ (q.95 [r, 60])	1.90	2.28	2.51	2.67	2.79	2.89	2.97

Table 10

Analysis of Variance Among Groups — Application Level, Concept 1

Source	SS	df	MS	F	F* (critical)
Between Groups	34.39	7	4.91	1.25	2.17
Within	250.89	64	3.92		
Total	285.28	71			

*Alpha of .05

Table 11

Comparison of Sample Mean Scores with the Critical Mean Score According to Taxonomic Level, Concept 1

Groups	Mean Score Knowledge	Mean Score Comprehension	Mean Score Application
2A	10.67*	9.11*	7.67
2H	10.11*	9.22*	8.00
3A	11.11*	10.89*	8.56
3H	11.00*	11.22*	9.00
4A	11.33*	10.33*	7.22
4H	13.56*	12.33*	8.11
5A	12.00*	10.78*	8.33
5H	14.33*	13.11*	9.56*

Critical Guessing Mean Score: 9.10

*Exceeds Critical Guessing Mean Score

Table 12

Percent of Groups by Grade Level Earning Scores of 65 Percent or Higher at the Three Taxonomic Levels, Concept 1

Groups	Knowledge		Comprehension		Application	
	Number of students scoring 65 percent or higher	Percent of group	Number of students scoring 65 percent or higher	Percent of group	Number of students scoring 65 percent or higher	Percent of group
2A	5	55.6	2	22.2	0	0.0
2H	5	55.6	2	22.2	2	22.2
3A	6	66.7	5	55.6	3	33.3
3H	4	44.4	5	55.6	1	11.1
4A	5	55.6	5	55.6	0	0.0
4H	8	88.9	8	88.9	2	22.2
5A	8	88.9	5	55.6	1	11.1
5H	9	100.0	9	100.0	3	33.3

Table 13

Rank Order of Groups by Grade Level According to Mean Scores Attained on the Three Taxonomic Test Forms, Concept 2

Knowledge		Comprehension		Application	
Group	Mean	Group	Mean	Group	Mean
5H	80.0	5H	69.4	4H	71.2
4H	79.4	3A	64.4	5H	69.4
5A	68.8	4A	61.3	3A	64.4
4A	65.0	4H	60.6	3H	58.8
3A	64.4	2A	60.6	2A	58.1
2H	62.5	5A	58.8	4A	56.9
3H	61.9	2H	58.1	5A	54.4
2A	53.8	3H	57.5	2H	43.8

Table 14

Analysis of Variance Among Groups — Knowledge Level, Concept 2

Source	SS	df	MS	F	F* (critical)
Between Groups	127.99	7	18.28	3.60	2.17
Within	324.89	64	5.08		
Total	452.88	71			

*Alpha of .05

Concept 2: The particles which make up matter have spaces between them.

From Table 13 it can be seen that the sequences of the groups in terms of mean percent scores varies as one moves from one taxonomic test type to another. The sequence is most orderly at the knowledge level and least orderly at the application level. The only group to consistently perform at a high level on the three taxonomic types of questions is 5H.

The transition from most orderly at the knowledge level to least orderly at the application level seems to lose some importance when it is revealed that: (a) at the knowledge level only the mean score earned by group 2A is significantly lower than those earned by groups 5H and 4H (Tables 14, 15, and 16); (b) at the comprehension level, significant differences do not exist among the mean scores earned by the groups (Table 17); and (c) at the application level, groups 5H, 4H, and 3A earned mean scores that are significantly higher than the mean score attained by group 2H (Tables 18, 19, and 20).

When the mean scores earned at each taxonomic level are compared with the theoretical random guessing mean score it is found that all the groups except (a) 2A, at the knowledge level, and (b) 5A and 2H, at the application level, earned scores higher than the guessing score (Table 21).

The groups, in which more than 50 percent of the members score 65 percent or higher, are (a) 5H, 5A, 4H, and 4A on the knowledge type questions, (b) 5H, 4H, and 3A on the comprehension type questions, and (c) 5H and 4H on the application type questions (Table 22).

Table 15

Differences Between Mean Scores — Knowledge Level, Concept 2

Groups		2A	3H	2H	3A	4A	5A	4H	5H
	Means	8.56	9.89	10.00	10.33	10.44	11.00	12.67	12.78
2A	8.56	0	1.33	1.44	1.77	1.88	2.44	4.11*	4.22*
3H	9.89		0	.11	.44	.55	1.11	2.78	2.89
2H	10.00			0	.33	.44	1.00	2.67	2.78
3A	10.33				0	.11	.67	2.34	2.45
4A	10.44					0	.56	2.23	2.34
5A	11.00						0	1.67	1.78
4H	12.67							0	1.11
5H	12.78								0

$*p < .05$

Table 16

Critical Values — Knowledge Level, Concept 2 (Newman-Keuls Test)

r	2	3	4	5	6	7	8
q .95 (r, 60)	2.83	3.40	3.74	3.98	4.16	4.31	4.44
$\sqrt{\frac{MS\ error}{n}}$ (q .95 [r, 60])	2.12	2.55	2.80	2.98	3.12	3.23	3.33

Table 17

Analysis of Variance Among Groups — Comprehension Level, Concept 2

Source	SS	df	MS	F	F* (critical)
Between Groups	24.43	7	3.49	.68	2.17
Within	330.22	64	5.16		
Total	354.65	71			

*Alpha of .05

Table 18

Analysis of Variance Among Groups — Application Level, Concept 2

Source	SS	df	MS	F	F* (critical)
Between Groups	127.56	7	18.22	4.19	2.17
Within	278.22	64	4.35		
Total	405.78	71			

*Alpha of .05

Table 19

Differences Between Mean Scores — Application Level, Concept 2

Groups		2H	5A	4A	2A	3H	3A	5H	4H
	Means	7.00	8.67	9.11	9.33	9.44	10.33	11.11	11.44
2H	7.00	0	1.67	2.11	2.33	2.44	3.33*	4.11*	4.44*
5A	8.67		0	.44	.66	.77	1.66	2.44	2.77
4A	9.11			0	.22	.33	1.22	2.00	2.33
2A	9.33				0	.11	1.00	1.78	2.11
3H	9.44					0	.89	1.67	2.00
3A	10.33						0	.78	1.11
5H	11.11							0	.33
4H	11.44								0

*$p < .05$

Table 20

Critical Values — Application Level, Concept 2 (Newman-Keuls Test)

r	2	3	4	5	6	7	8
$q_{.95}$ (r, 60)	2.83	3.40	3.74	3.98	4.16	4.31	4.44
$\sqrt{\frac{MS\ error}{n}}$ ($q_{.95}$ [r, 60])	1.98	2.38	2.62	2.79	2.91	3.02	3.11

Table 21

Comparison of Sample Mean Scores with the Critical Mean Score According to Taxonomic Level, Concept 2

Group	Mean Score		
	Knowledge	Comprehension	Application
2A	8.56	9.67*	9.33*
2H	10.00*	9.33*	7.00
3A	10.33*	10.33*	10.33*
3H	9.89*	9.22*	9.44*
4A	10.44*	9.78*	9.11*
4H	12.67*	9.67*	11.44*
5A	11.00*	9.44*	8.67
5H	12.78*	11.11*	11.11*

Critical Guessing Mean Score: 9.10
*Exceeds Critical Guessing Mean Score

Table 22

Percent of Groups by Grade Level Earning Scores of 65 Percent or Higher at the Three Taxonomic Levels, Concept 2

Groups	Knowledge		Comprehension		Application	
	Number of students scoring 65 percent or higher	Percent of group	Number of students scoring 65 percent or higher	Percent of group	Number of students scoring 65 percent or higher	Percent of group
2A	1	11.1	4	44.4	4	44.4
2H	4	44.4	3	33.3	0	0.0
3A	4	44.4	5	55.6	4	44.4
3H	3	33.3	4	44.4	3	33.3
4A	5	55.6	2	22.2	3	33.3
4H	6	66.7	5	55.6	6	66.7
5A	5	55.6	2	22.2	2	22.2
5H	8	88.9	6	66.7	5	55.6

Concept 3: The particles which make up matter are in motion.

From Table 23 it is noted that a different ordered sequence of groups is exhibited at each level of understanding; however, that sequence with the greatest uniformity is at the knowledge level. Other relative consistencies are noted in the performance of the 5H group at the high performance level and the 2A at the low performance level.

Although the sequence of the groups in terms of achievement at the knowledge level does not conform exactly to the grade level sequence of low to high most of the differences are not significant (Tables 24, 25, and 26). It is found that the achievement level of groups 5A and 5H are significantly different from 2A and that 5H is significantly different from 3H. Neither of these mean scores is significantly different from that of the other groups, including 2H. The level of performance of the 5H group, at the comprehension level of understanding, is significantly above that attained by any other group (Tables 27, 28, and 29); however, at the application level, group 5H did not earn a mean score significantly higher than that of any group (Table 30).

The groups that earned a mean score significantly higher than the theoretical random guessing mean score (Table 31) are (a) 5H, 5A, 4H, 4A, 3H, 3A, and 2H at the knowledge level, (b) 5H, 5A, 4H, 4A, and 3A at the comprehension level, and (c) 5H, 4H, 4A, 3H, and 3A at the application level.

A consideration of the performance of individuals at each level of understanding reveals that more than 50 percent of the following groups earned a score of 65 percent or higher: (a) at the knowledge level, 5H, 5A, 4H, 4A, 3H, 3A, and 2H and (b) 5H at the comprehension level (Table 32).

Table 23

Rank Order of Groups by Grade Level According to Mean Scores Attained on the Three Taxonomic Test Forms, Concept 3

Knowledge		Comprehension		Application	
Group	Mean (%)	Group	Mean (%)	Group	Mean (%)
5H	85.6	5H	81.9	5H	66.2
5A	75.0	4H	58.8	4H	60.6
3A	71.2	3A	58.8	3H	58.8
4A	70.0	5A	57.5	4A	57.5
4H	68.8	4A	56.9	3A	56.9
2H	68.8	2H	55.6	5A	55.6
3H	64.4	2A	54.4	2H	52.5
2A	55.0	3H	49.4	2A	45.6

Table 24

Analysis of Variance Among Groups — Knowledge Level, Concept 3

Source	SS	df	MS	F	F* (critical)
Between Groups	121.32	7	17.33	3.97	2.17
Within	279.33	64	4.36		
Total	400.65	71			

*Alpha of .05

Table 25

Differences Between Mean Scores — Knowledge Level, Concept 3

Groups		2A	3H	2H	4H	4A	3A	5A	5H
	Means	8.78	10.33	11.00	11.00	11.22	11.44	12.00	13.67
2A	8.78	0	1.55	2.22	2.22	2.44	2.66	3.22*	4.89*
3H	10.33		0	.67	.67	.89	1.11	1.67	3.34*
2H	11.00			0	0	.22	.44	1.00	2.67
4H	11.00				0	.22	.44	1.00	2.67
4A	11.22					0	.22	.78	2.45
3A	11.44						0	.56	2.23
5A	12.00							0	1.67
5H	13.67								0

*p < .05

Table 26

Critical Values — Knowledge Level, Concept 3 (Newman-Keuls Test)

r	2	3	4	5	6	7	8
q .95 (r, 60)	2.83	3.40	3.74	3.98	4.16	4.31	4.44
$\sqrt{\frac{\text{MS error}}{n}}$ (q .95 [r, 60])	1.98	2.38	2.62	2.79	2.91	3.02	3.11

Table 27

Analysis of Variance Among Groups — Comprehension Level, Concept 3

Source	SS	df	MS	F	F* (critical)
Between Groups	152.39	7	21.77	4.33	2.17
Within	321.56	64	5.02		
Total	473.95	71			

*Alpha of .05

Table 28

Differences Between Mean Scores — Comprehension Level, Concept 3

Groups		3H	2A	2H	4A	5A	3A	4H	5H
	Means	7.89	8.67	8.89	9.11	9.22	9.44	9.44	13.11
3H	7.89	0	.78	1.00	1.22	1.33	1.55	1.55	5.22*
2A	8.67		0	.22	.44	.55	.77	.77	4.44*
2H	8.89			0	.22	.33	.55	.55	4.22*
4A	9.11				0	.11	.33	.33	4.00*
5A	9.22					0	.22	.22	3.89*
3A	9.44						0	0	3.67*
4H	9.44							0	3.67*
5H	13.11								0

*$p < .05$

Table 29

Critical Values — Comprehension Level, Concept 3 (Newman-Keuls Test)

r	2	3	4	5	6	7	8
q .95 (r, 60)	2.83	3.40	3.74	3.98	4.16	4.31	4.44
$\sqrt{\frac{\text{MS error}}{n}}$ (q .95 [r, 60])	2.12	2.55	2.80	2.98	3.12	3.23	3.33

Table 30

Analysis of Variance Among Groups — Application Level, Concept 3

Source	SS	df	MS	F	F* (critical)
Between Groups	55.50	7	7.93	1.89	2.17
Within	268.00	64	4.19		
Total	323.50	71			

*Alpha of .05

Table 31

Comparison of Sample Mean Scores with the Critical Mean Score According to Taxonomic Level, Concept 3

Group	Mean Score: Knowledge	Comprehension	Application
2A	8.78	8.67	7.33
2H	11.00*	8.89	8.44
3A	11.44*	9.44*	9.11*
3H	10.33*	7.89	9.44*
4A	11.22*	9.11*	9.22*
4H	11.00*	9.44*	9.67*
5A	12.00*	9.22*	8.89
5H	13.67*	13.11*	10.56*

Critical Guessing Mean Score: 9.10
*Exceeds Critical Guessing Mean Score

Table 32

Percent of Groups by Grade Level Earning Scores of 65 Percent or Higher at the Three Taxonomic Levels, Concept 3

Groups	Knowledge		Comprehension		Application	
	Number of students scoring 65 percent or higher	Percent of group	Number of students scoring 65 percent or higher	Percent of group	Number of students scoring 65 percent or higher	Percent of group
2A	3	33.3	1	11.1	0	0.0
2H	5	55.6	3	33.3	0	0.0
3A	7	77.8	2	22.2	1	11.1
3H	6	66.7	1	11.1	4	44.4
4A	5	55.6	2	22.2	3	33.3
4H	5	55.6	2	22.2	2	22.2
5A	7	77.8	2	22.2	2	22.2
5H	9	100.0	9	100.0	4	44.4

Concept 4: Some matter is composed of molecules.

A comparison of the rank ordered sequences of the groups at the three taxonomic levels of understanding (Table 33) reveals variations in the relative positions of the individual groups and only roughly some conformity to the order of groups by grade level from 2A through 5H. It is noted that group 5H again consistently performs at a high level and group 2A consistently performs at a low level.

Although group 4H performed at a level higher than any other group on the knowledge type questions only one significant difference was found; that between groups 4H and 2A (Tables 34, 35, and 36). The level of performance of group 5H exceeded that of the remaining groups at the comprehension and application levels; however, significant differences among mean scores earned within the comprehension and application levels were not found (Tables 37 and 38).

The only groups that earned a mean score higher than the critical guessing mean score (Table 39) are (a) 5H, 4H, and 4A at the comprehension level and (b) 5H, 5A, 4H, and 2H at the application level of understanding.

The groups within which more than 50 percent of the members scored 65 percent or higher (Table 40) are (a) 4H on the knowledge type questions, (b) 5H, 4H, 4A, 3A, and 2H on the comprehension type questions, and (c) 5H, 5A, 4H, 3H, and 2H on the application type questions.

Table 33

Rank Order of Groups by Grade Level According to Mean Scores Attained on the Three Taxonomic Test Forms, Concept 4

Knowledge		Comprehension		Application	
Group	Mean (%)	Group	Mean (%)	Group	Mean (%)
4H	61.7	5H	71.7	5H	81.7
5H	55.0	4H	65.0	5A	68.3
3H	50.0	4A	65.0	4H	68.3
3A	48.3	3A	55.0	2H	65.0
5A	45.0	3H	51.7	3H	61.7
2H	36.7	2H	50.0	4A	60.0
4A	35.0	5A	48.3	2A	56.7
2A	31.7	2A	48.3	3A	55.0

Table 34

Analysis of Variance Among Groups — Knowledge Level, Concept 4

Source	SS	df	MS	F	F* (critical)
Between Groups	24.22	7	3.46	2.63	2.17
Within	84.22	64	1.32		
Total	108.44	71			

*Alpha of .05

Table 35

Differences Between Mean Scores — Knowledge Level, Concept 4

Groups	Means	2A 1.89	4A 2.11	2H 2.22	5A 2.67	3A 2.89	3H 3.00	5H 3.33	4H 3.67
2A	1.89	0	.22	.33	.78	1.00	1.11	1.44	1.78*
4A	2.11		0	.11	.56	.78	.89	1.22	1.56
2H	2.22			0	.45	.67	.78	1.11	1.45
5A	2.67				0	.22	.33	.66	1.00
3A	2.89					0	.11	.44	.78
3H	3.00						0	.33	.67
5H	3.33							0	.34
4H	3.67								0

*p < .05

Table 36

Critical Values — Knowledge Level, Concept 4 (Newman-Keuls Test)

r	2	3	4	5	6	7	8
q .95 (r, 60)	2.83	3.40	3.74	3.98	4.16	4.31	4.44
$\sqrt{\frac{MS\ error}{n}}$ (q.95 [r, 60])	1.08	1.29	1.42	1.51	1.58	1.64	1.69

Table 37

Analysis of Variance Among Groups — Comprehension Level, Concept 4

Source	SS	df	MS	F	F* (critical)
Between Groups	19.06	7	2.72	1.01	2.17
Within	172.44	64	2.69		
Total	191.50	71			

*Alpha of .05

Table 38

Analysis of Variance Among Groups — Application Level, Concept 4

Source	SS	df	MS	F	F* (critical)
Between Groups	15.88	7	2.27	1.54	2.17
Within	94.00	64	1.47		
Total	109.88	71			

*Alpha of .05

Table 39

Comparison of Sample Mean Scores with the Critical Mean Score According to Taxonomic Level, Concept 4

Group	Mean Score		
	Knowledge	Comprehension	Application
2A	1.89	2.89	3.44
2H	2.22	3.00	3.89*
3A	2.89	3.33	3.33
3H	3.00	3.11	3.67
4A	2.11	3.89*	3.56
4H	3.67	3.89*	4.11*
5A	2.67	2.89	4.11*
5H	3.33	4.33*	4.89

Critical Guessing Mean Score: 3.67

*Exceeds Critical Guessing Mean Score

Table 40

Percent of Groups by Grade Level Earning Scores of 65 Percent or Higher at the Three Taxonomic Levels, Concept 4

Groups	Knowledge		Comprehension		Application	
	Number of students scoring 65 percent or higher	Percent of group	Number of students scoring 65 percent or higher	Percent of group	Number of students scoring 65 percent or higher	Percent of group
2A	0	0.0	2	22.2	4	44.4
2H	1	11.1	5	55.6	6	66.7
3A	4	44.4	5	55.6	4	44.4
3H	3	33.3	4	44.4	6	66.7
4A	0	0.0	5	55.6	4	44.4
4H	5	55.6	5	55.6	6	66.7
5A	2	22.2	3	33.3	6	66.7
5H	3	33.3	6	66.7	7	77.8

Concept 5: Molecules are composed of atoms.

It is noted from Table 41 that the rank order of the groups according to mean scores attained on the three different tests varies and that little consistency is found at any level of understanding. The only group that performs with relative consistency at the high level is 5H. There appears to be little relationship existing between mean scores earned and the grade level of the group.

Tests for the significance of differences among mean scores reveals that: (a) at the knowledge level (Tables 42, 43, and 44), group 2H achieved a level significantly lower than that achieved by groups 4H and 5H and (b) within the comprehension and application levels no significant differences exist (Tables 45 and 46).

When a comparison is made between the attained mean scores and the theoretical random guessing mean score (Table 47), it is disclosed that groups (a) 5H, 5A, 4H, 4A, and 2A, at the knowledge level of understanding, and (b) 5H, at the comprehension level of understanding, earned mean scores significantly above that for random guessing.

An analysis of individual achievement reveals that groups (a) 5H, 5A, 4H, 4A, 3H, 3A, and 2A, on the knowledge type questions, (b) 5H, 5A, 4H, 3H, and 3A, on the comprehension type questions, and (c) 5H and 3H, on the application type questions, include more than 50 percent of their members with an earned score 65 percent or higher (Table 48).

Table 41

Rank Order of Groups by Grade Level According to Mean Scores Attained on the Three Taxonomic Test Forms, Concept 5

Knowledge		Comprehension		Application	
Group	Mean (%)	Group	Mean (%)	Group	Mean (%)
4H	78.3	5H	70.0	5H	61.7
5H	71.7	3A	61.7	5A	60.0
2A	66.7	3H	60.0	4H	60.0
5A	65.0	2H	60.0	3H	60.0
4A	63.3	4H	56.7	4A	55.0
3H	61.7	5A	51.7	2H	51.7
3A	55.0	4A	51.7	2A	51.7
2H	35.0	2A	51.7	3A	48.3

Table 42

Analysis of Variance Among Groups — Knowledge Level, Concept 5

Source	SS	df	MS	F	F* (critical)
Between Groups	37.11	7	5.30	2.47	2.17
Within	137.33	64	2.15		
Total	174.44	71			

*Alpha of .05

Table 43

Differences Between Mean Scores — Knowledge Level, Concept 5

Groups	Means	2H 2.11	3A 3.33	3H 3.67	4A 3.78	5A 3.89	2A 4.00	5H 4.33	4H 4.67
2H	2.11	0	1.22	1.56	1.67	1.78	1.89	2.22*	2.56*
3A	3.33		0	.34	.45	.56	.67	1.00	1.33
3H	3.67			0	.11	.22	.33	.66	1.00
4A	3.78				0	.11	.22	.55	.89
5A	3.89					0	.11	.44	.78
2A	4.00						0	.33	.67
5H	4.33							0	.34
4H	4.67								0

*$p < .05$

Table 44

Critical Values — Knowledge Level, Concept 5 (Newman-Keuls Test)

r	2	3	4	5	6	7	8
q .95 (r, 60)	2.83	3.40	3.74	3.98	4.16	4.31	4.44
$\sqrt{\frac{MS\ error}{n}}$ (q.95 [r, 60])	1.39	1.67	1.83	1.95	2.04	2.11	2.18

Table 45

Analysis of Variance Among Groups — Comprehension Level, Concept 5

Source	SS	df	MS	F	F* (critical)
Between Grades	9.06	7	1.29	.89	2.17
Within	92.89	64	1.45		
Total	101.95	71			

*Alpha of .05

Table 46

Analysis of Variance Among Groups — Application Level, Concept 5

Source	SS	df	MS	F	F* (critical)
Between Groups	4.99	7	.71	.68	2.17
Within	67.33	64	1.05		
Total	72.32	71			

*Alpha of .05

Table 47

Comparison of Sample Mean Scores with the Critical Mean Score According to Taxonomic Level, Concept 5

	Mean Score		
Group	Knowledge	Comprehension	Application
2A	4.00*	3.11	3.11
2H	2.11	3.56	3.11
3A	3.33	3.67	2.89
3H	3.67	3.56	3.56
4A	3.78*	3.11	3.33
4H	4.66*	3.44	3.56
5A	3.89*	3.11	3.56
5H	4.33*	4.22*	3.67

Critical Guessing Mean Score: 3.67

*Exceeds Critical Guessing Mean Score

Concept 6: Atoms may be composed of protons, neutrons, and electrons.

From Table 49 it is noted that the order of the group scores on the knowledge type questions is from 5H to 2A with the exception of 5A. It is also apparent that the 5A group is achieving at a level below that of 3H and is above only 2A, 2H, and 3A. The order of the groups at the comprehension and application levels lacks consistency except that the 5H group is consistently high and 2A or 2H is consistently low.

The performance of group 5A at the knowledge level is below that for 3H but not significantly different from the performance of each of the groups. However, the mean scores earned by groups 3A, 2H, and 2A at the knowledge level of understanding are significantly lower than the means attained by groups 5H and 4H (Tables 50, 51, and 52).

Although there are variations in the relative performance of the groups at the comprehension and at the application levels the mean scores earned by the groups within these levels are not significantly different (Tables 53 and 54).

The mean scores earned by groups (a) 5H, 5A, 4H, 4A, 3H, and 3A on the knowledge type questions; (b) 5H, 5A, 4H, 3H, and 3A on the comprehension type questions; and (c) 5H on the application type questions are significantly

Table 48

Percent of Groups by Grade Level Earning Scores of 65 Percent or Higher at the Three Taxonomic Levels, Concept 5

Groups	Knowledge		Comprehension		Application	
	Number of students scoring 65 percent or higher	Percent of group	Number of students scoring 65 percent or higher	Percent of group	Number of students scoring 65 percent or higher	Percent of group
2A	5	55.6	3	33.3	2	22.2
2H	2	22.2	3	33.3	4	44.4
3A	5	55.6	6	66.7	4	44.4
3H	5	55.6	6	66.7	5	55.6
4A	6	66.7	3	33.3	4	44.4
4H	7	77.8	5	55.6	4	44.4
5A	5	55.6	5	55.6	3	33.3
5H	8	88.9	8	88.9	5	55.6

Table 49

Rank Order of Groups by Grade Level According to Mean Scores Attained on the Three Taxonomic Test Forms, Concept 6

Knowledge		Comprehension		Application	
Group	Mean (%)	Group	Mean (%)	Group	Mean (%)
5H	90.0	5H	73.3	5H	66.7
4H	86.7	5A	70.0	4H	60.0
4A	78.3	3H	70.0	3A	55.0
3H	76.7	4H	68.3	5A	53.3
5A	70.0	3A	68.3	3H	53.3
3A	63.3	4A	60.0	2A	51.8
2H	61.7	2H	55.0	4A	48.3
2A	60.0	2A	51.8	2H	48.3

Table 50

Analysis of Variance Among Groups — Knowledge Level, Concept 6

Source	SS	df	MS	F	F* (critical)
Between Groups	31.78	7	4.54	4.59	2.17
Within	63.33	64	.99		
Total	95.11	71			

*Alpha of .05

higher than the theoretical random guessing mean score (Table 55).

A consideration of the individual scores attained at the three taxonomic levels of understanding discloses that: (a) all groups at the knowledge level; (b) groups 5H, 5A, 4H, 3H, and 3A at the comprehension level; and (c) groups 5H, 5A, and 3A at the application level have more than 50 percent of their members earning a score of 65 percent or higher (Table 56).

Table 51

Differences Between Mean Scores — Knowledge Level, Concept 6

Groups	Means	2A 3.56	2H 3.67	3A 3.78	5A 4.22	3H 4.56	4A 4.67	4H 5.22	5H 5.44
2A	3.56	0	.11	.22	.66	1.00	1.11	1.66*	1.88*
2H	3.67		0	.11	.55	.89	1.00	1.55*	1.77*
3A	3.78			0	.44	.78	.89	1.44*	1.66*
5A	4.22				0	.34	.45	1.00	1.22
3H	4.56					0	.11	.66	.68
4A	4.67						0	.55	.77
4H	5.22							0	.22
5H	5.44								0

*p < .05

Table 52

Critical Values — Knowledge Level, Concept 6 (Newman-Keuls Test)

r	2	3	4	5	6	7	8
q .95 (r, 60)	2.83	3.40	3.74	3.98	4.16	4.31	4.44
$\sqrt{\frac{\text{MS error}}{n}}$ (q .95 [r, 60])	.93	1.12	1.23	1.31	1.37	1.42	1.47

Table 53

Analysis of Variance Among Groups — Comprehension Level, Concept 6

Source	SS	df	MS	F	F* (critical)
Between Groups	14.89	7	2.13	1.77	2.17
Within	76.22	64	1.19		
Total	91.11	71			

*Alpha of .05

Table 54

Analysis of Variance Among Groups — Application Level, Concept 6

Source	SS	df	MS	F	F* (critical)
Between Groups	8.44	7	1.21	.82	2.17
Within	94.00	64	1.47		
Total	102.44	71			

*Alpha of .05

Table 55

Comparison of Sample Mean Scores with the Critical Mean Score According to Taxonomic Level, Concept 6

Group	Mean Score		
	Knowledge	Comprehension	Application
2A	3.56	3.11	3.11
2H	3.67	3.33	2.89
3A	3.78*	4.11*	3.33
3H	4.56*	4.22*	3.22
4A	4.67*	3.57	2.89
4H	5.22*	4.11*	3.56
5A	4.22*	4.22*	3.22
5H	5.44*	4.44*	4.00*

Critical Guessing Mean Score: 3.67
*Exceeds Critical Guessing Mean Score

Table 56

Percent of Groups by Grade Level Earning Scores of 65 Percent or Higher at the Three Taxonomic Levels, Concept 6

Groups	Knowledge		Comprehension		Application	
	Number of students scoring 65 percent or higher	Percent of group	Number of students scoring 65 percent or higher	Percent of group	Number of students scoring 65 percent or higher	Percent of group
2A	5	55.6	4	44.4	3	33.3
2H	5	55.6	3	33.8	3	33.3
3A	6	66.7	7	77.8	6	66.7
3H	6	66.7	7	77.8	4	44.4
4A	7	77.8	3	33.3	1	11.1
4H	9	100.0	6	66.7	4	44.4
5A	7	77.8	7	77.8	5	55.6
5H	9	100.0	6	66.7	6	66.7

Concept 7: The nature and the amount of char on an electron is a negative one.

Although group 5H consistently performed at a high level on each of the three taxonomic type tests (Table 57) for concept seven there are extreme variations noted in the relative posititions occupied by the groups in each rank ordered sequence. On this concept, there appears to be no relationship between grade level and level of performance by all groups except 5H.

Further evidence to support this belief is found in the facts that significant differences are not existent (a) among mean test scores within the knowledge, comprehension, and application levels of understanding (Tables 58, 59, 60, 61 and 62) and (b) between the mean scores earned at the knowledge level of understanding and a random guessing mean score. Significant differences were found between mean test scores at the comprehension level for groups 5H, 3H, and 3A and at the application level for group 2H and the random guessing mean score (Table 63).

The groups that have more than 50 percent of the members who earned a score of 65 percent or higher (Table 64) are (a) 4A at the knowledge level, (b) 5H, 3H, and 3A at the comprehension level, and (c) 3A, and 2H at the application level.

Table 57

Rank Order of Groups by Grade Level According to Mean Scores Attained on the Three Taxonomic Text Forms, Concept 7

Knowledge		Comprehension		Application	
Group	Mean (%)	Group	Mean (%)	Group	Mean (%)
4A	61.7	5H	70.0	2H	65.0
5H	53.3	3H	65.0	5H	61.7
3H	48.3	3A	63.3	3A	56.7
3A	48.3	2H	50.0	5A	53.3
2A	48.3	5A	48.3	3H	51.7
4H	46.7	2A	46.7	2A	50.0
5A	38.3	4A	43.3	4A	48.3
2H	36.7	4H	36.7	4H	45.0

Table 58

Analysis of Variance Among Groups — Knowledge Level, Concept 7

Source	SS	df	MS	F	F* (critical)
Between Groups	13.28	7	1.90	1.15	2.17
Within	105.33	64	1.65		
Total	118.61	71			

*Alpha of .05

Table 59

Analysis of Variance Among Groups — Comprehension Level, Concept 7

Source	S	df	MS	F	F* (critical)
Between Groups	31.78	7	4.54	2.50	2.17
Within	116.22	64	1.82		
Total	148.00	71			

*Alpha of .05

Table 60

Differences Between Mean Scores — Comprehension Level, Concept 7

Groups	Means	4H 2.22	4A 2.56	2A 2.78	5A 2.89	2H 3.00	3A 3.78	3H 3.89	5H 4.22
4H	2.22	0	.34	.56	.67	.78	1.56	1.67	2.00
4A	2.56		0	.22	.33	.44	1.22	1.33	1.66
2A	2.78			0	.11	.22	1.00	1.11	1.44
5A	2.89				0	.11	.89	1.00	1.33
2H	3.00					0	.78	.89	1.22
3A	3.78						0	.11	.44
3H	3.89							0	.33
5H	4.22								0

*p < .05

Table 61

Critical Values — Comprehension Level, Concept 7 (Newman-Keuls Test)

r	2	3	4	5	6	7	8
q .95 (r, 60)	2.83	3.40	3.74	3.98	4.16	4.31	4.44
$\sqrt{\frac{\text{MS error}}{n}}$ (q .95 [r, 60])	1.27	1.53	1.68	1.79	1.87	1.94	2.00

Table 62

Analysis of Variance Among Groups — Application Level, Concept 7

Source	SS	df	MS	F	F* (critical)
Between Groups	10.54	7	1.51	1.17	2.17
Within	82.44	64	1.29		
Total	92.98	71			

*Alpha of .05

Table 63

Comparison of Sample Mean Scores with the Critical Mean Score According to Taxonomic Level, Concept 7

Group	Mean Score		
	Knowledge	Comprehension	Application
2A	2.89	2.78	3.00
2H	2.22	3.00	3.89*
3A	2.89	3.78*	3.44
3H	2.89	3.89*	3.11
4A	3.67	2.56	2.89
4H	2.78	2.22	2.67
5A	2.33	2.89	3.22
5H	3.22	4.22*	3.67

Critical Guessing Mean Score: 3.67
*Exceeds Critical Guessing Mean Score

Concept 8: The natüre and the amount of charge on a proton is a positive one.

It is noted from Table 65 that the levels of performance of groups 5H, 5A, 4H, and 4A, at the knowledge level of understanding, are higher than those achieved by any of the groups at the comprehension and application levels. The only group to consistently perform at a high level is 5H. When a comparison of the order of groups in each sequence is made, it is found that the sequence of groups according to mean scores earned at the knowledge level is the most orderly.

Although group 5H consistently performed at a high level it did not perform at a significantly higher level than any other group. Significant differences were not found among the mean scores earned (a) at the knowledge level (Tables 66, 67, and 68), (b) at the comprehension level (Tables 69, 70, and 71), and (c) at the application level (Table 72).

When the mean scores earned are statistically compared to the random guessing mean score it is found that groups (a) 5H, 5A, 4H, and 4A, at the knowledge level, and (b) 5H and 3A, at the comprehension level, performed at a level significantly above guessing (Table 73).

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A consideration of the performance of individuals within groups reveals that groups (a) 5H, 5A, 4H, 4A, and 3H, on the knowledge type questions, and (b) 5H, 4A, 3A, and 2H, on the comprehension type questions, have more than 50 percent of their members with an earned score of 65 percent or higher (Table 74).

Table 64

Percent of Groups by Grade Level Earning Scores of 65 Percent or Higher at the Three Taxonomic Levels, Concept 7

Groups	Knowledge		Comprehension		Application	
	Number of students scoring 65 percent or higher	Percent of group	Number of students scoring 65 percent or higher	Percent of group	Number of students scoring 65 percent or higher	Percent of group
2A	2	22.2	3	33.3	2	22.2
2H	1	11.1	4	44.4	6	66.7
3A	3	33.3	6	66.7	6	66.7
3H	2	22.2	5	55.6	2	22.2
4A	5	55.6	2	22.2	2	22.2
4H	2	22.2	0	0.0	2	22.2
5A	2	22.2	3	33.3	3	33.3
5H	3	33.3	5	55.6	4	44.4

Table 65

Rank Order of Groups by Grade Level According to Mean Scores Attained on the Three Taxonomic Test Forms, Concept 8

Knowledge		Comprehension		Application	
Group	Mean (%)	Group	Mean (%)	Group	Mean (%)
5H	83.3	5H	66.7	4H	61.7
5A	76.7	3A	66.7	5H	60.0
4A	76.7	2H	61.7	3A	60.0
4H	70.0	4A	55.0	4A	51.7
3H	61.7	5A	48.3	3H	48.3
2A	51.7	3H	48.3	2H	46.7
3A	50.0	4H	43.3	5A	45.0
2H	50.0	2A	36.7	2A	33.3

Table 66

Analysis of Variance Among Groups — Knowledge Level, Concept 8

Source	SS	df	MS	F	F* (critical)
Between Groups	40.22	7	5.75	3.20	2.17
Within	114.89	64	1.80		
Total	155.11	71			

*Alpha of .05

Table 67

Differences Between Mean Scores — Knowledge Level, Concept 8

Groups	Means	2H 3.00	3A 3.00	2A 3.11	3H 3.67	4H 4.22	4A 4.56	5A 4.56	5H 5.00
2H	3.00	0	0	.11	.67	1.22	1.56	1.56	2.00
3A	3.00		0	.11	.67	1.22	1.56	1.56	2.00
2A	3.11			0	.56	1.11	1.45	1.45	1.89
3H	3.67				0	.55	.89	.89	1.33
4H	4.22					0	.34	.34	.78
4A	4.56						0	0	.44
5A	4.56							0	.44
5H	5.00								0

*p < .05

Table 68

Critical Values — Knowledge Level, Concept 8 (Newman-Keuls Test)

r	2	3	4	5	6	7	8
q .95 (r, 60)	2.83	3.40	3.74	3.98	4.16	4.31	4.44
$\sqrt{\frac{MS\ error}{n}}$ (q .95 [r, 60])	1.27	1.53	1.68	1.79	1.87	1.94	2.00

Table 69

Analysis of Variance Among Groups — Comprehension Level, Concept 8

Source	SS	df	MS	F	F* (critical)
Between Groups	27.72	7	3.96	2.40	2.17
Within	105.56	64	1.65		
Total	133.28	71			

*Alpha of .05

Table 70

Differences Between Mean Scores — Comprehension Level, Concept 8

Groups	Means	2A 2.22	4H 2.56	3H 2.89	5A 2.89	4A 3.33	2H 3.67	3A 4.00	5H 4.00
2A	2.22	0	.34	.67	.67	1.11	1.45	1.78	1.78
4H	2.56		0	.33	.33	.77	1.11	1.44	1.44
3H	2.89			0	0	.44	.78	1.11	1.11
5A	2.89				0	.44	.78	1.11	1.11
4A	3.33					0	.34	.67	.67
2H	3.67						0	.33	.33
3A	4.00							0	0
5H	4.00								0

*p < .05

Table 71

Critical Values — Comprehension Level, Concept 8 (Newman-Keuls Test)

r	2	3	4	5	6	7	8
q . 95 (r, 60)	2.83	3.40	3.74	3.98	4.16	4.31	4.44
$\sqrt{\frac{\text{MS error}}{n}}$ (q . 95 [r, 60])	1.22	1.46	1.61	1.71	1.79	1.85	1.91

Table 72

Analysis of Variance Among Groups — Application Level, Concept 8

Source	SS	df	MS	F	F* (critical)
Between Groups	20.17	7	2.88	1.74	2.17
Within	105.78	64	1.65		
Total	125.94	71			

*Alpha of . 05

Table 73

Comparison of Sample Mean Scores with the Critical Mean Score
According to Taxonomic Level, Concept 8

Group	Mean Score		
	Knowledge	Comprehension	Application
2A	3.11	2.22	2.00
2H	3.00	3.67	2.78
3A	3.00	4.00*	3.56
3H	3.67	2.89	2.89
4A	4.56*	3.33	3.11
4H	4.22*	2.56	3.67
5A	4.56*	2.89	2.67
5H	5.00*	4.00*	3.56

Critical Guessing Mean Score: 3.67
*Exceeds Critical Guessing Mean Score

Concept 9: A neutron does not have a charge.

From Table 75 it is noted that the relative achievement of the group varies from one level of understanding to another and that the performance of group 5H exceeds that of the other groups at each level of understanding.

When tests of significance are applied to these test scores it is found that: (a) no significant differences exist among the mean scores earned by the groups on the knowledge and application type questions (Tables 76 and 77) and (b) the mean score earned by group 5H on the comprehension type questions is significantly higher than those earned by groups 4A and 5A (Tables 78, 79, and 80).

The variations in the relative performance of the groups at different levels of understanding may best be described as chance since only (a) group 5H at the knowledge and comprehension levels and (b) groups 5H and 3H at the application level achieved mean scores that exceed the critical guessing mean score (Table 81).

When the scores are analyzed according to individual performances, it is found that groups (a) 5H, on the knowledge type questions, (b) 5H and 3A, on the comprehension type questions, and (c) 5H and 3H, on the application type questions, have more than 50 percent of the members who earned a score of 65 percent or higher (Table 82).

Table 74

Percent of Groups by Grade Level Earning Scores of 65 Percent or Higher at the Three Taxonomic Levels, Concept 8

Groups	Knowledge		Comprehension		Application	
	Number of students scoring 65 percent or higher	Percent of group	Number of students scoring 65 percent or higher	Percent of group	Number of students scoring 65 percent or higher	Percent of group
2A	4	44.4	1	11.1	1	11.1
2H	4	44.4	5	55.6	4	44.4
3A	3	33.3	6	66.7	4	44.4
3H	5	55.6	3	33.3	3	33.3
4A	8	88.9	5	55.6	3	33.3
4H	7	77.8	2	22.2	4	44.4
5A	8	88.9	2	22.2	2	22.2
5H	8	88.9	6	66.7	3	33.3

Table 75

Rank Order of Groups by Grade Level According to Mean Scores Attained on the Three Taxonomic Test Forms, Concept 9

Knowledge		Comprehension		Application	
Group	Mean (%)	Group	Mean (%)	Group	Mean (%)
5H	70.0	5H	68.3	5H	65.0
3H	60.0	3A	56.7	3H	63.3
4H	55.0	3H	53.3	5A	55.0
5A	46.7	4H	51.7	4H	55.0
4A	46.7	2H	50.0	3A	55.0
2H	46.7	2A	46.7	2H	55.0
3A	40.0	5A	38.3	4A	46.7
2A	38.3	4A	35.0	2A	33.3

Table 76

Analysis of Variance Among Groups — Knowledge Level, Concept 9

Source	SS	df	MS	F	F* (critical)
Between Groups	25.28	7	3.61	1.01	2.17
Within	228.67	64	3.57		
Total	253.95	71			

*Alpha of .05

Table 77

Analysis of Variance Among Groups — Application Level, Concept 9

Source	SS	df	MS	F	F* (critical)
Between Groups	22.44	7	3.21	1.58	2.17
Within	130.00	64	2.03		
Total	152.44	71			

*Alpha of .05

Table 78

Analysis of Variance Among Groups — Comprehension Level, Concept 9

Source	SS	df	MS	F	F* (critical)
Between Groups	24.99	7	3.57	2.43	2.17
Within	94.00	64	1.47		
Total	118.99	71			

*Alpha of .05

Table 79

Differences Between Mean Scores — Comprehension Level, Concept 9

Groups	Means	4A 2.11	5A 2.33	2A 2.78	2H 3.00	4H 3.11	3H 3.22	3A 3.44	5H 4.11
4A	2.11	0	.22	.67	.89	1.00	1.11	1.33	2.00*
5A	2.33		0	.45	.67	.78	.89	1.11	1.78*
2A	2.78			0	.22	.33	.44	.66	1.33
2H	3.00				0	.11	.22	.44	1.11
4H	3.11					0	.11	.33	1.00
3H	3.22						0	.22	.89
3A	3.44							0	.67
5H	4.11								0

*$p < .05$

Table 80

Critical Values — Comprehension Level, Concept 9 (Newman-Keuls Test)

r	2	3	4	5	6	7	8
q .95 (r, 60)	2.83	3.40	3.74	3.98	4.16	4.31	4.44
$\sqrt{\frac{MS\ error}{n}}$ (q .95 [r, 60])	1.13	1.36	1.50	1.59	1.66	1.72	1.78

Table 81

Comparison of Sample Mean Scores with the Critical Mean Score According to Taxonomic Level, Concept 9

Group	Mean Score: Knowledge	Comprehension	Application
2A	2.33	2.78	2.00
2H	2.78	3.00	3.33
3A	2.44	3.44	3.33
3H	3.56	3.22	3.78*
4A	2.78	2.11	2.78
4H	3.33	3.11	3.33
5A	2.78	2.33	3.33
5H	4.22*	4.11*	3.89*

Critical Guessing Mean Score: 3.67
*Exceeds Critical Guessing Mean Score

Table 82

Percent of Groups by Grade Level Earning Scores of 65 Percent or Higher at the Three Taxonomic Levels, Concept 9

Groups	Knowledge		Comprehension		Application	
	Number of students scoring 65 percent or higher	Percent of group	Number of students scoring 65 percent or higher	Percent of group	Number of students scoring 65 percent or higher	Percent of group
2A	3	33.3	2	22.2	0	0.0
2H	3	33.3	2	22.2	4	44.4
3A	3	33.3	5	55.6	3	33.3
3H	4	44.4	3	33.3	5	55.6
4A	2	22.2	1	11.1	2	22.2
4H	3	33.3	3	33.3	4	44.4
5A	4	44.4	1	11.1	4	44.4
5H	5	55.6	6	66.7	6	66.7

Concept 10: Atoms have the same number of protons as electrons.

The relative positions occupied by the groups in the rank order sequences in Table 83 vary from one level of understanding to another. The apparent consistencies in levels of performance are by group 5H at a high level and group 2A at a low level. It is noted that at the comprehension level the achievement of the high ability groups exceeds that of the average ability groups.

Although the relative performance, in terms of test scores of the groups, varies from one level of understanding to another it is to be noted that significant differences do not exist among the mean scores earned by the groups within the knowledge, comprehension, and application levels (Tables 84, 85, 86, 87, and 88).

The earned mean scores that significantly exceed the theoretical random guessing mean score (Table 89) are those attained by groups (a) 5H, 5A, 4H, 4A, 3H, and 3A at the knowledge level, (b) 5H, 4H, 4A, 3H, 3A, 2H, and 2A at the comprehension level, and (c) 5H, 5A, 4H, and 3H at the application level.

The groups in which more than 50 percent of the members earned a score of 65 percent or higher are: (a) 5H, 5A, 4H, 4A, 3H, 3A, and 2A on the knowledge type questions, (b) 5H, 4H, 4A, 3H, 3A, 2H, and 2A on the comprehension type questions, and (c) 5H, 5A, and 3H on the application type questions (Table 90).

Table 83

Rank Order of Groups by Grade Level According to Mean Scores Attained on the Three Taxonomic Test Forms, Concept 10

Knowledge		Comprehension		Application	
Group	Mean (%)	Group	Mean (%)	Group	Mean (%)
5H	80.0	5H	80.0	5H	78.3
4A	78.3	4H	78.3	3H	70.0
4H	73.3	3H	73.3	5A	66.7
3H	66.7	2H	71.7	4H	65.0
5A	65.0	4A	70.0	3A	56.7
3A	65.0	3A	68.3	4A	51.7
2A	56.7	2A	63.3	2A	48.3
2H	55.0	5A	51.7	2H	45.0

Table 84

Analysis of Variance Among Groups — Knowledge Level, Concept 10

Source	SS	df	MS	F	F* (critical)
Between Groups	18.00	7	2.57	1.56	2.17
Within	105.78	64	1.65		
Total	123.78	71			

*Alpha of .05

Table 85

Analysis of Variance Among Groups — Comprehension Level, Concept 10

Source	SS	df	MS	F	F* (critical)
Between Groups	17.99	7	2.57	1.41	2.17
Within	116.67	64	1.82		
Total	134.66	71			

*Alpha of .05

Table 86

Analysis of Variance Among Groups — Application Level, Concept 10

Source	SS	df	MS	F	F* (critical)
Between Groups	30.67	7	4.38	2.18	2.17
Within	128.44	64	2.01		
Total	159.11	71			

*Alpha of .05

Table 87

Differences Between Mean Scores — Application Level, Concept 10

Groups		2H	2A	4A	3A	4H	5A	3H	5H
	Means	2.67	2.89	3.11	3.44	3.89	4.00	4.22	4.67
2H	2.67	0	.22	.44	.77	1.22	1.33	1.55	2.00
2A	2.89		0	.22	.55	1.00	1.11	1.33	1.78
4A	3.11			0	.33	.78	.89	1.11	1.56
3A	3.44				0	.45	.56	.78	1.23
4H	3.89					0	.11	.33	.78
5A	4.00						0	.22	.67
3H	4.22							0	.45
5H	4.67								0

*p < .05

Table 88

Critical Values — Application Level, Concept 10 (Newman-Keuls Test)

r	2	3	4	5	6	7	8
q .95 (r, 60)	2.83	3.40	3.74	3.98	4.16	4.31	4.44
$\sqrt{\frac{\text{MS error}}{n}}$ (q .95 [r, 60])	1.33	1.60	1.76	1.87	1.96	2.03	2.09

Table 89

Comparison of Sample Mean Scores with the Critical Mean Score According to Taxonomic Level, Concept 10

Group	Mean Score		
	Knowledge	Comprehension	Application
2A	3.44	3.78*	2.89
2H	3.33	4.33*	2.67
3A	3.89*	4.11*	3.44
3H	4.00*	4.44*	4.22*
4A	4.67*	4.22*	3.11
4H	4.44*	4.67*	3.89*
5A	3.89*	3.11	4.00*
5H	4.78*	4.78*	4.67*

Critical Guessing Mean Score: 3.67
*Exceeds Critical Guessing Mean Score

Table 90

Percent of Groups by Grade Level Earning Scores of 65 Percent or Higher at the Three Taxonomic Levels, Concept 10

Groups	Knowledge		Comprehension		Application	
	Number of students scoring 65 percent or higher	Percent of groups	Number of students scoring 65 percent or higher	Percent of groups	Number of students scoring 65 percent or higher	Percent of groups
2A	5	55.6	5	55.6	3	33.3
2H	4	44.4	7	77.8	3	33.3
3A	5	55.6	6	66.7	3	33.3
3H	6	66.7	8	88.9	7	77.8
4A	8	88.9	6	66.7	2	22.2
4H	5	55.6	7	77.8	4	44.4
5A	6	66.7	2	22.2	5	55.6
5H	9	100.0	8	88.9	7	77.8

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Concept 11: All atoms of the same element have the same number of protons

It is noted from Table 91 that the order of groups according to mean percent scores is different at each level of understanding. It appears that the relative positions occupied by the groups are represented more by chance than by grade level.

Further evidence of the chance nature of the relative position of any one group within any of the three levels of understanding is found in the following facts: 1. No significant differences are found among mean scores within any of the three levels (Tables 92, 93, and 94). 2. Only those mean scores earned by groups 5H, 5A, and 4H at the knowledge level are significantly different from guessing.

When the groups are evaluated according to the performance of individual members it is found that groups (a) 5H, 5A, 4H, 3H, and 2H at the knowledge level, and (b) 5H, 3A, and 2A at the comprehension level have more than 50 percent of their members with an earned score of 65 percent or higher (Table 96).

Table 91

Rank Order of Groups by Grade Level According to Mean Scores Attained on the Three Taxonomic Test Forms, Concept 11

Knowledge		Comprehension		Application	
Group	Mean (%)	Group	Mean (%)	Group	Mean (%)
5H	76.7	2A	60.0	5H	61.7
4H	66.7	3A	56.7	3H	55.0
5A	65.0	5H	55.0	5A	48.3
3H	60.0	2H	50.0	4A	48.3
2H	55.0	5A	43.3	3A	45.0
3A	53.3	4A	40.0	2A	45.0
2A	50.0	3H	40.0	2H	40.0
4A	45.0	4H	36.7	4H	38.3

Table 92

Analysis of Variance Among Groups — Knowledge Level, Concept 11

Source	SS	df	MS	F	F* (critical)
Between Groups	23.06	7	3.29	1.87	2.17
Within	112.89	64	1.76		
Total	135.95	71			

*Alpha of .05

Table 93

Analysis of Variance Among Groups — Comprehension Level, Concept 11

Source	SS	df	MS	F	F* (critical)
Between Groups	17.21	7	2.46	1.37	2.17
Within	114.67	64	1.79		
Total	131.88	71			

*Alpha of .05

Table 94

Analysis of Variance Among Groups — Application Level, Concept 11

Source	SS	df	MS	F	F* (critical)
Between Groups	12.61	7	1.80	.98	2.17
Within	118.00	64	1.84		
Total	130.61	71			

*Alpha of .05

Table 95

Comparison of Sample Mean Scores with the Critical Mean Score According to Taxonomic Level, Concept 11

Group	Mean Score: Knowledge	Mean Score: Comprehension	Mean Score: Application
2A	3.00	3.56	2.67
2H	3.33	3.00	2.44
3A	3.22	3.44	2.67
3H	3.56	2.44	3.33
4A	2.67	2.44	2.89
4H	4.00*	2.22	2.33
5A	3.89*	2.56	2.89
5H	4.56*	3.33	2.89

Critical Guessing Mean Score: 3.67
*Exceeds Critical Guessing Mean Score

Table 96

Percent of Groups by Grade Level Earning Scores of 65 Percent or Higher at the Three Taxonomic Levels, Concept 11

Groups	Knowledge		Comprehension		Application	
	Number of students scoring 65 percent or higher	Percent of group	Number of students scoring 65 percent or higher	Percent of group	Number of students scoring 65 percent or higher	Percent of group
2A	3	33.3	5	55.6	1	11.1
2H	5	55.6	4	44.4	1	11.1
3A	3	33.3	5	55.6	2	22.2
3H	5	55.6	2	22.2	4	44.4
4A	3	33.3	2	22.2	2	22.2
4H	6	66.7	0	0.0	1	11.1
5A	6	66.7	2	22.2	2	22.2
5H	6	66.7	5	55.6	4	44.4

Concept 12: Some matter is composed of ions.

An analysis of the sequences of the groups in Table 97 reveals that the relative performance of the groups according to percent mean scores varies from one taxonomic level to another. It is noted that the only order of groups to approximate a sequence ranked according to grade levels is at the comprehension level of understanding. The only groups to perform at a high level with relative consistency are 5H and 4A.

The performance of group 5H, at the knowledge level, is significantly higher than that of groups 5A, 3H, 3A, 2H, and 2A (Tables 98, 99, and 100); however, no significant differences were found among the mean scores earned within the comprehension and application levels (Tables 101 and 102).

When the mean scores by group and taxonomic level are compared to the guessing mean score (Table 103), it is found that groups (a) 5H, 4H, 4A, 3H, 2H, and 2A at the knowledge level, (b) 5H, 5A, 4H, and 4A at the comprehension level, and (c) 5H, 4H, 4A, and 3H at the application level earned mean scores that are significantly higher than guessing.

The groups that have more than 50 percent of their members earning a score of 65 percent or higher (Table 104) are (a) 5H, 4H, 4A, 2H, and 2A, on the knowledge type questions, and (b) 5H and 5A, on the comprehension type questions.

Table 97

Rank Order of Groups by Grade Level According to Mean Scores Attained on the Three Taxonomic Test Forms, Concept 12

Knowledge		Comprehension		Application	
Group	Mean (%)	Group	Mean (%)	Group	Mean (%)
5H	83.0	5A	67.0	5H	63.0
4H	70.0	4A	67.0	4A	60.0
4A	69.0	5H	62.0	3H	60.0
2H	63.0	4H	61.0	4H	59.0
3H	60.0	3A	58.0	3A	57.0
2A	59.0	3H	56.0	5A	56.0
3A	56.0	2A	52.0	2A	51.0
5A	50.0	2H	51.0	2H	47.0

Table 98

Analysis of Variance Among Groups — Knowledge Level, Concept 12

Source	SS	df	MS	F	F* (critical)
Between Groups	66.88	7	9.55	3.73	2.17
Within	164.00	64	2.56		
Total	230.88	71			

*Alpha of .05

Table 99

Differences Between Mean Scores — Knowledge Level, Concept 12

Groups	Means	5A 5.00	3A 5.56	2A 5.89	3H 6.00	2H 6.33	4A 6.89	4H 7.00	5H 8.33
5A	5.00	0	.56	.89	1.00	1.33	1.89	2.00	3.33*
3A	5.56		0	.33	.44	.77	1.33	1.44	2.77*
2A	5.89			0	.11	.44	1.00	1.11	2.44*
3H	6.00				0	.33	.89	1.00	2.33*
2H	6.33					0	.56	.67	2.00*
4A	6.89						0	.11	1.44
4H	7.00							0	1.33
5H	8.33								0

*p < .05

Table 100

Critical Values — Knowledge Level, Concept 12 (Newman-Keuls Test)

r	2	3	4	5	6	7	8
q .95 (r, 60)	2.83	3.40	3.74	3.98	4.16	4.31	4.44
$\sqrt{\frac{MS\ error}{n}}$ (q .95 [r, 60])	1.50	1.80	1.98	2.11	2.20	2.28	2.35

Table 101

Analysis of Variance Among Groups — Comprehension Level, Concept 12

Source	SS	df	MS	F	F* (critical)
Between Groups	22.83	7	3.26	1.10	2.17
Within	190.67	64	2.98		
Total	213.50	71			

*Alpha of .05

Table 102

Analysis of Variance Among Groups — Application Level, Concept 12

Source	SS	df	MS	F	F* (critical)
Between Groups	18.32	7	2.62	1.15	2.17
Within	146.00	64	2.28		
Total	164.32	71			

*Alpha of .05

Table 103

Comparison of Sample Mean Scores with the Critical Mean Score According to Taxonomic Level, Concept 12

Group	Mean Score		
	Knowledge	Comprehension	Application
2A	5.89*	5.22	5.11
2H	6.33*	5.11	4.67
3A	5.56	5.78	5.67
3H	6.00*	5.56	6.00*
4A	6.89*	6.67*	6.00*
4H	7.00*	6.11*	5.89*
5A	5.00	6.67*	5.56
5H	8.33*	6.22*	6.33*

Critical Guessing Mean Score: 5.86
*Exceeds Critical Guessing Mean Score

Table 104

Percent of Groups by Grade Level Earning Scores of 65 Percent or Higher at the Three Taxonomic Levels, Concept 12

Groups	Knowledge		Comprehension		Application	
	Number of students scoring 65 percent or higher	Percent of group	Number of students scoring 65 percent or higher	Percent of group	Number of students scoring 65 percent or higher	Percent of group
2A	5	55.6	2	22.2	1	11.1
2H	5	55.6	2	22.2	2	22.2
3A	2	22.2	2	22.2	3	33.3
3H	3	33.3	4	44.4	3	33.3
4A	7	77.8	4	44.4	4	44 4
4H	6	66.7	3	33.3	2	22.2
5A	1	11.1	6	66.7	2	22.2
5H	9	100.0	5	55.6	3	33.3

Concept 13: An ion is a particle or group of particles which has more electrons than protons or more protons than electrons.

From Table 105 it is noted that the relative levels of achievement of the several groups, when arranged serially according to percent mean scores, are not consistent at the three levels of understanding. The order of the groups, at the comprehension level, roughly conforms to the grade levels from 2H through 5H.

The mean scores earned within the knowledge and application levels are not significantly different (Tables 106 and 107); however, at the comprehension level, the mean scores earned by groups 5H and 4H are significantly higher than those attained by groups 2H, 2A, 3A and 3H (Tables 108, 109, and 110).

A comparison of the earned mean scores with the theoretical guessing mean score (Table 111) reveals that (a) all the groups except 5A and 2A at the knowledge level; (b) groups 5H, 5A, 4H, and 4A at the comprehension level; and (c) group 4A at the application level earned a mean score significantly higher than guessing.

When the performance of individuals is considered, it is found that the groups in which more than 50 percent of the members earned a score of 65 percent or higher (Table 112) are: (a) 5H on the knowledge type questions, (b) 5H, 4H, and 4A on the comprehension type questions, and (c) 4A on the application type questions.

Table 105

Rank Order of Groups by Grade Level According to Mean Scores Attained on the Three Taxonomic Test Forms, Concept 13

Knowledge		Comprehension		Application	
Group	Mean (%)	Group	Mean (%)	Group	Mean (%)
5H	67.0	5H	79.0	4A	64.0
3H	63.0	4H	79.0	3A	57.0
4H	61.0	4A	62.0	4H	54.0
3A	61.0	5A	59.0	3H	52.0
4A	60.0	3H	51.0	5A	50.0
2H	60.0	3A	50.0	2A	49.0
2A	50.0	2A	49.0	2H	48.0
5A	49.0	2H	48.0	5H	46.0

Table 106

Analysis of Variance Among Groups — Knowledge Level, Concept 13

Source	SS	df	MS	F	F* (critical)
Between Groups	24.44	7	3.49	.97	2.17
Within	230.67	64	3.60		
Total	255.11	71			

*Alpha of .05

Table 107

Analysis of Variance Among Groups — Application Level, Concept 13

Source	SS	df	MS	F	F* (critical)
Between Groups	22.83	7	3.26	1.28	2.17
Within	162.67	64	2.54		
Total	185.50	71			

*Alpha of .05

Table 108

Analysis of Variance Among Groups — Comprehension Level, Concept 13

Source	SS	df	MS	F	F* (critical)
Between Groups	105.32	7	15.05	3.65	2.17
Within	263.56	64	4.12		
Total	368.88	71			

*Alpha of .05

Table 109

Differences Between Mean Scores — Comprehension Level, Concept 13

Groups	Means	2H 4.78	2A 4.89	3A 5.00	3H 5.11	5A 5.89	4A 6.22	4H 7.89	5H 7.89
2H	4.78	0	.11	.22	.33	1.11	1.44	3.11*	3.11*
2A	4.89		0	.11	.22	1.00	1.33	3.00*	3.00*
3A	5.00			0	.11	.89	1.22	2.89*	2.89*
3H	5.11				0	.78	1.11	2.78*	2.78*
5A	5.89					0	.33	2.00	2.00
4A	6.22						0	1.67	1.67
4H	7.89							0	0
5H	7.89								0
									0

*p < .05

Table 110

Critical Values — Comprehension Level, Concept 13 (Newman-Keuls Test)

r	2	3	4	5	6	7	8
q .95 (r, 60)	2.83	3.40	3.74	3.98	4.16	4.31	4.44
$\sqrt{\frac{\text{MS error}}{n}}$ (q .95 [r, 60])	1.92	2.31	2.54	2.71	2.83	2.93	3.02

Table 111

Comparison of Sample Mean Scores with the Critical Mean Score According to Taxonomic Level, Concept 13

Group	Mean Score		
	Knowledge	Comprehension	Application
2A	5.00	4.89	4.89
2H	6.00*	4.78	4.78
3A	6.11*	5.00	5.67
3H	6.33*	5.11	5.22
4A	6.00*	6.22*	6.44*
4H	6.11*	7.89*	5.44
5A	4.89	5.89*	5.00
5H	6.67*	7.89*	4.56

Critical Guessing Mean Score: 5.86
*Exceeds Critical Guessing Mean Score

Table 112

Percent of Groups by Grade Level Earning Scores of 65 Percent or Higher at the Three Taxonomic Levels, Concept 13

Groups	Knowledge		Comprehension		Application	
	Number of students scoring 65 percent or higher	Percent of group	Number of students scoring 65 percent or higher	Percent of group	Number of students scoring 65 percent or higher	Percent of group
2A	2	22.2	2	22.2	1	11.1
2H	3	33.3	2	22.2	1	11.1
3A	3	33.3	2	22.2	1	11.1
3H	3	33.3	2	22.2	3	33.3
4A	3	33.3	5	55.6	5	55.6
4H	3	33.3	7	77.8	2	22.2
5A	2	22.2	2	22.2	1	11.1
5H	6	66.7	7	77.8	1	11.1

Concept 14: Ions can differ in the nature and magnitude of the net unbalanced charge.

It can be seen from Table 113 that at each level of understanding the high ability group at each grade level performed at a higher level than the average ability group with the exception of the high ability group of grade two at the application level. Although the sequence of groups at the knowledge and application levels is best described as chance, it is apparent that the order of the group mean scores on the comprehension type questions is from 5H to 2A with the exception of 5A. The achievement level of 5A is below that of 4A and is above only 3H, 3A, 2H, and 2A. The groups that consistently performed at a high level are 5H and 4A.

Although each high ability group earned a mean score at the knowledge level which exceeds that of the respective average ability group, the difference is not statistically significant. There is a significant difference between the mean scores earned by groups 2A and 3A and that earned by group 5H at the knowledge level (Tables 114, 115, and 116).

The performance of group 5A on the comprehension type questions is at a lower level than that of groups 5H, 4H, and 4A but not at a statistically lower level. However, the mean scores earned by groups 2A, 2H, and 3A are significantly lower than that attained by group 5H (Tables 117, 118, and 119).

Groups 4H and 5H performed at a high level on the application type questions according to earned percent mean scores, but only the performance of group 4H is significantly higher than that of group 2H which performed at the lowest level (Tables 120, 121, and 122).

The groups that earned a mean score that exceeds the critical guessing mean score (Table 123) are: (a) 5H, 4H, 4A, and 3H at the knowledge level; (b) 5H, 5A, 4H, 4A, 3H, and 3A at the comprehension level; and (c) 5H, 4H, 4A, and 3H at the application level.

The groups in which more than 50 percent of the members earned a score of 65 percent or higher (Table 124) are: (a) 5H and 4H on the knowledge type questions, (b) 5H, 5A, 4H, and 4A on the comprehension type questions, and (c) 5H and 4H on the application type questions.

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Table 113

Rank Order of Groups by Grade Level According to Mean Scores Attained on the Three Taxonomic Test Forms, Concept 14

Knowledge		Comprehension		Application	
Group	Mean (%)	Group	Mean (%)	Group	Mean (%)
5H	72.0	5H	86.0	4H	76.0
4H	67.0	4H	69.0	5H	67.0
3H	61.0	4A	69.0	4A	62.0
4A	60.0	5A	68.0	3H	60.0
5A	53.0	3H	66.0	5A	53.0
2H	52.0	3A	60.0	2A	51.0
3A	50.0	2H	53.0	3A	49.0
2A	46.0	2A	52.0	2H	42.0

Table 114

Analysis of Variance Among Groups — Knowledge Level, Concept 14

Source	SS	df	MS	F	F* (critical)
Between Groups	50.76	7	7.25	3.31	2.17
Within	140.22	64	2.19		
Total	190.98	71			

*Alpha of .05

Table 115

Differences Between Mean Scores — Knowledge Level, Concept 14

Groups	Means	2A 4.56	3A 5.00	2H 5.22	5A 5.33	4A 6.00	3H 6.11	4H 6.67	5H 7.22
2A	4.56	0	.44	.66	.77	1.44	1.55	2.11	2.66*
3A	5.00		0	.22	.33	1.00	1.11	1.67	2.22*
2H	5.22			0	.11	.78	.89	1.45	2.00
5A	5.33				0	.67	.78	1.34	1.89
4A	6.00					0	.11	.67	1.22
3H	6.11						0	.56	1.11
4H	6.67							0	.55
5H	7.22								0

*p < .05

Table 116

Critical Values — Knowledge Level, Concept 14 (Newman-Keuls Test)

r	2	3	4	5	6	7	8
q .95 (r, 60)	2.83	3.40	3.74	3.98	4.16	4.31	4.41
$\sqrt{\frac{MS\ error}{n}}$ (q .95 [r, 60])	1.39	1.67	1.83	1.95	2.04	2.11	2.18

Table 117

Analysis of Variance Among Groups — Comprehension Level, Concept 14

Source	SS	df	MS	F	F* (critical)
Between Groups	70.61	7	10.09	3.48	2.17
Within	185.33	64	2.90		
Total	255.94	71			

*Alpha of .05

Table 118

Differences Between Mean Scores — Comprehension Level, Concept 14

Groups	Means	2A 5.22	2H 5.33	3A 6.00	3H 6.56	5A 6.78	4A 6.89	4H 6.89	5H 8.56
2A	5.22	0	.11	.78	1.34	1.56	1.67	1.67	3.34*
2H	5.33		0	.67	1.23	1.45	1.56	1.56	3.23*
3A	6.00			0	.56	.78	.89	.89	2.56*
3H	6.56				0	.22	.33	.33	2.00
5A	6.78					0	.11	.11	1.78
4A	6.89						0	0	1.67
4H	6.89							0	1.67
5H	8.56								0

*p < .05

Table 119

Critical Values — Comprehension Level, Concept 14 (Newman-Keuls Test)

r	2	3	4	5	6	7	8
q .95 (r, 60)	2.83	3.40	3.74	3.98	4.16	4.31	4.44
$\sqrt{\frac{\text{MS error}}{n}}$ (q .95 [r, 60])	1.61	1.94	2.13	2.27	2.37	2.46	2.53

Table 120

Analysis of Variance Among Groups — Application Level, Concept 14

Source	SS	df	MS	F	F* (critical)
Between Groups	72.39	7	10.34	2.42	2.17
Within	273.11	64	4.27		
Total	345.50	71			

*Alpha of .05

Table 121

Differences Between Mean Scores — Application Level, Concept 14

Groups	Means	2H 4.22	3A 4.89	2A 5.11	5A 5.33	3H 6.00	4A 6.22	5H 6.67	4H 7.56
2H	4.22	0	.67	.89	1.11	1.78	2.00	2.45	3.34*
3A	4.89		0	.22	.44	1.11	1.33	1.78	2.67
2A	5.11			0	.22	.89	1.11	1.56	2.45
5A	5.33				0	.67	.89	1.34	2.23
3H	6.00					0	.22	.67	1.56
4A	6.22						0	.45	1.34
5H	6.67							0	.89
4H	7.56								0

*p < .05

Table 122

Critical Values — Application Level, Concept 14 (Newman-Keuls Test)

r	2	3	4	5	6	7	8
q .95 (r, 60)	2.83	3.40	3.74	3.98	4.16	4.31	4.44
$\sqrt{\frac{MS\ error}{n}}$ (q .95 [r, 60])	1.95	2.35	2.58	2.75	2.87	2.97	3.06

Table 123

Comparison of Sample Mean Scores with the Critical Mean Score According to Taxonomic Level, Concept 14

Group	Mean Score		
	Knowledge	Comprehension	Application
2A	4.56	5.22	5.11
2H	5.22	5.33	4.22
3A	5.00	6.00*	4.89
3H	6.11*	6.56*	6.00*
4A	6.00*	6.89*	6.22*
4H	6.67*	6.89*	7.56*
5A	5.33	6.78*	5.33
5H	7.22*	8.56*	6.67*

Critical Guessing Mean Score: 5.86

*Exceeds Critical Guessing Mean Score

Table 124

Percent of Groups by Grade Level Earning Scores of 65 Percent or Higher at the Three Taxonomic Levels, Concept 14

Groups	Knowledge		Comprehension		Application	
	Number of students scoring 65 percent or higher	Percent of group	Number of students scoring 65 percent or higher	Percent of group	Number of students scoring 65 percent or higher	Percent of group
2A	0	0.0	1	11.1	1	11.1
2H	3	33.3	2	22.2	2	22.2
3A	1	11.0	2	22.2	0	0.0
3H	4	44.4	4	44.4	4	44.4
4A	3	33.3	5	55.6	3	33.3
4H	5	55.6	5	55.6	7	77.8
5A	1	11.1	6	66.7	3	33.3
5H	5	55.6	9	100.0	6	66.7

Concept 15: Ions are formed from atoms when the atoms lose or gain electrons.

From Table 125 it is noted that at each level of understanding group 5H performed at the highest level and group 4H performed at a level below only that of group 5H. The relative positions occupied in the rank orders by the groups with the exception of 5H and 4H vary from one level cf understanding to another. These variations can best be described as chance.

Although the performances c*i* groups 5H and 4H exceed that of the other groups at each level of understanding significant differences among the mean scores earned within the knowledge and application levels were not found (Tables 126 and 127). It was found that at the comprehension level the mean score earned by group 5H is significantly higher than those attained by groups 5A, 4A, 3H, 3A, 2H, and 2A (Tables 128, 129, and 130).

The groups that performed at a level significantly higher than can be described as chance are: (a) 5H, 4H, and 4A, at the knowledge level; (b) 5H, 4H, and 3A, at the comprehension level; and (c) 5H, 5A, and 4H, at the application level (Table 131).

When the performance of individuals is considered it is found that: (a) groups 5H, 4H, and 3A at the comprehension level and (b) group 5H at the application level have more than 50 percent of their members attaining a score of 65 percent or higher (Table 132).

Table 125

Rank Order of Groups by Grade Level According to Mean Scores Attained on the Three Taxonomic Test Forms, Concept 15

Knowledge		Comprehension		Application	
Group	Mean (%)	Group	Mean (%)	Group	Mean (%)
5H	66.0	5H	87.0	5H	74.0
4H	60.0	4H	69.0	4H	66.0
4A	59.0	3A	59.0	5A	62.0
3H	58.0	4A	58.0	3A	57.0
2H	57.0	2A	58.0	4A	56.0
3A	52.0	5A	53.0	3H	56.0
5A	51.0	3H	51.0	2H	56.0
2A	47.0	2H	42.0	2A	56.0

Table 126

Analysis of Variance Among Groups — Knowledge Level, Concept 15

Source	SS	df	MS	F	F* (critical)
Between Groups	22.00	7	3.14	1.19	2.17
Within	169.11	64	2.64		
Total	191.11	71			

*Alpha of .05

Table 127

Analysis of Variance Among Groups — Application Level, Concept 15

Source	SS	df	MS	F	F* (critical)
Between Groups	30.10	7	4.30	1.67	2.17
Within	164.89	64	2.58		
Total	194.99	71			

*Alpha of .05

Table 128

Analysis of Variance Among Groups — Comprehension Level, Concept 15

Source	SS	df	MS	F	F* (critical)
Between Groups	111.54	7	15.94	3.41	2.17
Within	299.33	64	4.68		
Total	410.87	71			

* Alpha of .05

Table 129

Differences Between Mean Scores — Comprehension Level, Concept 15

Groups		2H	3H	5A	2A	4A	3A	4H	5H
	Means	4.22	5.11	5.33	5.78	5.78	5.89	6.89	8.67
2H	4.22	0	.89	1.11	1.56	1.56	1.67	2.67	4.45*
3H	5.11		0	.22	.67	.67	.78	1.78	3.56*
5A	5.33			0	.45	.45	.56	1.56	3.34*
2A	5.78				0	0	.11	1.11	2.89*
4A	5.78					0	.11	1.11	2.89*
3A	5.89						0	1.00	2.78*
4H	6.89							0	1.78
5H	8.67								0

*p < .05

Table 130

Critical Values — Comprehension Level, Concept 15 (Newman-Keuls Test)

r	2	3	4	5	6	7	8
q .95 (r, 60)	2.83	3.40	3.74	3.98	4.16	4.31	4.44
$\sqrt{\frac{\text{MS error}}{n}}$ (q .95 [r, 60])	2.04	2.45	2.69	2.87	3.00	3.10	3.20

Table 131

Comparison of Sample Mean Scores with the Critical Mean Score According to Taxonomic Level, Concept 15

Group	Mean Score		
	Knowledge	Comprehension	Application
2A	4.67	5.78	5.56
2H	5.67	4.22	5.56
3A	5.22	5.89*	5.67
3H	5.78	5.11	5.56
4A	5.89*	5.78	5.56
4H	6.00*	6.89*	6.56*
5A	5.11	5.33	6.22*
5H	6.56*	8.67*	7.44*

Critical Guessing Mean Score: 5.86
*Exceeds Critical Guessing Mean Score

Table 132

Percent of Groups by Grade Level Earning Scores of 65 Percent or Higher at the Three Taxonomic Levels, Concept 15

Groups	Knowledge		Comprehension		Application	
	Number of students scoring 65 percent or higher	Percent of group	Number of students scoring 65 percent or higher	Percent of group	Number of students scoring 65 percent or higher	Percent of group
2A	2	22.2	4	44.4	3	33.3
2H	2	22.2	0	0.0	2	22.2
3A	2	22.2	6	66.7	2	22.2
3H	3	33.3	2	22.2	2	22.2
4A	3	33.3	3	33.3	2	22.2
4H	4	44.4	7	77.8	3	33.3
5A	3	33.3	3	33.3	3	33.3
5H	4	44.4	9	100.0	6	66.7

Concept 16: Atoms may be formed when ions gain or lose electrons.

It can be seen from Table 133 that the performance of group 5H exceeds that of the other groups at each level of understanding. Also, it is apparent that either group 2A or 2H performed at the lowest level on all taxonomic type questions. The relative positions occupied by all groups, except 5H, in a sequence varies from one taxonomic level to another. The order of the groups at the knowledge level approximates a rank order according to grade level with the exception of groups 5A and 4A and at the comprehension level the groups 3H and 5A are not in the proper positions to represent a rank order according to grade level.

Group 5H performed at a higher level than any other group on the knowledge and comprehension type questions but it did not attain a mean score significantly higher than those earned by the other groups (Tables 134 and 135). However, at the application level, group 5H earned a mean score significantly higher than that attained by group 2H (Tables 136, 137, and 138).

A comparison of the earned mean scores with the guessing mean score (Table 139) reveals that groups: (a) 5H, at the knowledge level; (b) 5H, 4H, and 3H, at the comprehension level; and (c) 5H, 5A, 4H, 3H, and 3A, at the application level attained mean scores significantly higher than the guessing mean score.

An evaluation of the performance of a group according to individual scores discloses that the only groups in which more than 50 percent of the members earned a score of 65 percent or higher (Table 140) are 5H and 3H on the comprehension type questions.

Table 133

Rank Order of Groups by Grade Level According to Mean Scores Attained on the Three Taxonomic Test Forms, Concept 16

Knowledge		Comprehension		Application	
Group	Mean (%)	Group	Mean (%)	Group	Mean (%)
5H	59.0	5H	76.0	5H	68.0
4H	58.0	3H	71.0	3A	62.0
3A	57.0	4H	61.0	4H	60.0
3H	56.0	4A	58.0	3H	60.0
5A	52.0	3A	58.0	5A	59.0
4A	50.0	2H	58.0	4A	58.0
2H	47.0	5A	57.0	2A	51.0
2A	43.0	2A	56.0	2H	46.0

Table 134

Analysis of Variance Among Groups — Knowledge Level, Concept 16

Source	SS	df	MS	F	F* (critical)
Between Groups	19.76	7	2.82	1.31	2.17
Within	138.22	64	2.16		
Total	157.98	71			

*Alpha of .05

Table 135

Analysis of Variance Among Groups — Comprehension Level, Concept 16

Source	SS	df	MS	F	F* (critical)
Between Groups	35.11	7	5.02	1.34	2.17
Within	238.89	64	3.73		
Total	274.00	71			

*Alpha of .05

Table 136

Analysis of Variance Among Groups — Application Level, Concept 16

Source	SS	df	MS	F	F* (critical)
Between Groups	29.21	7	4.17	2.29	2.17
Within	116.67	64	1.82		
Total	145.88	71			

*Alpha of .05

Table 137

Differences Between Mean Scores — Application Level, Concept 16

Groups		2H	2A	4A	5A	3H	4H	3A	5H
	Means	4.56	5.11	5.78	5.89	6.00	6.00	6.22	6.78
2H	4.56	0	.55	1.22	1.33	1.44	1.44	1.66	2.22*
2A	5.11		0	.67	.78	.89	.89	1.11	1.67
4A	5.78			0	.11	.22	.22	.44	1.00
5A	5.89				0	.11	.11	.33	.89
3H	6.00					0	0	.22	.78
4H	6.00						0	.22	.78
3A	6.22							0	.56
5H	6.78								0

*p < .05

Table 138

Critical Values — Application Level, Concept 16 (Newman-Keuls Test)

r	2	3	4	5	6	7	8
q .95 (r, 60)	2.83	3.40	3.74	3.98	4.16	4.31	4.44
$\sqrt{\frac{MS\ error}{n}}$ (q .95 [r, 60])	1.27	1.53	1.68	1.79	1.87	1.94	2.00

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Table 139

Comparison of Sample Mean Scores with the Critical Mean Score According to Taxonomic Level, Concept 16

Group	Mean Score		
	Knowledge	Comprehension	Application
2A	4.33	5.56	5.11
2H	4.67	5.78	4.56
3A	5.67	5.78	6.22*
3H	5.56	7.11*	6.00*
4A	5.00	5.78	5.78
4H	5.78	6.11*	6.00*
5A	5.22	5.67	5.89*
5H	5.89*	7.56*	6.78*

Critical Guessing Mean Score: 5.86
*Exceeds Critical Guessing Mean Score

Table 140

Percent of Groups by Grade Level Earning Scores of 65 Percent or Higher at the Three Taxonomic Levels, Concept 16

Groups	Knowledge		Comprehension		Application	
	Number of students scoring 65 percent or higher	Percent of group	Number of students scoring 65 percent or higher	Percent of group	Number of students scoring 65 percent or higher	Percent of group
2A	0	0.0	2	22.2	1	11.1
2H	1	11.1	2	22.2	0	0.0
3A	2	22.2	3	33.3	4	44.4
3H	2	22.2	5	55.6	3	33.3
4A	2	22.2	4	44.4	3	33.3
4H	2	22.2	4	44.4	3	33.3
5A	1	11.1	3	33.3	2	22.2
5H	2	22.2	6	66.7	4	44.4

The results of groups are summarized by grade level in Table 141.

Table 141

Achievement of Groups by Grade Level

Level of understanding	Groups by Grade Level								Groups Earning Significantly Different Mean Scores
	5H	5A	4H	4A	3H	3A	2H	2A	
Concept 1. Matter is made up of particles.									
K	x#	x#	x#	x#	x	x#	x#	x#	5H > 2H, 2A, 3H, 3A, 4A; 4H > 2H
C	x#	x#	x#	x#	x#	x#	x	x	5H, 4H >2A, 2H
A	x								n. s. d.
Concept 2. The particles which make up matter have spaces between them.									
K	x#	x#	x#	x#	x	x	x		5H, 4H >2A
C	x#	x	x#	x	x	x#	x	x	n. s. d.
A	x#		x#	x	x	x		x	5H, 4H, 3A > 2H
Concept 3. The particles which make up matter are in motion.									
K	x#	x#	x#	x#	x#	x#	x#		5H > 2A, 3H; 5H >2A
C	x#	x	x	x		x			5H > 5A, 4H, 4A 3H, 3A, 2H, 2A
A	x		x	x	x	x			n. s. d.
Concept 4. Some matter is composed of molecules.									
K			#						4H > 2A
C	x#		x#	x#		#	#		n. s. d.
A	x#	x#	x#		#		x#		n. s. d.
Concept 5. Molecules are composed of atoms.									
K	x#	x#	x#	x#	#	#		x#	5H, 4H > 2H
C	x#	#	#		#	#			n. s. d.
A	#				#				n. s. d.
Concept 6. Atoms may be composed of protons, neutrons, and electrons.									
K	x#	x#	x#	x#	x#	x#	#	#	5H, 4H > 3A, 2H, 2A
C	x#	x#	x#		x#	x#			n. s. d.
A	x#	#				#			n. s. d.
Concept 7. The nature and the amount of charge on an electron is a negative one.									
K				#					n. s. d.
C	x#				x#	x#			n. s. d.
A						#	x#		n. s. d.

x mean score significantly higher than the guessing mean score.
group having more than 50 percent of its members scoring 65 percent or higher.
n.s.d. no significant difference
K-Knowledge, C-Comprehension, A-Application

Table 141 (cont.)

Level of under-standing	5H	5A	4H	4A	3H	3A	2H	2A	Groups Earning Significantly Different Mean Scores
	Groups by Grade Level								
Concept 8. The nature and the amount of charge on a proton is a positive one.									
K	x#	x#	x#	x#	#				n. s. d.
C	x#			#		x#	#		n. s. d.
A									n. s. d.
Concept 9. A neutron does not have a charge.									
K	x#								n. s. d.
C	x#					#			5H > 5A, 4A
A	x#				x#				n. s. d.
Concept 10. Atoms have the same number of protons as electrons.									
K	x#	x#	x#	x#	x#	x#		#	n. s. d.
C	x#		x#	x#	x#	x#	x#	x#	n. s. d.
A	x#	x#	x		x#				n. s. d.
Concept 11. All atoms of the same element have the same number of protons.									
K	x#	x#	x#		#		#		n. s. d.
C	#					#		#	n. s. d.
A									n. s. d.
Concept 12. Some matter is composed of ions.									
K	x#		x#	x#	x		x#	x#	5H > 5A, 3H, 3A, 2H, 2A
C	x#	x#	x	x					n. s. d.
A	x		x	x	x				n. s. d.
Concept 13. An ion is a particle or group of particles which has more electrons than protons or more protons than electrons.									
K	x#		x	x	x	x	x		n. s. d.
C	x#	x	x#	x#					5H, 4H > 3H, 3A, 2H, 2A
A				x#					n. s. d.
Concept 14. Ions can differ in the nature and magnitude of the net unbalanced charge.									
K	x#		x#	x	x				5H > 3A, 2A
C	x#	x#	x#	x#	x	x			5H > 3A, 2H, 2A
A	x#		x#	x	x				4H > 2H
Concept 15. Ions are formed from atoms when the atoms lose or gain electrons.									
K	x		x	x					n. s. d.
C	x#		x#			x#			5H > 5A, 4A, 3H, 3A, 2H, 2A
A	x#	x	x						n. s. d.
Concept 16. Atoms may be formed when ions gain or lose electrons.									
K	x								n. s. d.
C	x#		x		x#				n. s. d.
A	x	x	x		x	x			5H > 2H

V

CONCLUSIONS AND IMPLICATIONS

The purpose of this study was to determine the relative levels of understanding of 16 concepts, within the conceptual scheme the particle nature of matter, achieved by pupils in Grades 2-5 when all pupils received comparable instruction. The probable hierarchy in terms of difficulty of learning the concepts is indicated by scores earned by individuals within groups and by comparing the mean scores earned by the several groups with each other and with a probable guessing score. A hierarchy is revealed when the level of understanding desired for inclusion of a concept for a given group is determined by utilizing the two criteria (1) the earned mean score is significantly different from guessing and (2) more than 50 percent of the members earn a score of 65 percent or higher.

Concept 1: Matter is made up of particles.

a. Concept 1 was mastered (1) at the knowledge level by pupils of average or above average ability in Grade 2 and (2) at the knowledge and comprehension levels by pupils of average or above average ability in Grades 3, 4 and 5.

b. The probability of success in learning Concept 1 at the knowledge level is greater (1) for pupils of above average ability in Grade 5 than for pupils of average or above average ability in Grades 2 and 3 and pupils of average ability in Grade 4 and (2) for pupils of above average ability in Grade 4 than for pupils of above average ability in Grade 2.

Concept 2: The particles which make up matter have spaces between them.

a. Concept 2 was mastered (1) at the knowledge level by pupils of average ability in Grades 4 and 5 and (2) at the knowledge, comprehension, and application levels by pupils of above average ability in Grades 4 and 5.

b. At each level of mastery, the probability of success in learning Concept 2 appears to be the same for pupils within both ability groups.

c. Although pupils of average ability in Grade 3 are able to meet the criteria for understanding at the comprehension level, variations in mastery of Concept 2 by pupils below grade 4 make the inclusion of this concept as a part of the instructional program doubtful for pupils of average or above average ability in Grades 2 and 3.

Concept 3: The particles which make up matter are in motion.

a. Concept 3 was mastered (1) at the knowledge level by pupils of above average ability in Grade 2, by pupils of average or above average ability in Grades 3 and 4, and by pupils of average ability in Grade 5; and (2) at the knowledge and comprehension levels by pupils of above average ability in Grade 5.

b. The probability of success in learning Concept 3 at the knowledge level of understanding is greater for pupils of above average ability in Grade 5 than for pupils of above average ability in Grade 3.

Concept 4: Some matter is composed of molecules.

a. Since the pupils of above average ability in Grades 4 and 5 are able to meet the criteria for understanding at the comprehension and application levels, but not at the knowledge level, it appears that their level of mastery of Concept 4 includes the knowledge level of understanding.

b. Concept 4 was mastered at the knowledge, comprehension, and application levels, with the same probability of success in learning, by pupils of above average ability in Grades 4 and 5. The levels of mastery by pupils within the other grade groups were not considered due to their erratic nature.

Concept 5: Molecules are composed of atoms.

a. Concept 5 was mastered (1) at the knowledge level by pupils of average or above average ability in Grade 4 and by pupils of average ability in Grade 5 and (2) at the knowledge and comprehension levels by pupils of above average ability in Grade 5. The pupils of average ability in Grade 2 were able to meet the criteria for understanding at the knowledge level but were not considered because other ability groups below that of Grade 4 are not able to meet the criteria.

b. It appears that the probability of success in learning Concept 5 at the knowledge level is the same for the pupils within the several grade groups.

Concept 6: Atoms may be composed of protons, neutrons, and electrons.

a. Concept 6 was mastered (1) at the knowledge and comprehension levels by pupils of average or above average ability in Grades 3 and 4 and by pupils of average ability in Grade 5 and (2) at the knowledge, comprehension, and application levels by pupils of above average ability in Grade 5. The pupils of average ability in Grade 4 were considered to have mastered Concept 6 at both the knowledge and comprehension levels since the pupils of average or above average ability in Grade 3 were able to meet the criteria for understanding at these two levels.

b. The probability of success in learning Concept 6 at the knowledge and comprehension levels is greater for pupils of above average ability in Grades 4 and 5 than for pupils of average ability in Grade 3.

Concept 7: The nature and the amount of charge on an electron is a negative one.

a. Due to the erratic nature of the levels of performance of the several grade groups, the pupils of average or above average ability in Grades 2-5 are not considered to have mastered Concept 7 at either the knowledge, comprehension, or application level of understanding.

b. No one of the grade groups seems to have an advantage in learning Concept 7.

Concept 8: The nature and the amount of charge on a proton is a positive one.

a. Concept 8 was mastered (1) at the knowledge level by pupils of average or above average ability in Grade 4 and by pupils of average ability in Grade 5 and (2) at the knowledge and comprehension levels by pupils of above average ability in Grade 5. The ability groups below those in Grade 4 were not considered due to the erratic nature of the levels of performance of these groups.

b. The probability of success in learning Concept 8 at the knowledge level is the same for all pupils within the several grade groups.

Concept 9: A neutron does not have a charge.

a. Concept 9 was mastered at the knowledge, comprehension, and application levels by pupils of above average ability in Grade 5.

b. Due to the erratic nature of the levels of performance of several grade groups, pupils in the ability groups below that of the above average ability group in Grade 5 are not considered to have mastered Concept 9 at either the knowledge, comprehension, or application level of understanding.

Concept 10: Atoms have the same number of protons as electrons.

a. Concept 10 was mastered (1) at the knowledge and comprehension levels by pupils of average or above average ability in Grades 3 and 4 and (2) at the knowledge, comprehension, and application levels by pupils of average or above average ability in Grade 5. Although pupils of average ability in Grade 5 were not able to meet the criteria for understanding at the comprehension level they were considered to have mastered Concept 10 at all three levels since (a) they are able to meet the criteria for understanding at the knowledge and application levels and (b) the pupils of average or above average ability in Grade 4 are able to meet the criteria for understanding at the knowledge and comprehension levels.

b. The probability of success in learning Concept 10 at each level of mastery appears to be the same within the several grade groups.

Concept 11: All atoms of the same element have the same number of protons.

a. Concept 11 was mastered at the knowledge level by pupils of above average ability in Grade 4 and by pupils of average or above average ability in Grade 5.

b. It appears that the probability of success in learning Concept 11 at the knowledge level is the same for the pupils within the several grade groups.

Concept 12: Some matter is composed of ions.

a. Concept 12 was mastered (1) at the knowledge level by pupils of average or above average ability in Grade 4 and (2) at the knowledge and comprehension levels by pupils of above average ability in Grade 5. The other ability groups were not considered due to the erratic nature of their levels of performance.

b. The probability of success in learning Concept 12 at the knowledge level appears to be the same for the pupils within the several grade groups.

Concept 13: An ion is a particle or group of particles which has more electrons than protons or more protons than electrons.

a. Concept 13 was mastered at the knowledge and comprehension levels by pupils of above average ability in Grade 5.

b. Due to the erratic nature of the levels of performance of several grade groups, pupils of average or above average ability in groups below the high ability group in Grade 5 are not considered to have mastered Concept 13 at either the knowledge, comprehension, or application level of understanding.

Concept 14: Ions can differ in the nature and magnitude of the net unbalanced charge.

a. Concept 14 was mastered at the knowledge, comprehension, and application levels by pupils of above average ability in Grades 4 and 5. The other ability groups were not considered due to the erratic nature of their levels of performance.

b. The probability of success in learning Concept 14 at the knowledge, comprehension, and application levels appears to be the same for the pupils within the several grade groups.

Concept 15: Ions are formed from atoms when the atoms lose or gain electrons.

a. Concept 15 was mastered at the knowledge, comprehension, and application levels by pupils of above average ability in Grade 5.

b. Concept 15 is not considered to have been mastered at either the knowledge, comprehension, or application level by any of the grade groups below the above average ability group in Grade 5 since the levels of performance of these groups are of an erratic nature.

Concept 16: Atoms may be formed when ions gain or lose electrons.

a. Due to the erratic nature of the levels of performance of the several grade groups, the pupils of average or above average ability in Grades 2-5 are not considered to have mastered Concept 16 at either the knowledge, comprehension, or application level of understanding.

b. No one of the grade groups, except the above average in Grade 5 at the application level, seems to have an advantage in learning Concept 16.

These conclusions are applicable only to the population from which the samples were drawn.

The implications from this study are as follows:

1. Concept 1 may be included as a part of the instructional program (1) in Grade 2 for pupils of average or above average ability when the desired level of mastery is knowledge and (2) in Grades 3, 4, and 5 for pupils of average or above average ability when the desired level of mastery is knowledge and comprehension.

2. Concept 2 may be included as part of the instructional program (1) in Grades 4 and 5 for pupils of average ability when the desired level of mastery is knowledge and (2) in Grades 4 and 5 for pupils of above average ability when the desired level is knowledge, comprehension, and application.

3. Concept 3 may be included as a part of the instructional program (1) in Grade 2 for pupils of above average ability, in Grades 3 and 4 for pupils of average or above average ability, and in Grade 5 for pupils of average ability when the desired level of mastery is knowledge and (2) in Grade 5 for pupils of above average ability when the desired level of mastery is knowledge and comprehension.

4. Concept 4 may be included as a part of the instructional program in Grades 4 amd 5 for pupils of above average ability, with the same probability of success in learning, when the desired level of mastery is knowledge, comprehension, and application.

5. Concept 5 may be included as a part of the instructional program (1) in Grade 4 for pupils of average or above average ability and in Grade 5 for pupils of average ability when the desired level of mastery is knowledge and (2) in Grade 5 for pupils of above average ability when the desired level is knowledge and comprehension.

6. Concept 6 may be included as a part of the instructional program (1) in Grades 3 and 4 for pupils of average or above average ability and in Grade 5 for pupils of average ability when the desired level of mastery is knowledge and comprehension and (2) in Grade 5 for pupils of above average ability when the desired level of mastery is knowledge, comprehension, and application.

7. Concept 7 should not be included as a part of the instructional programs for pupils of

average or above average ability in Grades 2-5 due to the erratic nature of the levels of performance of the several grade groups.

8. Concept 8 may be included as a part of the instructional program (1) in Grade 3 for pupils of average or above average ability and in Grade 5 for pupils of average ability when the desired level of mastery is knowledge and (2) in Grade 5 for pupils of above average ability when the desired level is knowledge and comprehension.

9. Concept 9 may be included as a part of the instructional program in Grade 5 for pupils of above average ability when the desired level of mastery is knowledge, comprehension, and application.

10. Concept 10 may be included as a part of the instructional program (1) in Grades 3 and 4 for pupils of average or above average ability when the desired level of mastery is knowledge and comprehension and (2) in Grade 5 for pupils of average or above average ability when the desired level of mastery is knowledge, comprehension, and application.

11. Concept 11 may be included as a part of the instructional program in Grade 4 for pupils of above average ability and in Grade 5 for pupils of average or above average ability when the desired level of mastery is knowledge.

12. Concept 12 may be included as a part of the instructional program (1) in Grade 4 for pupils of average or above average ability when the desired level of mastery is knowledge and (2) in Grade 5 for pupils of above average ability when the desired level of mastery is knowledge and comprehension. Concept 12 is not recommended as a part of the instructional program for other ability groups due to the erratic nature of their levels of performance.

13. Concept 13 may be included as a part of the instructional program in Grade 5 for pupils of above average ability when the desired level of mastery is knowledge and comprehension.

14. Concept 14 may be included as a part of the instructional program in Grades 4 and 5 for pupils of above average ability when the desired level of mastery is knowledge, comprehension and application.

15. Concept 15 may be included as a part of the instructional program in Grade 5 for pupils of above average ability when the desired level of mastery is knowledge, comprehension, and application.

16. Concept 16 should not be included as a part of the instructional program for pupils of average or above average ability in Grades 2-5 when the desired levels of understanding are knowledge, comprehension, and application. The erratic nature of the levels of performance of the several grade groups prevents confidence in recommending its inclusion.

17. For pupils in Grades 2-5, there appears to be a hierarchy in terms of difficulty in learning the theoretical concepts used in this study. The hierarchy is a function of the grade level and ability of the pupils and the level of mastery of the concepts. The grade level and ability of the pupils and the desired level of mastery of the concept should be considered before determining what pupils should be taught any or the theoretical concepts used in this study.

18. It appears that the number of theoretical concepts used in this study which may be included as a part of the instructional program in Grades 2-5 for pupils of above average ability increases from grade level to grade level.

19. It does not appear that concepts of ions should be included as a part of the instructional program for pupils in Grades 2 and 3.

20. The theoretical concepts used in this study which contain such words as "charge, nature, and element" do not seem to be appropriate to be included as a part of the instructional program for pupils in Grades 2-5 even when a low level of mastery is desired.

APPENDIX

TEXTBOOKS ANALYZED

High School Chemistry

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