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THE EFFECT OF THE UTILIZATION OF SELECTED MATHEMATICS CONCEPTS AND SKILLS ON ACHIEVEMENT IN HIGH SCHOOL CHEMISTRY BY STUDENTS FROM TWO DIFFERENT POPULATIONS

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OTIS O. LAWRENCE

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THE EFFECT OF THE UTILIZATION OF SELECTED MATHEMATICS CONCEPTS AND SKILLS ON ACHIEVEMENT IN HIGH SCHOOL CHEMISTRY BY STUDENTS FROM TWO DIFFERENT POPULATIONS

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DISSERTATION COMMITTEE

To

My Wife, Vivian,

My Daughter, Veotis,

And My Mother, Stella

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The writer wishes to thank a number of people for their encouragement, support, contributions, and guidance in the graduate program and in conducting the investigation.

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TABLE OF CONTENTS

Chapter	Page

LIST OF TABLES

Table		Page

LIST OF FIGURES

THE EFFECT OF THE UTILIZATION OF SELECTED MATHEMATICS CONCEPTS AND SKILLS ON ACHIEVEMENT IN HIGH SCHOOL CHEMISTRY BY STUDENTS FROM TWO DIFFERENT POPULATIONS

CHAPTER I

INTRODUCTION

Approximately sixty million dollars have been spent by the National Science Foundation (NSF) over the last twelve years on the development of new innovative science curricula. The purpose of the NSF curricular program is to produce "improved up-to-date course materials . . ." by supporting leading scientists, assisted by classroom teachers, for research and development work on course content, investigative activities, and teaching styles (National Science Foundation, 1962, p. 88). These projects resulted in the production of several science courses for kindergarten through the twelfth grade. In a review of science in the secondary schools, Hurd and Rowe (1964) stated the following regarding the work of curricular groups:

> Although each of the NSF curriculum groups worked independently, a progressive congruency of educational ideas and processes evolved. The purpose of instruction was to develop an understanding of current

> scientific knowledge--its concepts and methods of inquiry. Textbooks were organized around large themes or principles of science to provide unity and sequential coherence. Concepts introduced early in the courses were used later to explain or to expand related concepts and theories. Laboratory activities were designed to be less illustrative and more investigative and quantitative than they had been. . . .
>
> A teaching style consistent with the purposes of the new science courses was required. The new movement in science instruction is as much a matter of improved teaching methods as of new goals and up-to-date content. Understanding rather than memorization was sought. Concepts were to be taught in depth to increase their meaning, retention, and intellectual usefulness.

These new courses represented highly significant contributions that were based on systematic and cooperative study by leading scientists and curricular specialists. These innovations also left many unresolved problems and perhaps created several others. Some of the problems related to the courses developed by the NSF projects have been identified by Smith (1968).

> Vast sums of money have been spent in developing curriculum materials without any very consistent guide as to what ends will be served by the materials produced. Great masses of materials have been produced in recent years and most of them have reflected an "elitist philosophy." The emphasis has definitely been on subject matter content. The educational axiom that content should be selected in terms of the need of people has been too cavalierly abandoned. . . . I have said in print elsewhere that I am convinced that materials produced by the large scale curriculum projects which have been so generously funded are largely irrelevant for more than half of the students in our schools. And I think that statement is probably too conservative. It may be closer to being irrelevant for 80-85% of our students. . . .

Smith also suggests that many of the new courses have been almost exclusively directed toward the cognitive aspect of education. The affective domain of attitudes, appreciations, hopes and aspirations have too often been ignored. The real issue these new educational tools addressed themselves to was teaching functional subject matter in such a way that students recognize and accept its validity and utility.

A major problem area related to the new courses is whether or not teachers are implementing them in an acceptable manner. Wide variations in behavior may be found among teachers who teach the same course. Assessing the importance of that variation is difficult. Some behaviors may be important because the frequency of occurrence may be significantly related to student outcome measures. Some may have no educational meaning. But some of the behaviors may indicate classroom conditions which effect student achievement in a negative way.

It is not surprising that in such a milieu of curricular reform, science education and instruction have been beset by numerous perplexing problems. Much research has been completed regarding the identification and resolution of the various problems. Additional research is being conducted continually. The present investigation stemmed in part from the investigator's concern regarding how well a particular instructional strategy operates with individual students who have their own personalized styles of learning. It has resulted in part from the investigator's concern for developing plans for the most effective use of the improved high school mathematics instructional programs to enhance instruction in high school chemistry classes. Finally, the investigation has stemmed in part from the investigator's concern regarding the extent to which a student's ability to process information logically (stage of logical thought development) contributes to his achievement in chemistry as taught in the schools of a metropolitan school system. Thus, this investigation had its origin in a desire of the investigator to acquire additional insight into instructional concepts as they relate to chemistry and to mathematics.

Statement of the Problems

The problem of this study is divided into two parts. First, is there a relationship between student achievement in mathematics and achievement in chemistry? Second, is an instructional approach for chemistry which uses selected mathematical concepts and skills (a quantitative approach developed by the participating teachers) as effective as a non-mathematical approach (qualitative approach developed by the same group of participating teachers) in two different racial populations?

More specifically, relationships were sought between the use of mathematics in the instructional process in secondary classes and achievement as reflected by:

1. the student's ability to recall chemical information;

2. the student's ability to comprehend and apply chemical principles;

3. the student's ability to apply chemical principles in a quantitative manner.

The investigation compared, and evaluated the extent to which these were developed in the student members of selected chemistry classes in two different racial populations taught by the two different instructional strategies. The student scores of the 1969 ACS-NSTA National Highschool Chemistry Tests were used for measuring the abilities of the students.

Three additional factors, i.e., the student's sex, the student's stage of logical thought process as described by Piaget, and the student's general intelligence, were studied to determine the relationship of the use of mathematics in the instructional process of the chemistry class.

Purposes of the Study

A major purpose of this study was to investigate and analyze the relationships between achievement in mathematics and achievement in chemistry by students from two different populations. Another purpose was to study the use of two instructional strategies for teaching chemistry (See Appendix C). One instructional strategy was based on employing mathematical concepts and skills in teaching concepts of chemistry. The second was based on the use of non-mathematical qualitative explanations of the same key chemistry concepts. Information was sought which would permit the investigator and other teachers to develop insight regarding which instructional strategy is more suitable for use with the students who possess certain specific sets or combinations of learning characteristics.

Justification and Need for the Study

"Efforts in science curriculum development should be accompanied by corresponding developments in mathematics, and the two must be closely correlated at all levels." This is the National Science Teachers Association position on curriculum development.(The National Science Teachers Association, 1962). The position of the association is shared by many science educators who believe that a program which makes use of mathematics skills will add to the student's capacity to gain a quantitative and deeper understanding of his physical and biological environment. Ahrens (1965) has suggested that in reciprocal fashion, the science program can serve to initiate and develop concepts of mathematics. This type of science program can provide the opportunities for and emphasize the necessity of using mathematical skills. Courses designed to encourage students to examine critically the intimate relationships between science and mathematics will facilitate teaching both mathematics and science in greater depth. Thus, the principle of coordinated science and mathematics instruction appears to be logical and practical.

Swartz (1964) suggests that from the very beginning, science should be presented as a discipline usually requiring quantitative treatment. In discussing the topic of measurement, Renner and Ragan (1968, pp. 143-144) state:

> The topic of measurement then, does represent an area of knowledge which can be used as a vehicle to lead children to develop their rational powers. Measurements of one kind or another are around us at all times, i.e., the notion of measurement constitutes a significant aspect of our environment and, as such represents a topic with which children should have experience. . . . Taking and interpreting measurements represent two of the most important activities of a scientist. He must be concerned with standards of measurement, variations in his measurements and methods of depicting the measurements taken. There can be no doubt that when children engage in activities such as those just described [for four sample lessons] that they are participating in "good science."

Other writers have expressed similar views regarding instructional strategies for elementary school science (Thier, 1966; Coffia, 1967; Newbury, 1967). These writers indicate that children have built-in wonderment and natural curiosity which can be nurtured and developed through the process of inquiry using quantitative data. Through gathering and studying quantitative data, they feel the child can test the validity of a scientific hypothesis, as well as discover the answers to questions in science. In elementary school science, children can use scales, balances, calipers, and rulers to obtain quantitative measurements. Through quantitative means, they learn to organize procedures for problem solving, and ways to evaluate evidence. In other words, the student learns the methods of science by doing quantitative investigations.

The views advanced for elementary science education are similar to those held by many educators interested in secondary school science programs. Taylor (1959), in discussing high school chemistry expressed the feeling that one of the distinctions between science and non-science is the extent to which the former makes use of quantitative descriptions. The reluctance of chemistry teachers to present chemistry in a quantitative way is according to Taylor, probably based on the belief that the students are unable to cope with basic mathematical relationships and that an easy way can be found to present the mathematics needed for chemistry or it should be omitted. Taylor believes that students can handle the mathematics and that there can be no real understanding of chemistry without mastery of the fundamental mathematical tools. He also feels that the difficulty which the elementary chemistry student experiences in solving chemical problems is probably the result of his having absorbed something of the form of mathematics without understanding its substance. Finally, Taylor expressed the opinion that the essentials of mathematics required for the understanding of chemistry are very few and can be taught in a brief period of time. The principles presented as essential are: the one-constant linear relationship; the two-constant linear relationship; and the inverse linear relationships.

Rising (1967), like Taylor, feels that many youngsters have the functional competence in mathematics required for secondary school science courses which have been "beefed-up" with mathematical applications. The students can do problems in the mathematics classroom, that they do not recognize in another classroom. Science teachers must employ instructional tactics which help the students to: (a) identify science problems that are applications of elementary mathematics principles; (b) select correct procedures to solve them; and (c) apply those procedures correctly.

Platt (1964) takes an opposite stand regarding the value of mathematics in science instruction. He states:

> I think that anyone who asks the question about scientific effectiveness will also conclude that much of the mathematicizing in physics and chemistry is irrelevant if not misleading.
>
> The great value of mathematical formulation is that when an experiment agrees with a calculation to five decimal places, a great many alternative hypotheses are pretty well excluded (through the Bohr theory and the Schrodinger theory both predict exactly the same Rydberg constant!). But when the fit is only to two decimal places, or one, it may be a trap for the unwary; it may be no better than any rule-of-thumb extrapolation, and some other kind of qualitative exclusion might be more rigorous for testing the assumptions and more important to scientific understanding than the quantitative fit. I know this is like saying that the emperor has no clothes. Today we

> preach that science is not science unless it is quantitative. We substitute correlations for causal studies, and physical equations for organic reasoning. Measurements and equations are supposed to sharpen thinking, but, in my observations, they more often tend to make the thinking non-causal and fuzzy. They tend to become the object of scientific manipulation instead of auxiliary tests of crucial inferences.

Platt pointed out that many, perhaps most, of the great issues of science are qualitative, not quantitative. This is especially true of physics and chemistry in his opinion. Equations and measurements are useful when and only when they are for proof; but proof or disproof is in fact strongest when it is absolutely convincing without any quantitative measurement. Platt explained further:

> You can catch phenomena in a logical box or in a mathematical box. The logical box is coarse but strong. The mathematical box is fine-grained but flimsy. The mathematical box is a beautiful way of wrapping up a problem, but it will not hold the phenomena unless they have been caught in a logical box to begin with.
>
> What I am saying is that in numerous areas that we call science, we have come to like our habitual ways, and our studies that can be continued indefinitely. We measure, we define, we compute, we analyze, but we do not exclude. And this is not the way to use our minds most effectively or to make the fastest progress in solving scientific questions.

Clearly two opposing points of view exist regarding the value of mathematics in science and in science instruction. Many research studies and curriculum development projects have proceeded from the position that mathematics was essential to the adequate development of science and science courses. But the problem that Platt raises is one that must be explored by research and which gave the present research much of its importance. Is a qualitative instructional strategy better than a quantitative strategy for all or some of the students in high school chemistry? In using a quantitative strategy, do we indeed employ habitual practices and fail to use effectively the logical thought processing abilities of students? Do we fail to exclude?

Herein lies the basis of the need for the present investigation. It was designed to compare the effectiveness of two instructional strategies for teaching high school chemistry to students with a wide variety of learning styles and abilities. The investigation was made to gain insight into some of the perplexing problems cited above.

Review of the Literature

The purpose of this study was to investigate and analyze the relationships between achievement in chemistry by students from two different populations and the use of qualitative and quantitative instructional strategies. In reviewing the literature, the investigator decided to concentrate on those journal articles, research studies, and text chapters that define a need for or attempted objective evaluation of instructional procedures in terms of clearly defined outcomes. The reviews were either on the outcome attained or the procedure used. Some attention was given to a description of recent research in science education and to studies regarding Piaget's logical thought processes and the school curriculum.

Hurd and Rowe (1964) reviewed 103 research studies in secondary school science programs. They concluded that research in secondary school science was fragmentary in concept and limited in duration. Clinical studies of the influence of social class and group dynamic variables on learning and attitude were found to be almost non-existent. They found few studies which were more than simple cataloging of opinions on some aspect of science education. They reported that few investigations attempted to examine the consequences of the systematic manipulation of one or more variables. They found no direct research on formation of scientific concepts or ways in which students learn science.

Summaries of Research studies in secondary school science have been published by the United States Department of Health, Education and Welfare (Office of Education, United States Department of Health, Education and Welfare, 1965). The questionnaire technique was used extensively in studies from 1957 to 1963. Studies related to philosophy and objectives were concerned with the rationale for the establishment of objectives within a specific philosophical framework. Many of the curriculum studies are related to subject matter content of secondary school science courses, excluding almost completely problems related to the processes of inquiry. Studies related to method were primarily comparisons of achievement in the use and non-use of film.

No consistent patterns of superiority of either method were evident when total groups were compared.

Ramsey and Howe (1969) reviewed and analyzed research on instructional procedures in secondary school science in two parts. They focused on studies emphasizing outcomes obtained from generalized instruction in a classroom or a classroom-laboratory setting in Part I. In Part II, they included studies that identified a particular instructional procedure. Among the several conclusions they formulated, the six which seemed most significant to the present study are listed below:

> 1) There is considerable confusion in the terminology used to describe any given instructional procedure. Some standard set of terms needs to be devised so that the same descriptions are used for similar instructional means . . .;
>
> 2) Teacher characteristics seem more significant in deciding outcomes than any imposed external arrangement; however, if some minimum criteria of teacher performance are defined, then the external arrangement, e.g. course description or pedagogical method, may have an effect on student outcomes;
>
> 3) Instructional procedures can be designed to teach students to think critically and to deepen their understanding of the scientific enterprise;
>
> 4) Much more useful information is likely to be gained by investigating different instructional procedures for teaching a given course or instructional module than by attempting to compare one course with another;
>
> 5) There is a deep need for more sensitive and more imaginative instruments for measuring various outcomes. The instruments available measure performance on pencil-and-paper tests but say nothing about many changes in behavior produced in students by instructional procedure;

> 6) Integration of different content areas is effective in terms of improved student outcomes provided the reasons for integration are clear, and the instruction is consciously directed toward the required outcomes . . .;

Rosenshine (1970) in a recent review of research on evaluation of instruction, identifies three current major needs:

1) Greater specification of teaching strategies to be used with instructional materials;
2) Improved observational instruments that attend to the context of the interactions and describe classroom interactions in more appropriate units than frequency counts; and
3) More research into the relationships between classroom events and student outcome measures.

The investigator feels that the present study is an attempt to meet each of the needs described above for instruction in high school chemistry.

Hendricks et al (1962) conducted a study to determine the effect of high school science and mathematics courses on freshman college chemistry courses. They found that student groups who had taken advanced mathematics and a high school science course scored significantly higher than those who did not have these courses. Sex was not a significant factor in their findings. The influence of teacher-pupil ratio, and size of high school, were not significant factors in determining success in college chemistry.

Davis (1964) has described a clinical approach to the development of a theory of instruction in mathematics which he suggests is consistent with modern views of learning. In a report on the Madison elementary mathematics project, he cites criteria to use for providing pupils informal exploratory experiences in mathematics. He suggests that mathematics experience must have underlying patterns which make the students look beyond the immediate problem, and develop creative thinking.

Dessart (1964) studied the research in mathematics education in the secondary schools during 1960-63. He identified the need for additional research in order to fulfill several purposes. Among the areas in need of research, he listed the determination of the plausibility of teaching particular mathematical topics and of relating them to other sciences. He also listed the need for research to discover the interactions of pupils, materials, teachers, parents, and general school characteristics that affect instruction and achievement.

Stake (1968), in an article on testing in the evaluation of curriculum development, pointed out that almost all current evaluation studies are defined by a certain content. He found it impossible to cite what he considered representative examples of existing studies because of the wide variations of techniques and purpose across subject matter, grade level, teaching style, and student type. He suggested that evaluation research studies regarding how curriculum developments in mathematics harmonize with those in science and social studies should be activated.

A study designed to study how curriculum developments in mathematics harmonize with a physical science program was conducted by Collagan (1969). The primary problem of Collagan was to develop a programmed mathematics text that would:

1) teach that mathematics essential to successful manipulation of quantitative problems in the physical sciences;
2) minimize the importance of reading in the teaching of such mathematics; and
3) emphasize the importance of mathematics not as an abstraction but as it relates to problems in the physical world.

The purposes of Collagan's study were twofold:

1) to determine whether a programmed course in mathematics prepared the pupil better in mathematics essential to understanding science than did a conventional program of the same duration and content emphasis;
2) to determine whether those students who had completed the programmed course performed better in a physical science course than did those

who had taken the conventional course in mathematics.

The results indicated that the group which completed the programmed mathematics course exceeded the group which took the conventional mathematics course in learning levels of both mathematics and science and completed the course in less time.

The Piaget tasks were used to determine the extent to which the student's ability to do formal thinking contributed to achievement in chemistry. Therefore, an overview of literature regarding Piaget's theories on the development of students' intellect is important to the present study. Excellent reviews of this literature were found in Stafford (1969); Friot (1970); and McKinnon (1970).

Stafford (1969) investigated the rate of achievement of conservation as described by Piaget, between children who use the first grade program of the Science Curriculum Improvement Study. Length, number, liquid amount, solid amount, weight, and area were the particular conservation areas explored in his investigation. The evidence for conservation or nonconservation was based on linguistic judgment rather than on conservation-in-action. Stafford concluded that:

> (a) The rate of attainment of the conservation skills is significantly enhanced by the experiences made possible by the first grade program of the Science Curriculum Improvement Study;

(b) A positive influence of the first grade program of the Science Curriculum Improvement Study can be shown in the above average and below average Readiness score divisions. The influence is even more pronounced in the average and below average Readiness score divisions;

(c) Ability to conserve appears to be positively related to I.Q. The rate of attainment of the conservations by the Experimental sample, however, is less dependent on I.Q. than the Control sample. The treatment given the Experimental sample appears to be effective in enhancing the attainment of the conservations in the entire range of I.Q.'s usually found in the classroom; and

(d) Kindergarten experience is positively related to the acquisition of conservation. The experiences made possible by the first grade program of the Science Curriculum Improvement Study appear to compensate for not having kindergarten.

Friot (1970) made a comparative study of students who were exposed to an inquiry type science course and those who were instructed by a traditional lecture-demonstration type course in order to ascertain significant gains in these students' ability to think logically. Friot found that although all students showed gain in achievement, those students of the inquiry type science course showed improvement greater than that of the traditional lecture-demonstration course in eight of the nine cases. The difference was significant in seven of the eight cases where improvement was shown. She also found that there was not a significant correlation between I.Q. and rate of gain of formal operational thought. There appeared to be some factor operating which caused a significant gain in attainment of formal operational thought. Friot hypothesized that the operating factor was the inquiry-centered science materials which allowed the learners to achieve a greater gain in formal thinking than did the lecture-demonstration-type materials.

McKinnon (1970) studied the influence of a college inquiry-centered course in science on student entry into the formal operational stage. The study examined the effect upon the logical thought processes of incoming college freshmen when provided adequate opportunities to inquire into the nature of science and the methods by which science operates. The selected tasks designed to determine whether the student does think logically when presented with problems were: conservation of volume, reversible operations, reconciliation of irrelevant variables, and elimination of irrelevant variables. McKinnon found that:

> (a) Fifty-one percent of these students initially tested were operating at Piaget's lowest level of operational thought (concrete) with another 27% not having attained his criteria for formal thought;
>
> (b) . . . The newly developed inquiry-oriented science course had an appreciable effect upon the students' capacity to think logically;
>
> (c) The net gain in favor of the experimental group resulted in 15 versus six students moving to the formal stage, while 20 versus 12 moved out of the concrete stage; and
>
> (d) Associated data collected and compared with Piagetian scores indicated that a high school physics course had no effect upon female capacity to think logically; . . . female students of the School of Music were significantly

> lower in their capacity to think logically when compared with all other female students. Correlations of ACT scores with Piagetian data indicated near zero relationships for students scoring less than 22 on the ACT.

Karplus and Karplus (1970) conducted a study to assess abstract reasoning ability beyond elementary school. They felt that this was a neglected area of educational research which has significant bearing on large-scale improvement in scientific literacy. They used the Islands Puzzle, a tool created to assess abstract reasoning ability for groups of subjects in the study. They found that intellectual development in abstract reasoning reached a plateau in the high school age group and did not progress much further. They also found the plateau to be at a disappointingly low level. They advanced a question regarding the desirability of an educational policy which would result in a larger fraction of the adult population being able to use abstract thought.

Karplus and Peterson (1970) also conducted a study to assess abstract reasoning ability beyond elementary school. They used a tool designed to measure the ability of a group of subjects to apply the concept of ratio (or proportion) in a problem requiring a change in the unit of length measurement. As in the Islands Puzzle, the children were required to give a specific answer and also to provide an explanation or rationale of their answer. They found that the ability to solve the ratio problem develops during the secondary school years. Only a small minority of elementary school subjects could solve it. But most of the 11th and 12th grade subjects were able to do so successfully. Subjects in the 9th and 10th grades presented an intermediate picture. A much smaller number of these subjects were in the preoperational stage. The number of subjects in the preoperational stage increased with a substantial number of subjects in the transitional category, where they solve the problem successfully but do not explain it completely. They felt that a serious gap existed between the school mathematics curricula and the children's reasoning ability since successful proportional reasoning is not achieved until the last years of high school, even though the ratio and proportion topics are most often introduced in grade 6, 7, or 8. This information is significant for the present study since it indicates that secondary school students taking chemistry most likely will possess the ability to apply the concept of ratio and proportion which has wide application in a high school chemistry course.

Significance of the Study

This study is significant in several aspects. First, it provides information in an area where very little information based on research exists. Second, a strategy was introduced which provides experiences in the use of mathematics, which may increase the probability of developing in students conceptual understandings, skills, and positive attitudes toward chemistry. This is of great interest to people concerned with curriculum planning such as chemistry teachers, administrators, and science consultants and/or supervisors. Third, the study will provide an exploratory investigation on which future studies and experiments may be based. Fourth, the results of this study may possibly suggest clues for increasing individualized or personalized instruction in the chemistry classes of secondary schools. The results may lead to the development of teaching strategies compatible with the extant variation in students' intelligence, and stages of logical thought processes, but which may have significance for the educational diagnosis of and prescription for the individual.

Further, the study examines the relationships among and between several factors such as race, intelligence, sex, stage of logical thought process, achievement in chemistry, and instructional strategy. The value of such information is indicated by Lunsdaine (1964, p. 393).

> In view of the complexity of human learning and the diversity of human learning tasks, we can expect to find relatively few generalizations that hold for all classes of instructional objectives, all classes of learners, and all conditions of instruction. Rather, what is likely to be most needed is a series of contingent generalizations that take account of the interaction of variables. Experimentally, this position argues for factorial experiments in which two or more variables are studied in combination so that qualifications on a generalization can be determined.

Finally, the data collected in this investigation may indicate some relatedness to Bruner's work on instructional theory (1966). The results could show, as Bruner had indicated, that the need is for theories rather than a theory of instruction compatible with the different theories of learning.

Assumptions

Several assumptions are basic to this investigation: It was assumed that:

1. the placement of students in a particular class was done randomly and prior to the initiation of this study;

2. the randomly selected samples from each school represent the population of that school which studies chemistry;

3. the stage of logical thought processes may be accurately determined for each student through the use of the equipment and interviews developed for the Piaget-type tests;

4. achievement in chemistry can be measured effectively by the <u>1969 ACS-NSTA National Highschool Chemistry Test</u>;

5. the content introduced into the instructional program of the chemistry classes, due to involvement in this investigation, will be representative of the content used in chemistry classes;

6. the content introduced into the instructional programs of the chemistry classes for the quantitative approach will not be different from the content used for the qualitative approach. Only the way the courses are designed will be different.

Operational Definitions

Achievement is the knowledge of Chemistry as measured by the ACS-NSTA Cooperative Examination for High School Chemistry, prepared by the examination committee of the division of chemical education of the American Chemical Society.

Chemistry course is an instructional program provided generally in senior high school which permits the student to devote a class period for both the first and second semesters to the study of matter, its properties and the energy relationship involved during the changes that matter undergoes.

Homoscedasticity is a condition of a set of raw data in which the standard deviations or variances of the various rows of columns or arrays tend to be equal.

Intelligence is the ability to work with ideas and the relationship among ideas.

Interaction is a statistical term used to indicate that a relationship or difference under analysis is between the dependent variable and the combined interrelationship of two (or more) independent variables.

Logical thought processes are the sum total of events and operations which the learner has experienced and which have permitted him to develop a cognitive structure that facilitates his acquisition of knowledge.

Mathematics achievement index is a number used to indicate on a relative basis the number of semesters of mathematics a pupil has taken in grades 9 through 12 and the average of the final grades earned for the courses.

Qualitative approach is a non-mathematical instructural procedure which utilizes verbal descriptions and explanations for providing learning experiences related to key chemistry concepts.

Race or socio-economic population is the largest group of people whose members have intimate access to one another on racial, social, and economic basis, but who are restricted in access to free competition, and full social integration with the members of different populations (Myrdal, 1944, p. 673).

Hypotheses

Hypothesis 1_a: There is no significant correlation between the mathematics achievement indices and the post-test scores of students enrolled in chemistry classes of the selected two senior high schools of the metropolitan school system participating in the study.

In hypotheses 2_a through 8_a which follow, adjustments were made statistically for initial group differences in the covariates, intelligence and stage of logical thought processes. Gain scores were used as the dependent variable to indicate achievement in chemistry.

Hypothesis 2_a: There is no significant difference in chemistry achievement between groups of students taught by a qualitative strategy and groups of students taught by a quantitative strategy.

Hypothesis 3_a: There is no significant difference in chemistry achievement between groups of chemistry students from two different racial populations, black and white.

Hypothesis 4_a: There is no significant difference in chemistry achievement between groups of male chemistry students and groups of female chemistry students.

Hypothesis 5_a: There is no significant interaction among the various black, white, quantitative, and qualitative groups and subgroups.

Hypothesis 6_a: There is no significant interaction among the various male, female, qualitative, and quantitative groups and subgroups.

Hypothesis 7_a: There is no significant interaction among the various black, white, male, and female groups and subgroups.

Hypothesis 8_a: There is no significant interaction among the various qualitative, quantitative, black, white, male, and female groups and sub-groups.

In Hypotheses 1_b through 7_b which follow, adjustments were made for initial group differences in the covariates, intelligence, and pretest scores. The posttest scores were used as dependent variable to indicate achievement in chemistry.

Hypothesis 1_b: There is no significant difference in chemistry achievement between groups of students taught by a qualitative strategy and groups of students taught by a quantitative strategy.

Hypothesis 2_b: There is no significant difference in chemistry achievement between groups of chemistry students from two different racial populations, black and white.

Hypothesis 3_b: There is no significant difference in chemistry achievement between groups of male chemistry students and groups of female chemistry students.

Hypothesis 4_b: There is no significant interaction among the various black, white, quantitative and qualitative groups and subgroups.

Hypothesis 5_b: There is no significant interaction among the various male, female, quantitative, and qualitative groups and subgroups.

Hypothesis 6_b: There is no significant interaction among the various black, white, male, and female groups and subgroups.

Hypothesis 7_b: There is no significant interaction among the various qualitative, quantitative, black, white, male, and female groups and subgroups.

Limitations

The study was limited to the 114 students who were enrolled in four chemistry classes of two senior high schools in a metropolitan school system during the 1969-70 school year.

The study was further limited to determining the ability of students taught by two different instructional strategies to recall chemical information, the ability to comprehend and apply chemical principles, and the ability to apply chemical principles in a quantitative manner. The students were evaluated for the abilities listed above in groups based on instructional strategy, race, and sex. Statistical adjustments were made between groups for initial differences in intelligence, Piaget task indices, and pretest scores when they were used as covariates.

Although these limitations exist, they do not invalidate the study. The obtained results will, as defined in the stated purpose for the study, be valid for the sample. The results will also provide useful insights for teaching chemistry not only to the total population of chemistry students in the two schools, but also for many other high school chemistry students who have learning characteristics similar to students in the sample.

CHAPTER II

METHODS AND PROCEDURE

Subjects

The subjects for this study were enrolled in chemistry classes of two senior high schools of a large metropolitan school system. In one of the schools 140 students, 7.7 percent of the total student body, were enrolled in chemistry. The second school had 188 students, 14.6 percent of the total student body, enrolled in chemistry. In both schools, the subjects for this study were taught by certified teachers in 55 minute periods for a total exposure of 275 minutes per week.

The two senior high schools used in the study were selected because the classroom facilities in both schools were approximately equal and were adequate for providing the students experiences needed for the study. The race and socioeconomic background of the students in the two schools were important factors in their selection. One school was predominately black, the other predominately white. Both schools had similar requirements in regards to student eligibility for enrollment in chemistry. Both schools used the same materials for instructional purposes which was Chemistry, an Experimental Science (Chemical Education Materials Study, 1963). Films developed to be used with the course were available from the central film library.

Chemistry in both schools is an elective course. Although it is not specifically required for graduation, it was elected by many of the subjects of the study as a laboratory science to meet graduation requirements. This was especially true for science oriented 10th grade subjects in the study who were permitted to take biology in the 9th grade. Many of the other subjects were enrolled in chemistry because they were interested in science and wanted more than the one year of instruction in science required for graduation.

Twenty (20) of the subjects of this study were in the 10th grade, 77 were in the 11th grade, and 17 were in the 12th grade. The subjects were members of four intact classes which were established by the normal enrollment procedures employed by counselors in the two schools. Normal enrollment procedures did not include dividing students into groups according to academic achievement or mental maturity.

Selection and Description of Instruments

All of the subjects in both schools were requested to take a standardized chemistry achievement test at the beginning of the study and another form of the same test at the end of the study. The subjects were also required to complete Piagetian tasks selected by the investigator for use in the study because those tasks involve students in the logical processing of information in the way that professional chemists do. Additional standardized multi-factor test scores were secured for each subject from the research department of the school system. Each standardized test and Piagetian task was selected to gather specific data such as the intelligence index, the Piagetian task index, the pretest score, the posttest score, and the difference or gain score for each subject. These data, which have been compiled in Appendix A, were needed to test the hypotheses of the study. Descriptive information regarding each test and task follows. The ACS-NSTA Examination in High School Chemistry Form 1969 (Judge, 1969) was used to measure the growth in knowledge and understanding of the subjects that resulted from participation in the respective chemistry classes during the nine weeks of the study. More specifically, the test was an instrument for measuring achievement as it was reflected by:

1) the student's ability to recall chemical information;
2) the student's ability to comprehend and apply chemical principles; and
3) the student's ability to apply chemical principles in a quantitative manner.

The ACS-NSTA Examination is divided into two sections comprised of 40 items each. Each part tests a year's course. The parts are of equal difficulty and are also balanced for content. Forty minutes are required for either section. If both sections are administered, the reliability of the examination is increased. All the questions are five-response multiple-choice items which cover important concepts and quantitative relationships in chemistry. The published norms of the standardized test provide sufficient evidence that the test is a valid instrument for use in this study.

<u>The Differential Aptitude Test</u> (DAT) is the most widely used multi-factor test in American public schools. In at least one evaluation, it is described as the best of the current multifactor tests (Super, 1958). The DAT contains eight sub-tests: (1) verbal reasoning, (2) numerical ability, (3) abstract reasoning, (4) space relations, (5) mechanical reasoning, (6) clerical ability, (7) spelling ability, and (8) sentence usage. The test is divided into easily administered parts, answer sheets are provided for machine scoring, and directions are clear on the two available forms. Three hours and six minutes of actual testing time are needed to administer the test. The test is administered annually to every ninth grade student enrolled in the school system of which both schools participating in the research are a part.

The student scores on the combined verbal reasoning, numerical ability, and sentence usage components of the DAT correlate very highly (.70 to .90) with student intelligence test scores (Smith and Hudgins, 1964, p. 79) and are, therefore, adequate indicators of intelligence according to the definition used in this investigation.

Piaget's Tasks require the use of logical thought processes which have been defined for this study as the sum total of events and operations which the learner has experienced and which have permitted him to develop a cognitive structure that facilitates his acquisition of knowledge. These processes have been identified and defined by Piaget, a Swiss psychologist. Piaget has been researching child development for more than 40 years, and has advanced a new concept of intelligence which indicates that intelligence develops with the child's experiences. Intelligence, rather than being fixed by genetic factors at birth, emerges as it is nurtured. Each stage of development carries with it possibilities for acquisition of new abilities, i.e., new ways of processing information.

Piaget developed methods for determining the stage of logical thought processes for individual pupils. Special equipment and interview techniques are used in identifying the subject's stage of logical thought. Five Piagetian tasks were used in this study. They measure:

(a) conservation of quantity;

(b) conservation of volume;

(c) reciprocal implications;

(d) separation of variables;

(e) operations of exclusion;

(f) elimination of contradictions.

The tasks are presented to pupils individually and require the student to demonstrate an ability to process information and perform mental operations that are the basis of reasoning. The five tasks required approximately 25 minutes per student to administer (see Appendix B).

Procedure

The procedure of this study was to determine, by means of standardized tests, final course marks, and Piagetian type tasks, the achievement in both chemistry and mathematics of the participating subjects. In addition, the students' performance level in terms of logical thought processes was identified. Determinations were also made of the intelligence of the subjects. Information regarding race and sex of the subjects was considered important data for the study. Through analysis and synthesis of the data, efforts were made to identify group differences and to determine relationships of the various factors on achievement in chemistry. The relationships and differences were used to determine which instructional strategy is most suitable for use with the students who possess certain specific sets or combinations of learning characteristics.

Population and Sample

This population consisted of 328 chemistry students in two senior high schools of a large metropolitan school system. The investigator and the respective principals of the two schools selected two intact chemistry classes in each participating school, i.e., a total of four classes. The four classes constituted the sample of the study and were assigned a particular kind of instruction on a random basis. One class in each school used a qualitative instructional program for the study. The second class in each school used a quantitative instructional program. The 114 students selected for the sample to be studied were representative of the total enrollment in chemistry of the two schools. The sample distribution is recorded in Table 1.

Table 1

Distribution of Samples

	Qualitative Group		Quantitative Group		
School	Male	Female	Male	Female	Totals
1	10	9	19	10	48
2	5	29	19	13	66
Totals	15	38	38	23	114

Preparing the Curriculum

Four two-hour inservice workshops were provided for the participating teachers during the month of January 1970. The inservice workshops were prior to the beginning of this investigation. During the workshops, the investigator and the participating teachers selected the mathematics concepts and skills to be developed in the quantitative classes. Decisions were also made regarding chemistry concepts to be developed in both the qualitative and quantitative classes. The investigator and participating teachers developed units which defined instructional strategy for both groups. The units of study are described in Appendix C of this study. The instructional units were used during a nine week instructional period which began in February and ended in April, 1970.

Data Collection

The procedure described below was used to collect the data required for the investigation. The mathematics grades earned by each student in the sample were obtained from official transcripts. A mathematics achievement index was calculated for each student. This index represented the sum of the final semester marks earned in mathematics courses by the students in grades nine through twelve. A five point scale was used to assign a value to the final semester marks in the following way: F = 0; D = 1; C = 2; B = 3; and A = 4. The indices of the participants in the qualitative group ranged from four to 23. The indices of the participants in the quantitative group ranged from four to 24.

In February, 1970, the ACS-NSTA was administered as a pretest of the students in the qualitative and quantitative groups of both schools. The investigator and participating teachers administered the pretest. No teacher or principal had access to the scores of students other than his own.

Between February 1 and March 30, each student participant was allowed to attempt the Piagetian task and was rated according to his stage of development in the logical thought process. Using the following scale, a Piaget task index was calculated for each student. This index represented the sum of the marks earned by the students on each of the individual tasks.

(a) Conservation of quantity	0--2 points
(b) Conservation of volume	0--1 point
(c) Reciprocal implications	0--7 points
(d) Separation of variables	0--7 points
(e) Operations of exclusion	0--7 points
(f) Elimination of contradiction	0--7 points

Task a, conservation of quantity, consists of two sections. Task b, conservation of volume, consists of one section. The students earned one point for each section in which they demonstrated the ability to process the information correctly. Tasks c, reciprocal implications; d, separation of variables; e, operations of exclusion; and f, elimination of contradiction, each contained four sections. A total of seven points was awarded to students who were able to process all four sections correctly. One point each was awarded for correctly processing the first two sections. Two points were awarded for correctly processing the third part, and three points were awarded for the fourth part. The maximum score possible on the Piagetian task instrument was 31. The Piaget task indices of the participants in the qualitative group ranged from four to 31. The indices of the participants in the quantitative group ranged from five to 31.

The DAT was administered annually by guidance counselors to all 9th grade students in the school system of which both schools are a part. Classroom teachers act as proctors and assistants to the counselors during the testing procedure. The answer cards are computer processed in the research department of the school system. A copy of the test results is sent to the central testing-office. The verbal reasoning, numerical ability, and sentence usage scores of the DAT were applicable to this study, and were obtained from the central testing-office. These scores were used to calculate an intelligence index for each of the participants. The index represented the sum of the three scores earned by the students on verbal reasoning, numerical ability, and sentence usage. The indices for the qualitative group ranged from 15 to 184. The indices for the quantitative group ranged from 18 to 198.

The students were instructed by use of the especially-prepared chemistry units which were designed for this study. The instructional period was of nine weeks duration and lasted from February through April, 1970. Upon termination of the nine week instructional period, the posttest was administered to all participating students. The alternate form of the ACS-NSTA Examination was preselected as the posttest of this study. All tests were administered by the investigator with assistance from the participating classroom teachers. A testing schedule was carefully planned and followed to prevent undesirable time differences among the classes within a school and between the two schools. The answer sheets were hand scored.

All of the data collected in the investigation were recorded in Appendix A. The data included were school, treatment or instructional strategy, grade, sex, race, intelligence index, Piaget task index, mathematics achievement index, the pretest and posttest scores, and gain scores for each of the participants. All of the data were recorded according to an assigned student number. In order to protect the rights of students and their parents, the participating school system does not permit the reproduction of test data identifiable by student name.

Design

The design selected for this study is an adaptation of the before and after control-group design 17.3 as described by Kerlinger (1964, pp. 308-309). The structure of the design employed was especially suited for the investigation of the intact chemistry classes and a pretest-posttest procedure. By using this design the investigator was able to statistically control important covariates, such as the intelligence index and the Piagetian task index, which he would not have been able to control otherwise because intact classes were used in the study. Significance of differences between the mean scores of groups are tested with a multiple-classification analysis of covariance _F_ test. The Pearson product-moment correlation coefficient was used to test the magnitude and direction of the relationship between selected variables. All hypotheses were tested for significance of difference at the 0.05 level of confidence. This level was selected because the investigator felt that the results of the study may be used for educational decisions regarding instructional strategies to be employed for personalizing chemistry instruction for students who possess a wide variety of learning characteristics. The investigator felt that if it was discovered that there was only five chances in 100 that the relationship defined by a hypothesis is a mere "fluke," then the null hypothesis can be rejected with a very high probability of being correct. The investigator sought to avoid the type I error of rejecting a null hypothesis which is true.

Consideration was given to raising the level of confidence to 0.10 because it would decrease the probability of making a type II error from 24.5% to 14.5%. In other words, the probability of accepting a null hypothesis which was in fact false would be decreased by 10%. But it increased the probability of committing a type I error. More stringent levels of confidence such as 0.01 and 0.001 were also considered. Although these levels reduced the probability of committing the type I error, the investigator felt that the 0.05 level was adequate.

There are several additional reasons why the investigator sought to avoid the type I error. They are listed below:

a) The size of the study sample was relatively small. In order to use the 0.10 level so as to avoid the type II error, several hundred randomly selected subjects would be needed (Mood, Harris, and Horvitz, 1948). The larger sample would allow for smaller confidence limits;

b) Because of the small sample from two schools, there is an inherent limitation in the generalizability of results. Using the 0.10 confidence level as a means to avoid the type II error would simply increase the extent of the problems caused by generalizing;

c) One of the instruments (the Piaget task scales) used in the study has not been standardized. The validity and reliability of the instrument may be subject to question. In order to increase the confidence interval and to allow for a greater standard error of the means, it was necessary to avoid the type I error and hold the confidence level to 0.05 or less.

The investigator was aware of the limitations to the use of the results when one considers the many sources of systematic and error variance that somehow seem to "creep" into studies. He felt that the study with the limitations listed above merited the .05 confidence level. He further concluded that in the study, the type II error was held to an appropriate minimum due to the extreme power of the covariance techniques used. He focused his concern on the type I error and used the 0.05 confidence level because it should indicate any significant results that could be used feasibly in curriculum planning.

CHAPTER III

RESULTS

Introduction

This study was designed to seek answers to a problem which essentially had two parts. First, the study was designed to determine the relationship between the achievement in mathematics and achievement in chemistry of the students enrolled in two senior high schools of a metropolitan school system. A Pearson product-moment correlation coefficient was calculated by using the subjects' mathematics achievement indices and the subjects' posttest scores on the ACS-NSTA Examination in High School Chemistry test. The posttest scores were selected for use in the calculation of correlation rather than final semester marks because the ACS-NSTA Examination would indicate the students' achievement in chemistry in a most objective manner.

The second purpose of the study was to determine the comparative effectiveness of two different instructional strategies on the achievement in chemistry of high school students from two different race populations. One strategy required the use of mathematical concepts and skills to teach selected chemistry concepts. The other strategy required the use of qualitative or non-mathematical explanations to teach the same chemistry concepts. Data for analysis were obtained by determining the difference between the ACS-NSTA examination in high school chemistry pretest and posttest scores (gain scores) for each of the subjects. The gain scores are recorded in the appendix. They were used as the dependent or criterion variable in this study.

The significant difference in gain scores was determined for the following groups and subgroups: (1) The students taught by the qualitative strategy and students taught by the quantitative strategy; (2) The black students and the white students; (3) Female students and male students. The race, sex, and instructional strategy (treatment) factors were used as independent variables in the study. The intelligence index and the Piaget task index were used as relevant variables or covariates for the study.

In order to begin the study during the second semester of the school year, it was necessary to use intact classes. This eliminated any possibility of establishing subgroups which were equivalent in regards to the covariates. The statistical treatment employed for testing the hypotheses regarding differences between the intact groups was the analysis of covariance (Popham, 1967). The significance of difference was tested at the .05 level of confidence for the obtained *F* ratios. The Monroe Epic 2000 highspeed electronic calculator and the IBM 1401 data processing systems were used for all computations in the investigation.

Popham pointed out that the requisite assumptions which must be satisfied for the proper interpretation of analysis of covariance are: (1) the relationship between variables is linear; (2) homoscedasticity exists; (3) measures must be randomly drawn; and (4) variance in subgroups must be homogeneous. Popham also pointed out that stringent satisfaction of these assumptions is probably not required but departure from them should not be too great.

Testing the Hypotheses

Hypothesis 1_a stated that there is no significant correlation between the mathematics achievement indices and the posttest scores of students enrolled in chemistry classes of the selected two senior high schools of the metropolitan school system participating in the study. Testing the hypothesis permitted the investigator to determine if a coefficient of correlation *r* would be more than a mere chance deviation in the sampling distribution in which the population correlation coefficient *R* is zero. The data used in the sample coefficient of correlation *r* calculation may be found in Appendix A. The hypothesis was tested according to the procedure recommended for testing the Pearson *r* correlation coefficient by Downie and Heath (pp. 85, 155-156). Table 2 contains the results of the calculations and the test of significance of difference, which was tested at the .05 level of confidence.

Table 2

Coefficient of Correlation *r* between the Mathematics Achievement Index and the Chemistry Posttest Scores

Sample Size *n*	114
Sum of Achievement Indices	1333
Sum of Posttest Scores	1663
Sum of Squared Achievement Indices	18,149
Sum of Squared Posttest Scores	29,751
Sum of Products of x and y	20,862
Coefficient of Correlation *r*	0.38*

*.05 *r* (112) = 0.1946

The coefficient of correlation was 0.38. An examination of Table 6 of Downie and Heath (1965, p. 306) revealed that the obtained correlation value at 112 degrees of freedom was greater than the necessary 0.1946 for significance at the .05 level of confidence. Therefore the obtained correlation was more than a chance deviation, and the hypothesis of no correlation between mathematics achievement index and the posttest scores was rejected.

Hypotheses 2_a, 3_a, 4_a, 5_a, 6_a, 7_a, and 8_a were tested simultaneously by a multiple-classification analysis of covariance statistical treatment. This statistical treatment tests the mean scores of all the groups with a single set of calculations and permits the investigator to statistically control the effect of initial differences between groups based on intelligence and stage of logical thought development.

Hypothesis 2_a stated that there is no significant difference in chemistry achievement between groups of students taught by a qualitative strategy and groups of students taught by a quantitative strategy.

Hypothesis 3_a stated that there is no significant difference in chemistry achievement between groups of chemistry students from two different racial populations, black and white.

Hypothesis 4_a stated that there is no significant difference in chemistry achievement between groups of male chemistry students and groups of female chemistry students.

Hypothesis 5_a stated that there is no significant interaction among the various black, white, quantitative, and qualitative groups and subgroups.

Hypothesis 6_a stated that there is no significant interaction among the various male, female, qualitative, and quantitative groups and subgroups.

Hypothesis 7_a stated that there is no significant interaction among the various black, white, male and female groups and subgroups.

Hypothesis 8_a stated that there is no significant interaction among the various qualitative, quantitative, black, white, male, and female groups and subgroups.

As previously indicated the significance of difference was tested at the .05 level of confidence. Table 3 contains the sums and means of the intelligence index (x_1), Piaget task index (stage of logical thought processes) indicated by (x_2) and achievement gain scores (y) for each group. Raw score data of the criterion variables and the covariates for the participating students are recorded in Appendix A.

Popham (1967), gives a complete description of the calculation procedures which were followed throughout the study.

Table 3

Sums and Means of Criterion Variables and Covariates by Group

	Criterion Difference Scores			Control Intelligence		Piaget Task	
Groups	n	y	$\bar{y}$	x_1	$\bar{x}_1$	x_2	$\bar{x}_2$
White Subjects #1							
Qualitative Males	10	23	2.3	680	68.0	176	17.6
Qualitative Females	9	45	5.0	884	98.2	113	12.6
Quantitative Males	19	44	2.3	1790	94.2	337	17.7
Quantitative Females	10	31	3.1	843	84.3	135	13.4
Subtotals	48	143	3.17	4197	86.2	761	15.5
Black Subjects #2							
Qualitative Males	5	19	3.8	220	44.0	100	20.0
Qualitative Females	29	113	3.9	2028	70.0	340	11.7
Quantitative Males	19	78	4.1	1452	76.4	339	17.8
Quantitative Females	13	36	2.8	840	64.6	173	13.3
Subtotals	66	246	3.65	4540	63.8	952	15.7
Total	114	389	3.41	8737	74.96	1713	15.52

Table 4 contains a summary of raw score squares and crossproducts for criterion variable and covariates by groups.

Table 4

Summary of Raw Score Squares and Crossproducts for Criterion Variable and Covariates by Group

Measure	Symbol	Total	Symbol	Total
Difference Score	Σy^2	2,552		
Intelligence Index	$\Sigma x_1{}^2$	852,729		
Piaget Task Index	Σx_2	30,311		
Crossproducts				
White Subjects #1				
Qualitative Males	$\Sigma x_1 y$	1790	$\Sigma x_2 y$	374
Qualitative Females	$\Sigma x_1 y$	4907	$\Sigma x_2 y$	638
Quantitative Males	$\Sigma x_1 y$	4390	$\Sigma x_2 y$	862
Quantitative Females	$\Sigma x_1 y$	3942	$\Sigma x_2 y$	490
Black Subjects #2				
Qualitative Males	$\Sigma x_1 y$	745	$\Sigma x_2 y$	355
Qualitative Females	$\Sigma x_1 y$	8394	$\Sigma x_2 y$	1508
Quantitative Males	$\Sigma x_1 y$	7466	$\Sigma x_2 y$	1563
Quantitative Females	$\Sigma x_1 y$	2620	$\Sigma x_2 y$	450

The analysis of covariance for the criterion variable (y) is summarized in Table 5.

Table 5

Analysis of Covariance Significance Tests for the Criterion Variable y

Source	Degrees of Freedom	Sum of Squares	Mean Square	F
Instructional Strategy (A)	1	13.3	13.3	1.23
Race (B)	1	15.9	15.9	1.47
Sex (C)	1	10.4	10.4	0.96
AxB	1	-0.27	-0.27	-0.03
AxC	1	10.7	10.7	0.99
BxC	1	5.5	5.5	0.51
AxBxC	1	25.47	25.47	2.36
Within	106	1144	10.8	
Total	113	1225	10.8	

.05 F (1,106) = 3.94

Adjustments of criterion scores based on initial differences in the covariates were not needed because none of the obtained F values was significant. The results of the test were used for final judgement on the hypotheses.

The instructional strategy source of variation (A) in the analysis of covariance test was related to hypothesis two, which states that no significant difference in achievement exists between groups taught by a qualitative strategy and groups taught by a quantitative strategy.

An examination of Table G of Popham (pp. 399-402) revealed that the obtained _F_ value of 1.23 was smaller than the necessary 3.94 for significance at the .05 level of confidence. Therefore, the difference in achievement between the two groups was not significant at the .05 level of confidence. It was concluded that relatively little difference between the means of the separate groups exists. The hypothesis of no significant difference in achievement between the qualitative and quantitative groups was accepted.

The race source of variation in the analysis of covariance test is related to hypothesis three which states that no significant difference in achievement exists between the students from two different races. An examination of Table G of Popham (pp. 399-402) revealed that the obtained _F_ value of 1.47 was smaller than the necessary 3.94 for significance at the .05 level of confidence. Therefore, the difference in achievement between the student groups from two different races was not significant at the .05 level of confidence. It was concluded that relatively little difference between the means of the separate groups exists. The hypothesis of no significant difference in achievement between the students from two different race groups was accepted.

The source of variation based on sex in the analysis of covariance test is related to hypothesis four which states that no significant difference in achievement exists between male and female students. An examination of Table G of Popham (pp. 399-402) revealed that the obtained _F_ value of 0.96 was smaller than the necessary 3.94 for significance at the .05 level of confidence. Therefore, the difference in achievement between the male and female student groups was not significant at the .05 level of confidence. It was concluded that relatively little difference exists between the means of the separate groups. The hypothesis of no significant difference in achievement between male and female students was accepted.

The source of variation in the analysis of covariance based on the interaction of instructional strategy and the race groups is related to hypothesis five which states that no significant interaction or difference in achievement exists among students in groups regarding the two factors. An examination of Table G from Popham (pp. 399-402) revealed that the obtained _F_ value of 0.03 is much smaller than the necessary 3.94 for significance at the .05 level of confidence. Therefore, the difference in achievement among the student membership in the various groups and subgroups based on instructional strategy and race was not significant at the .05 level of confidence. It was concluded that relatively little difference exists between the means of the separate groups and subgroups. The hypothesis of no significant interaction among student membership in groups regarding race and instructional strategy was accepted.

The source of variation in the analysis of covariance test based on the interaction of instructional strategy and the sex of the subjects is related to hypothesis six which states that no significant interaction or difference in achievement exists between students in groups regarding the two factors. An examination of Table G from Popham (pp. 399-402) revealed that the obtained _F_ value of 0.99 is much smaller than the necessary 3.94 for significance at the .05 level of confidence. Therefore, the difference in achievement among the student membership in the various groups and subgroups based on instructional strategy and the sex of the subject was not significant at the .05 level of confidence. It was concluded that relatively little difference among the means of the separate groups and subgroups exists. The hypothesis of no significant interaction among student membership in groups regarding instructional strategy and sex was accepted.

The source of variation in the analysis of covariance test based on the interaction of race of the subject and the sex of the subject is related to hypothesis seven. Hypothesis seven states that no significant interaction or difference in achievement exists among students in groups regarding the two factors. An examination of

Table G from Popham (pp. 399-402) revealed that the obtained *F* value is much smaller than the necessary 3.94 for significance at the .05 level of confidence. Therefore, the difference in achievement among the student membership in the various groups and subgroups based on race and sex was not significant at the .05 level of confidence. It was concluded that relatively little difference among the means of the separate groups and subgroups exists. The hypothesis of no significant interaction among student membership in groups and subgroups regarding the race and sex was accepted.

The source of variation in the analysis of covariance test based on the interaction of the instructional strategy, race, and sex of the subjects is related to hypothesis eight. Hypothesis eight states that no significant interaction or difference in achievement exists among students in groups and subgroups regarding the three factors. An examination of Table G from Popham (pp. 399-402) revealed that the obtained *F* value of 2.36 is smaller than the necessary 3.94 for significance at the .05 level of confidence. Therefore, the difference in achievement among the student membership in the various groups and subgroups based on the three independent variables was not significant at the .05 level of confidence. It was concluded that relatively little difference among the means of the separate groups and subgroups exists. The hypothesis of no significant interaction among student membership in groups and subgroups regarding instructional strategy, race, and sex was accepted.

Summary

On the basis of the data presented, it was evident that the relationship between the achievement in mathematics and the achievement in chemistry was more than a mere chance relation. It was also evident that none of the independent variables of instructional strategy, race, or sex had a significant effect on the criterion variable of achievement in chemistry. The interaction between the various pairs of variables and among the three independent variables were also insignificant. The gain score means for the various independent variable groups and subgroups were all nearly equal. The small F values indicated that the average variance within the separate groups was about the same as the variance for the pooled group.

Another Statistical Treatment

The investigator noted by an inspection of the raw data that a greater degree of variance was related to post-test scores than for the difference scores (recorded in Appendix A). The following Pearson r coefficients of correlation were calculated:

(1) Intelligence indices and Piaget task indices 0.42

(2) Intelligence indices and pretest scores 0.58

(3) Piaget task indices and pretest scores 0.27

(4) Piaget task indices and gain scores 0.14

There was a very low correlation between the Piaget task indices and the pretest scores as compared to the correlation of the intelligence indices and the pretest scores. There was also a relatively low correlation between gain scores and Piaget task indices. This information along with the insignificant results previously described for the analysis of covariance for the achievement in chemistry as indicated by gain scores was evidence that factors were operating in the study which were not identified in the statistical treatment used. The investigator decided to apply another statistical treatment to the raw data.

A second analysis of covariance test on the raw data was made using the posttest scores as the criterion or dependent variable to indicate achievement in chemistry. The intelligence indices and the pretest scores were used as covariates. The pretest scores were selected as one of the covariates because they could designate the level of achievement attained by the subjects in chemistry prior to the start of the study. The Piaget task scores were obviously not valid as one of the covariates because of the low correlation between these scores and the gain scores. Instructional strategy, race, and sex were retained as independent variables.

The hypotheses of the other statistical treatment of the data were formulated in the null form.

Hypothesis 1_b stated that there is no significant difference in chemistry achievement between groups of students taught by a qualitative strategy and groups of students taught by a quantitative strategy.

Hypothesis 2_b stated that there is no significant difference in chemistry achievement between groups of chemistry students from two different racial populations, black and white.

Hypothesis 3_b stated that there is no significant difference in chemistry achievement between groups of male chemistry students and groups of female chemistry students.

Hypothesis 4_b stated that there is no significant interaction among the various black, white, quantitative and qualitative groups and subgroups.

Hypothesis 5_b stated that there is no significant interaction among the various male, female, quantitative, and qualitative groups and subgroups.

Hypothesis 6_b stated that there is no significant interaction among the various black, white, male, and female groups and subgroups.

Hypothesis 7_b stated that there is no significant interaction among the various qualitative, quantitative, black, white, male, and female groups and subgroups.

All of the hypotheses were tested simultaneously by a multiple-classification analysis of covariance statistical treatment. The significance of difference was also tested at the .05 level of confidence. Raw score data of the intelligence index (x_1), the pretest scores (x_2), and the posttest scores for each group were recorded in Appendix A. Table 6 contains the sums and means of the criterion variable (posttest scores) and covariates for the participating students.

Table 6

Sums and Means of Criterion Variable (y) and Covariates (x_1 and x_2)

		Criterion Posttest Scores		Control Intelligence		Control Pretest Scores	
Group	N	y	y	x_1	$\bar{x}_1$	x_2	$\bar{x}_2$
White Subj. #1							
Qual. Males	10	108	10.8	680	68.0	185	8.5
Qual. Females	9	165	18.3	884	98.2	120	13.3
Quan. Males	19	304	16.0	1790	94.2	264	13.5
Quan. Females	10	116	11.6	843	84.3	85	8.5
Subtotal	48	693	14.2	4197	86.2	654	11.0
Black Subj. #2							
Qual. Males	5	89	17.8	220	44.0	70	14.0
Qual. Females	29	393	13.5	2028	70.0	290	10.0
Quan. Males	19	333	17.5	1452	76.4	255	17.8
Quan. Females	13	155	11.6	840	64.6	115	8.8
Subtotal	66	970	15.1	4540	63.8	730	12.7
Total	114	1663	14.6	8737	75.0	1384	11.8

Table 7 contains a summary of raw score squares and crossproducts for criterion variable and covariates by groups.

Table 7

Summary of Raw Score Squares and Crossproducts for Criterion Variable and Covariates by Groups

Measure	Symbol	Total	Symbol	Total
Posttest	x	29,751		
Intelligence	Σx_1^2	852,729		
Pretest	Σx_2^2	18,504		
Crossproducts				
White Subjects #1				
Qualitative Males	$\Sigma x_1 y$	1225	$\Sigma x_2 y$	918
Qualitative Females	$\Sigma x_1 y$	2417	$\Sigma x_2 y$	2208
Quantitative Males	$\Sigma x_1 y$	4597	$\Sigma x_2 y$	4224
Quantitative Females	$\Sigma x_1 y$	1500	$\Sigma x_2 y$	986
Black Subjects #2				
Qualitative Males	$\Sigma x_1 y$	1301	$\Sigma x_2 y$	1246
Qualitative Females	$\Sigma x_1 y$	4819	$\Sigma x_2 y$	3930
Quantitative Males	$\Sigma x_1 y$	5454	$\Sigma x_2 y$	4550
Quantitative Females	$\Sigma x_1 y$	1529	$\Sigma x_2 y$	1371

The analysis of covariance for the criterion variable (y) is summarized in Table 8.

Table 8

Analysis of Covariance Significance Test for the Criterion Variable (y)

Source	Degrees of Freedom	Sum of Squares	Mean Square	F
Instructional Strategy (A)	1	12	12	.3
Race (B)	1	2.3	2.3	.1
Sex (C)	1	131	131	3.0
AxB	1	7.7	7.7	.2
AxC	1	24	24	.5
BxC	1	187	187	4.2*
AxBxC	1	372	372	8.3*
Within	106	4756	44.9	
Total	113	5491	48.6	

*.05 F (1,106) = 3.94

The obtained F value for the interaction of the race and sex variables was significant at the .05 level of confidence. The obtained F value for the interaction of the three independent variables was significant at the .05 level of confidence. Because significant F values were found on posttest scores, the covariates x_1 and x_2 must be tested for significant F ratios and adjusted for differences found by calculating the residual sums of squares. Table 9 contains the test for the intelligence index variable x_1.

Table 9

Analysis of Covariance Significance Test for the Intelligence Index Covariate (x_1)

Source	Degrees of Freedom	Sum of Squares	Mean Square	F
Instructional Strategy (A)	1	2202	2202	1.4
Race (B)	1	9965	9965	6.5*
Sex (C)	1	226	226	.1
AxB	1	1177	1177	.8
AxC	1	4862	4862	3.2
BxC	1	170	170	.1
AxBxC	1	1302	1302	.8
Within	106	163,218	1540	
Total	113	183,122	1621	

*.05 F (1,106) = 3.94

The obtained F value for the race variable (B) was significant at the .05 level of confidence. The mean of the criterion variable (y) will be adjusted for this initial difference. Table 10 contains the test for the pretest score variable x_2.

Table 10

Analysis of Covariance Significance Test for the Pretest Score Covariate x_2

Source	Degrees of Freedom	Sum of Squares	Mean Square	F
Instructional Strategy (A)	1	36	36	5.0*
Race (B)	1	6.2	6.2	.8
Sex (C)	1	209	209	28.6*
AxB	1	-2.4	-2.4	.3
AxC	1	826	826	113.2*
BxC	1	41	41	5.6*
AxBxC	1	2081	2081	285.0*
Within	106	845	7.3	
Total	113	4042	35.8	

*.05 $F_{(1,106)} = 3.94$

The obtained F value for the instructional strategy variable (A) and the sex variable (C) were significant at the .05 level of confidence. The obtained F value for the interaction of independent variables (B) and (C) was significant at the .05 level of confidence. The obtained F value for the interaction of all three independent variables (AxBxC) was significant at the .05 level of confidence. The mean of the criterion variable (y) was adjusted for each of these differences. The residual sums of squares were calculated and were used in the analysis of covariance significance test for the combined criterion variable and the intelligence index variables. Table 11 contains the data of this test.

Table 11

F Test for the Residuals of the Criterion and Intelligence Index Variables ($y\ x_1$)

Source	Degrees of Freedom	Residual Sum of Squares	Residual Mean Square	*F*
Between	7	658	95.4	3.0*
Within	105	3344	31.8	
Total	112	3992		

*.05 *F* (105,7) = 2.08

The obtained *F* value was significant at the .05 level of confidence. The residual sums of squares were calculated to determine whether or not the significant differences found in the criterion variable were still significant after they were adjusted in accordance with intelligence index scores. Table 12 contains the *F* test of the residual sums of squares due to yx_2.

Table 12

F Test for Residuals of the Criterion and Pretest Score Variables ($y\ x_2$)

Source	Degrees of Freedom	Residual Sum of Squares	Residual Mean Square	F
Between	7	682	97.4	18.04*
Within	105	567	5.4	
Total	112	1249	1249	

*.05 F (105,7) = 2.08

The obtained F values of Tables 11 and 12 were significant at the .05 level of confidence. Thus, after adjusting the criterion variable for initial differences in the covariates, a significant difference in posttest scores still exists between groups regarding the interaction of the race and sex variables. A significant difference in posttest scores also exists between the groups regarding the interaction of the three independent variables. The hypotheses that were significant as a result of the analysis of covariance on the criterion variables were rejected because the significant differences found were valid.

Hypothesis 6_b stated that after statistically adjusting for initial differences in the intelligence index and pretest scores among the student membership in groups regarding race and sex, there will be no significant interaction among the various groups and subgroups. Hypothesis 6_b was rejected.

Hypothesis 7_b stated that after statistically adjusting for initial differences in the intelligence index and pretest scores among the student membership in groups regarding the three independent variables (race, instructional strategy, and sex) there will be no significant interaction among the various groups and subgroups. Hypothesis 7_b was rejected.

Hypotheses 1_b, 2_b, 3_b, 4_b, and 5_b were accepted because a significant difference did not exist for any one of them.

The investigator wanted to know how each group would have performed on the criterion variable if they had been equivalent at the outset with respect to the covariates. An additional step in the analysis of covariance suggested by Popham (p. 242) permitted the investigator to adjust the criterion means to compensate for differences between groups on the covariates. This calculation would facilitate the interpretation of the obtained results. Each group criterion mean $\bar{y}$ was adjusted by using the within regression coefficients and the difference between subgroups covariate mean and the total sample's covariate mean. The formulas and calculations which follow illustrate the process for adjusting the criterion means.

Formulas for Adjusting Criterion Means

$$\bar{y}'_g = b_1(\bar{x}_{g_1} - \bar{x}_{T_1}) + b_2(\bar{x}_{g_2} - \bar{x}_{T_2})$$

$$\bar{y}'_g = .02(\bar{x}_{g_1} - 76.6) + .76(\bar{x}_{g_2} - 11.3)$$

where: $\bar{y}'_g$ = adjusted group mean;

$\bar{x}_{g_1}$ and $\bar{x}_{g_2}$ = Subgroup covariate means

$\bar{x}_{T_1}$ and $\bar{x}_{T_2}$ = Total sample covariate means

b_1 and b_2 = Regression coefficients

The formulas and calculations used to obtain regression coefficients are illustrated below:

$$\Sigma x_1 y = b_1 \Sigma x_1^2 + b_2 \Sigma x_1 x_2$$

$$\Sigma x_2 y = b_1 \Sigma x_1 x_2 + b_2 \Sigma x_2$$

$$16{,}568 = b_1(183{,}122) + b_2(16{,}587)$$

$$4{,}491 - b_1(16{,}587) + b_2(5{,}412)$$

solving the two equations simultaneously:

$b_1 = .0213$ $\qquad$ $b_2 = .7645$

Table 13 contains the adjusted mean values for the criterion variable.

Table 13

Adjusted Mean Values for the Criterion Variable ($\bar{y}$)

Race	Qualitative Male $\bar{y}'$	Female $\bar{y}'$	AxB $\bar{y}'$	Male $\bar{y}'$	Fem. $\bar{y}'$	AxB $\bar{y}'$	Male $\bar{y}'$	Fem. $\bar{y}'$	Total
White	8.5	20.3	14.1	18.3	9.6	15.3	14.9	14.7	14.8
Black	19.2	12.5	13.5	22.5	9.5	15.3	19.1	11.5	14.4
AxC	13.5	14.3	13.7	18.8	9.8	15.4	16.8	12.6	

In analyzing the table, the results described below were noted:

1. The quantitative scores of male subjects were higher for both race populations than the qualitative scores. However, the qualitative scores were higher than the quantitative scores for the female subjects.

2. The quantitative scores for male and female groups in both race populations were higher than corresponding qualitative groups in regard to the interaction of strategy (A) and population (B). A similar result was noted for the interaction of instructional strategy (A) and sex (C). The differences were not significant.

3. The male subjects from the black groups scored significantly higher than male students from the white groups. The reverse was true for female subjects.

4. The male and female subjects had nearly equal mean scores for the white groups, but the mean scores are significantly different between male and female subjects in the black groups.

The investigator decided to apply procedures suggested by Kerlinger (pp. 235-239) to illustrate the obtained results graphically. Data from table 13 was used to construct sets-of-means tables and graphs for the significant interactions. The sets-of-means for the interaction of the race (B) and sex (C) main effects are shown in Table 14.

Table 14

Adjusted Means for the Interaction of Race and Sex

Population	Male	Female	Interaction Mean
White	14.9	14.7	14.8
Black	19.1	11.5	15.3
Interaction Mean	17.0	13.1	

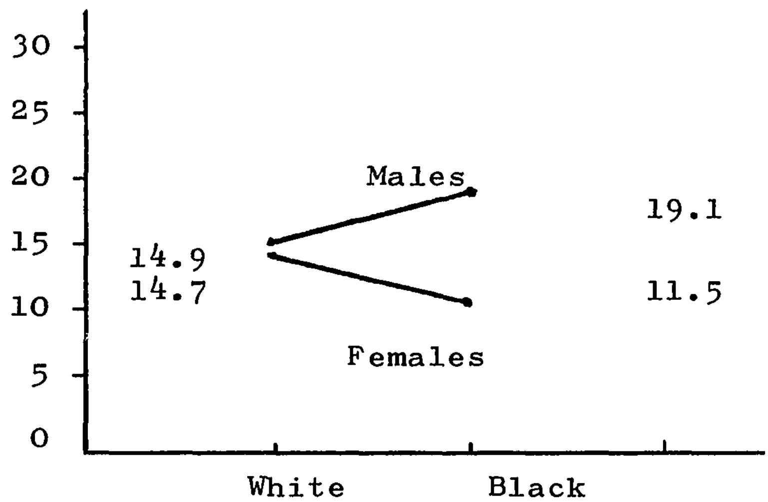

Fig. 1. A graph of the B X C interaction.

The slopes of the lines in figure 1 clearly indicate a pattern of non-symmetric interaction. Therefore, sex is effective in the black population, but is not a relevant factor in the white population.

Tables 15, 16, 17, 18, 19, and 20 contain the sets-of-means for the interaction of the three main effect variables, instructional strategy, race, and sex. In each table, sets-of-means are listed for two main effect variables with a third held constant, i.e., controlled.

Table 15

Adjusted Means for Interaction of Strategy, Race and Sex with Control for Qualitative Strategy

Population	Male	Female	Interaction Mean
White	8.5	20.3	14.6
Black	19.2	12.5	15.8
Interaction Mean	13.8	16.4	

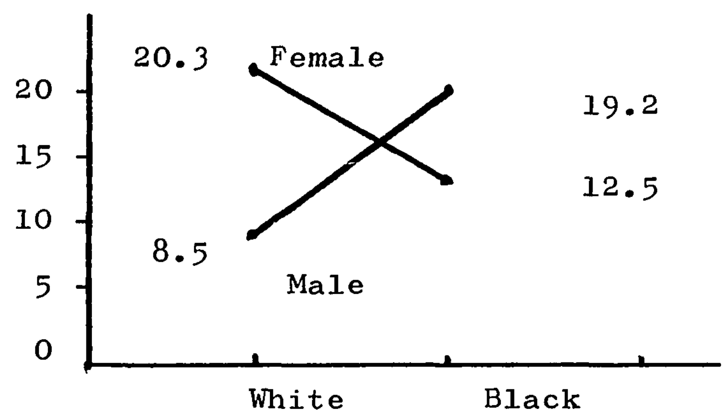

Fig. 2. The graph for adjusted means for interaction of strategy, race, and sex with control for qualitative strategy.

The set of means in Tables 15 and the graph in Fig. 2 indicate a classical pattern of symmetrical interaction. When one controls for the qualitative approach, the female subjects' achievement was significantly higher than that of male subjects for the white population.

The male subjects' achievement was significantly higher than the female subjects for the black population. The white female achievement was significantly higher than the black female achievement but the black male achievement was significantly higher than the white male achievement.

Table 16

Adjusted Means for Interaction of Strategy, Race and Sex with Control for Quantitative Strategy

Population	Male	Female	Interaction Mean
White	18.3	9.6	13.9
Black	22.5	9.5	16.0
Interaction Mean	20.4	9.5+	

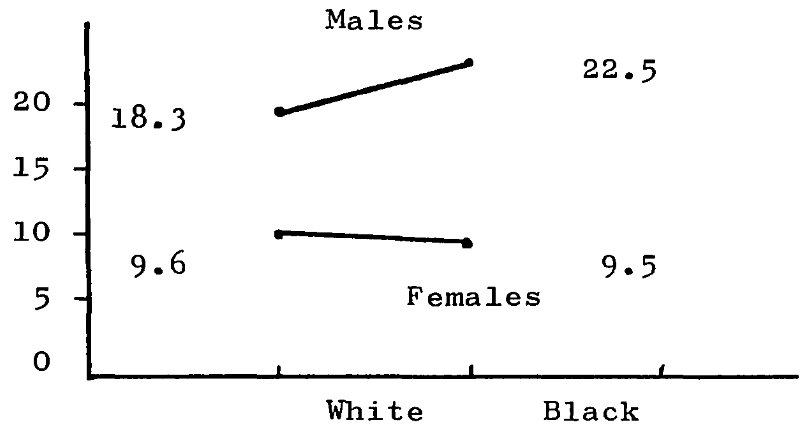

Fig. 3. The graph for adjusted means for interaction of strategy, race, and sex with control for quantitative strategy.

The set of means in Table 16 and the graph in Fig. 3 indicate that when the quantitative strategy is controlled, interaction is minimum and is non-symmetrical. The horizontal line for the female subjects' achievement indicates that no sex difference existed between black and white groups. The slope of the line for male subjects' achievement indicated that black male subjects achieved significantly higher than the white male subjects.

Table 17

Adjusted Means for Interaction of Strategy, Race, and Sex with Control for White Race

Strategy	Male	Female	Interaction Mean
Qualitative	8.5	20.3	14.4
Quantitative	18.3	9.6	13.9
Interaction Mean	13.4	14.3	

The set of means in Table 17 and the graph in Fig. 4 indicate a classical pattern of symmetrical interaction. When race (white) was used as a control, the achievement of female subjects was significantly higher than the achievement of male subjects for the qualitative strategy. The achievement of female subjects was significantly lower than the achievement of male subjects for the quantitative strategy. Females in the qualitative

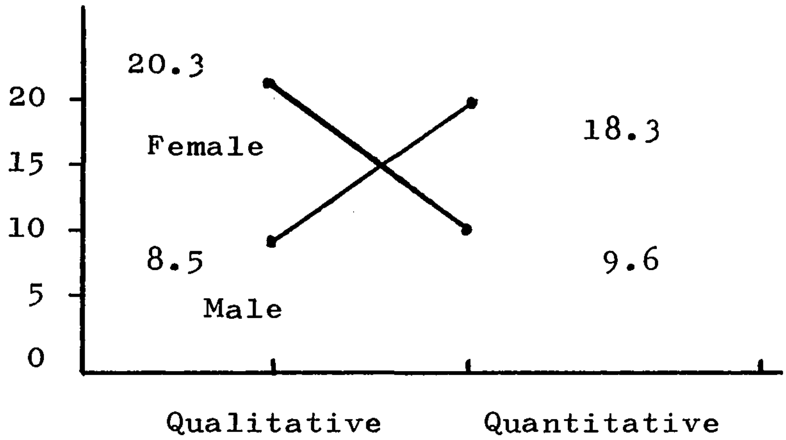

Fig. 4 is the graph for adjusted means for interaction of strategy, race, and sex with control for white race.

group scored significantly higher than females in the quantitative group, but males in the quantitative group scored significantly higher than males in the qualitative group.

Table 18

Adjusted Means for Interaction of Strategy, Race, and Sex with Control for Black Race

Strategy	Male	Female	Interaction Mean
Qualitative	19.2	12.5	15.8
Quantitative	22.5	9.5	16.0
Interaction Mean	20.8	11.0	

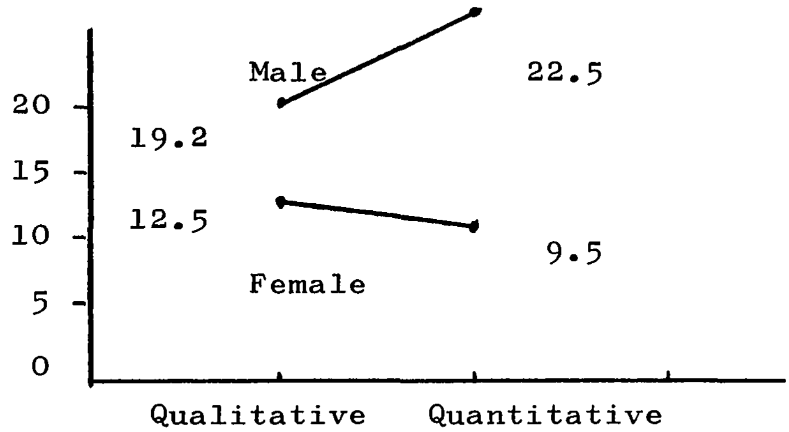

Fig. 5 is a graph of adjusted means for interaction of strategy, race, and sex with control for black race.

The set of means in Table 18 and the graph in Fig. 5 indicate that when race (black) was used as a control, a non-symmetrical interaction occurred. The achievement of male subjects was higher than the achievement of female subjects for both the qualitative and quantitative strategies, but the degree of significance of difference was greater for the quantitative strategy. Male subjects for the quantitative group achieved a higher level than the male subjects in the qualitative group. Female subjects in the qualitative group scored higher than the female subjects in the quantitative group.

The set of means in Table 19 and the graph in Fig. 6 indicate a pattern of non-symmetrical interaction. When sex (male) was used as a control, black male subjects achieved a significantly higher level than white male subjects for the qualitative and quantitative groups. Both

Table 19

Adjusted Means for Interaction of Strategy, Race, and Sex with Control for Male Sex

Strategy	Black	White	Interaction Mean
Qualitative	19.2	8.5	13.9
Quantitative	22.5	18.3	20.4
Interaction Mean	20.8	13.4	

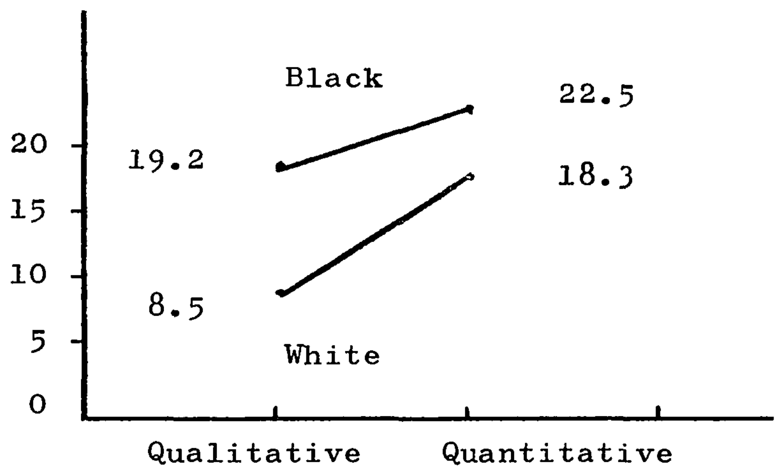

Fig. 6 is a graph of the adjusted means for interaction of strategy, race, and sex with control for male sex.

the black and white male subjects in the quantitative groups achieved significantly higher than corresponding qualitative groups.

The set of means in Table 20 and the graph in Fig. 7 indicate a pattern of non-symmetrical interaction. When sex (female) is used as a control, white female subjects in the qualitative group achieved significantly

Table 20

Adjusted Means for Interaction of Strategy, Race, and Sex with Control for Female Sex

Strategy	Black	White	Interaction Mean
Qualitative	12.5	20.3	16.4
Quantitative	9.5	9.6	9.6
Interaction Mean	11.0	14.9	

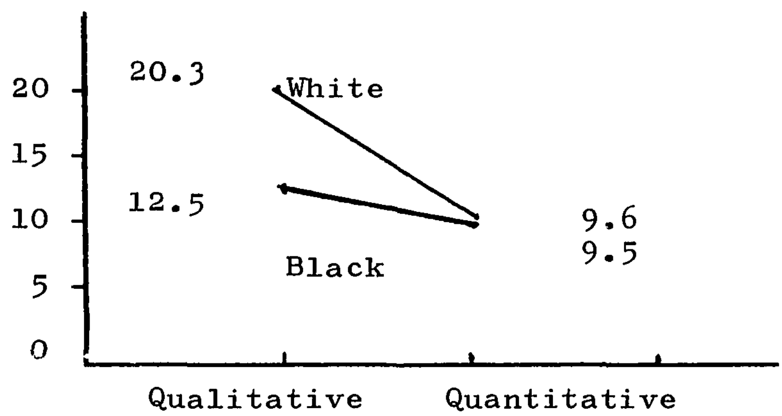

Fig. 7 is a graph of adjusted means for interaction of strategy, race, and sex with control for female sex.

higher than the black female subjects in the qualitative group. The achievement of both white and black female groups were nearly equal for the quantitative treatment. Both black and white female subjects in the qualitative strategy groups achieved significantly higher than black and white female subjects in the quantitative strategy groups.

Summary

On the basis of the results obtained in the second analysis of covariance statistical treatment of the data, none of the main effects, instructional strategy, race, or sex, in and of themselves, were significantly different in the achievement in chemistry measure. Each pair of strategy groups had approximately equal mean scores on the posttest measure. But two of the interactions were significant. The interaction of race and sex was significant. The interaction of all three of the main effects was also significant.

CHAPTER IV

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Introduction

The problem of this investigation had essentially two parts. The first part of the problem was to determine the relationship between achievement in mathematics and achievement in chemistry of students in two senior high schools of a metropolitan school system. The second part of the problem was to determine the comparative effectiveness of two different instructional strategies on the achievement in chemistry of high school students from two different races. One instructional strategy required the use of mathematical skills and concepts to teach selected principles of chemistry. The second instructional strategy required the use of qualitative or non-mathematical explanations to teach the same chemistry principles.

Review of Method and Design

Four intact chemistry classes were used in the study. Two of the classes were in a predominately black senior high school and two classes were in a predominately white senior high school of a metropolitan school system. One hundred fourteen (114) pupils were in the four participating classes and constituted the subjects of the study.

The ACS-NSTA High School Chemistry examination was administered prior to the beginning of the investigation period. A second form of the same examination was administered upon completion of the investigative instructional period. The test results were treated in two different ways to indicate achievement in chemistry. One statistical test utilized the gain scores obtained from raw data. Posttest scores were treated in two other statistical tests. The final semester mathematics marks of each subject in grades nine, ten, eleven, and twelve were gathered from transcripts. These marks were used to calculate an achievement index in mathematics for each subject. Differential-Aptitude-Test scores were used to indicate the average intelligence for each subject. Piaget task equipment and individual interviews were used to determine the stage of logical thought for each of the subjects.

Three statistical treatments were applied to the raw data. First, the Pearson product-moment correlation coefficient ($\underline{r}$) was calculated to test null hypothesis one which was concerned with the relationship between the mathematics achievement indices and posttest scores. The significance of the correlation coefficient was tested at the .05 level of confidence.

Second, null hypotheses 2_a; 3_a; 4_a; 5_a; 6_a; 7_a; and 8_a were tested by a multiple-classification analysis of covariance statistical treatment. Gain scores were used as the criterion variable (y) for achievement in chemistry. The intelligence indices (x_1) and the Piaget task indices (x_2) were used as covariates. The independent variables were instructional strategy (A), race (B), and sex (C). The .05 level of confidence was established as the critical region for finding significant differences.

The third statistical treatment employed the post-test scores as the criterion variable (y) for achievement in chemistry in a multiple classification analysis of covariance test. The intelligence indices (x_2) and the pretest scores (x_2) were used as the covariates. Instructional strategy (A), race (B), and sex (C) were retained as the independent variables. Another set of seven (7) null hypotheses were tested for significant differences at the .05 level of confidence.

The criterion means were adjusted to compensate for initial differences between groups on the covariates. This statistical treatment permitted the investigator to determine how each group would have performed on the criterion variable if they had been equivalent at the outset of the investigation with respect to the intelligence indices and the pretest scores.

Summary of Findings

1. The correlation coefficient between the mathematics achievement indices and the posttest scores, 0.38, was significant at the .05 level of confidence.

2. When the intelligence indices and the Piaget task indices were used as covariates, the following resulted with respect to the .05 level of confidence:

a. No significant differences in gain score measures were found to exist between groups taught by a qualitative strategy and groups taught by a quantitative strategy;

b. No significant differences in gain score measures were found to exist between the groups of subjects from the two different races;

c. No significant differences in gain score measures were found to exist between male and female groups;

d. No significant interaction differences in gain score measures were found to exist between subject groups regarding instructional strategy and race;

e. No significant interaction differences in gain score measures were found to exist between subject groups regarding instructional strategy and sex.

f. No significant interaction differences in gain score measures were found to exist between subject groups regarding race and sex.

g. No significant interaction differences in gain score measures were found to exist between subject groups regarding instructional strategy, race, and sex.

3. When the intelligence indices and the pretest scores were used as covariates and posttest score adjustments were made for initial group differences based on the covariates, the following resulted with respect to the .05 level of confidence:

a. No significant differences were found to exist in posttest scores between groups taught by a qualitative strategy and groups taught by a quantitative strategy;

b. No significant differences in posttest scores were found to exist between subject groups of the two different races;

c. No significant differences in posttest scores were found to exist between male and female groups;

d. No significant interaction differences in posttest scores were found to exist between subject groups regarding instructional strategy and race;

e. No significant interaction differences in posttest scores were found to exist between subject groups regarding instructional strategy and sex;

f. Significant interaction differences in posttest scores were found to exist between subject groups regarding race and sex;

g. Significant interaction differences were found to exist at the .05 level of confidence between student groups regarding instructional strategy, race, and sex.

4. The obtained results for the interaction of race and sex indicated that achievement was related to sex in the black population but was not related to sex in the white population.

5. The obtained results for the interaction of the three main effect variables is described in the following statements:

a. The findings for the qualitative strategy were:

1) White female subjects have a higher achievement than white male subjects;

2) Black male subjects have a higher achievement than black female subjects;

3) White female subjects' achievement was higher than black female subjects' achievement;

4) Black male subjects' achievement was significantly higher than that of white male subjects.

b. The findings for the quantitative strategy were:

1) The achievement of black and white female groups was approximately equal;

2) Black male subjects achieved significantly higher than white male subjects.

c. The findings for white subjects were:

1) Female subjects taught by a qualitative strategy achieved significantly higher than white male subjects taught by the same strategy;

2) White female subjects taught by the quantitative strategy achieved significantly lower than white male subjects taught by the same strategy;

3) White female subjects in the qualitative group achieved significantly higher than female subjects in the quantitative group;

4) Male subjects in the quantitative group achieved significantly higher than male subjects in the qualitative group.

d. The findings for black subjects were:

1) The male subjects' achievement was higher than female subjects' achievement for both the quantitative and qualitative strategies;

2) Black male subjects in the quantitative group achieved at a higher level than black male subjects in the qualitative group.

3) The black female subjects in the qualitative group achieved higher than the black

female subjects in the quantitative group.

e. The findings for male subjects were:

1) Black male subjects achieved higher than white male subjects for both the qualitative and quantitative strategy groups;

2) Black and white subjects in the quantitative group achieved significantly higher than corresponding qualitative groups.

f. The findings for female subjects were:

1) White female subjects in the qualitative group achieved significantly higher than black female subjects in the qualitative group;

2) The achievement for both black and white female subjects was approximately equal for the quantitative strategy groups;

3) Black and white female subjects in the qualitative strategy groups achieved significantly higher than black and white female subjects in the quantitative groups.

Conclusions

From the findings of this study the following conclusions were made:

1. Achievement in mathematics was positively related to achievement in chemistry, therefore, a relatively high achievement in chemistry should be expected generally for subjects who had a high mathematics achievement index. The reverse should be expected generally for subjects with a low mathematics achievement index;
2. An instructional style for chemistry which would employ either of the main variables, strategy, race, or sex, acting independently would apparently be inappropriate for use in the two schools, since neither variable in and of itself was effective in influencing achievement in chemistry;
3. An instructional style for chemistry which would employ the combined effects of the main variables would apparently be inappropriate to use in the two schools when the Piaget task indices and the intelligence indices are covariates since achievement in chemistry was not significantly effected by interactions of the main variables;
4. An instructional style for chemistry which would employ the combined effects of the race and sex variables would apparently be appropriate for use in the two schools when the pretest scores and intelligence indices are covariates since

the combined action of the race and sex variables had a significant effect on the chemistry achievement of the subjects in groups related to these variables; and

5. An instructional style in chemistry which would employ the combined effects of the main variables would apparently be appropriate for use in the two schools when the pretest scores and the intelligence indices are covariates since the combined action of the three main variables had a significant effect on the chemistry achievement of subjects in groups related to these variables.

It was also concluded that the results of the study were significant from a curriculum standpoint because they clearly indicate that the learning experiences in chemistry for high school students should be varied from one group or individual to another based on sex, race, and strategy. It is additionally significant in that some insight has been provided regarding the kinds of experiences which may be the most suitable for the student membership of various groups. For example, black and white male students received the greatest benefit from quantitative learning experiences. Black and white female students obtained the greatest benefit from qualitative learning experiences. Experiences based on the factors sex, race, or strategy, acting separately, will probably not result in an increased achievement in chemistry. The experiences must be designed to include the combined effect of the three factors or to include the combined effect of race and sex.

Recommendations

It is recommended that:

1. Research using a design similar to the one used in the present study be conducted to determine if the main variables, instructional strategy, race, and sex would operate differently with subjects from more affluent socio-economic populations. Both of the high schools participating in the present study were qualified for the Title I compensatory educational program as defined by Public Act #8910 of the Elementary and Secondary Act of 1965;

2. Research be used to identify appropriate ways to increase student achievement in chemistry through greater utilization of their ability to process information logically. The low correlation between the Piaget task index and pretest scores indicate that the students' thought processing abilities are not being used in a significant manner in the existing instructional programs;

3. Research using a design similar to the one used in the present study, but extending over a longer period of time, be conducted to determine the effectiveness of the main variables, acting in combination, on achievement in chemistry;

4. Research similar to this study and using a design which permits an investigator to establish groups of subjects equal with regard to the covariables, intelligence, and Piaget task be conducted to determine the most effective way to increase achievement in chemistry for students in each group. (This study accomplishes group equality through statistical treatment.);

5. Public schools include in the curriculum both quantitative and qualitative instructional strategies used in this study for teaching chemistry so that the more appropriate one may be employed for groups of students with certain learning characteristics;

6. Public schools include instructional programs in chemistry and other science subjects which not only use the students' ability to process information logically, but also facilitate continued growth in this ability;

7. That investigations be made to identify additional instructional strategies for chemistry in which mathematics would be used in a number of different ways so that a teacher would have access to a wide variety of options from which to choose in order to personalize chemistry instruction;

8. The curriculum division of the State Department of Education of Oklahoma take the leadership in developing appropriate instructional programs for chemistry based on

the findings of this and other studies. The State Department can do the following:

a. Secure grants to provide for similar studies;

b. Give assistance in the design of studies so that the results are valid, relevant, and contribute to areas where there is a continuing need for research and evaluation;

c. Provide for the dissemination of the information so that chemistry teachers can become more sensitive to the student need for using logical thought processing abilities more effectively in chemistry classes;

d. Encourage chemistry teachers to employ strategies which seem the most suited for the learning styles of their students;

e. Provide for the dissemination of the information to administrators and counselors at the local level who not only make curricular decisions, but who also make decisions regarding the placement of students in chemistry classes.

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APPENDIX A

Table 21

Raw Data for White Qualitative Group (Male n = 10)

Student No.	Grade	Intelligence Index	Piaget Task Index	Achievement Index--Math	Pretest	Posttest	Dif.
001	12	70	15	6	13	16	3
002	11	45	8	2	0	1	-1
003	11	115	31	15	13	18	5
004	11	45	15	5	2	2	0
005	11	60	26	11	5	4	-1
006	10	40	16	7	8	11	3
007	11	105	13	4	12	17	5
008	11	100	20	6	14	18	4
009	11	75	23	8	15	13	-2
010	11	25	9	5	3	8	5

Table 22

Raw Data for White Qualitative Group (Female n = 9)

Student No.	Grade	Intelligence Index	Piaget Task Index	Achievement Index--Math	Pretest	Posttest	Dif.
011	11	110	14	12	16	20	4
012	10	130	5	15	20	19	-1
013	11	65	14	12	12	17	5
014	11	50	9	11	0	5	5
015	11	115	13	13	15	20	5
016	11	95	19	14	17	24	7
017	11	40	14	9	11	16	5
018	11	95	11	16	19	21	2
019	11	184	14	21	10	23	13

Table 23

Raw Data for Black Qualitative Group (Male n = 5)

Student No.	Grade	Intelligence Index	Piaget Task Index	Achievement Index--Math	Pretest	Posttest	Dif.
020	11	25	17	6	11	12	1
021	11	90	19	11	12	14	-2
022	12	15	25	11	18	22	4
023	11	60	28	23	18	22	4
024	11	30	11	15	11	19	8

Table 24

Raw Data for Black Qualitative Group (Female n = 29)

Student No.	Grade	Intelligence Index	Piaget Task Index	Achievement Index--Math	Pretest	Posttest	Dif.
025	10	110	24	22	17	24	7
026	11	110	17	12	10	19	9
027	11	50	12	8	9	12	3
028	10	130	17	9	16	19	3
029	12	40	12	18	13	21	8
030	11	15	11	11	8	11	3
031	11	30	9	7	0	4	4
032	10	175	13	15	23	24	1
033	11	90	4	13	8	13	5
034	11	95	5	14	13	17	4
035	11	140	11	14	8	14	6
036	11	45	7	19	8	12	4
037	11	23	8	15	2	2	5
038	11	20	15	8	10	14	4

Table 24--Continued

Student No.	Grade	Intelligence Index	Piaget Task Index	Achievement Index--Math	Pretest	Posttest	Dif.
039	11	20	9	13	10	11	1
040	11	15	9	8	8	18	10
041	11	55	8	20	10	12	-2
042	11	60	13	9	13	16	3
043	10	50	8	8	4	3	-1
044	11	90	7	13	8	11	3
045	10	100	20	9	14	14	0
046	10	100	7	10	19	24	5
047	11	110	12	8	11	12	1
048	11	55	14	10	10	13	3
049	11	35	7	4	0	5	5
050	10	140	31	8	16	26	10
051	11	55	14	10	0	8	8
052	10	35	7	9	3	3	0
053	11	35	9	11	9	8	-1

Table 25

Raw Data for White Quantitative Group (Male n = 19)

Student No.	Grade	Intelligence Index	Piaget Task Index	Achievement Index--Math	Pretest	Posttest	Dif.
054	12	25	17	14	10	17	7
055	11	60	14	13	12	15	3
056	12	55	10	11	9	11	2
057	11	80	14	16	20	19	-1
058	12	100	16	17	16	21	5
059	11	60	14	16	16	16	0
060	12	135	22	15	17	19	2
061	11	90	17	5	15	16	1
062	11	25	9	5	6	6	0
063	12	185	31	6	13	13	0
064	11	85	18	8	5	5	-1
065	12	80	15	10	15	13	-2
066	11	135	15	8	17	18	1

Table 25--Continued

Student No.	Grade	Intelligence Index	Piaget Task Index	Achievement Index--Math	Pretest	Posttest	Dif.
067	11	150	26	18	10	16	6
068	12	135	15	13	10	16	6
069	10	125	15	7	18	19	-1
070	11	80	13	10	10	12	2
071	10	130	29	19	22	30	8
072	12	55	17	18	13	17	4

Table 26

Raw Data for White Quantitative Group (Female n = 10)

Student No.	Grade	Intelligence Index	Piaget Task Index	Achievement Index--Math	Pretest	Posttest	Dif.
073	11	40	10	7	8	8	0
074	11	60	14	13	1	2	-1
075	11	115	16	16	3	5	2
076	11	30	10	12	0	0	0
077	11	65	11	10	8	11	3
078	12	60	14	15	11	14	3
079	11	115	18	7	16	29	13
080	12	198	15	24	19	28	7
081	12	80	15	16	9	9	0
082	12	80	12	7	10	10	0

Table 27

Raw Data for Black Quantitative Group (Male n = 19)

Student No.	Grade	Intelligence Index	Piaget Task Index	Achievement Index--Math	Pretest	Posttest	Dif.
083	11	18	28	23	17	24	7
084	11	90	22	20	15	16	-1
085	11	100	12	11	20	32	12
086	11	75	26	17	20	25	5
087	10	70	25	5	16	21	5
088	11	65	13	19	17	24	7
089	10	155	9	11	15	18	3
090	10	125	23	10	22	22	0
091	11	25	6	6	1	3	2
092	11	25	22	10	12	20	8
093	11	80	20	7	9	10	1
094	12	29	9	6	9	9	0
095	11	95	22	11	8	20	12
096	11	65	11	10	8	9	1

Table 27--Continued

Student No.	Grade	Intelligence Index	Piaget Task Index	Achievement Index--Math	Pretest	Posttest	Dif.
097	11	85	17	21	13	19	6
098	10	165	20	10	29	31	2
099	11	60	16	13	8	11	-3
100	11	50	27	8	0	1	1
101	11	75	11	19	16	18	2

Table 28

Raw Data for Black Quantitative Group (Female n = 13)

Student No.	Grade	Intelligence Index	Piaget Task Index	Achievement Index--Math	Pretest	Posttest	Dif.
102	11	50	7	16	8	16	8
103	10	120	19	10	18	19	-1
104	11	45	21	12	3	6	3
105	11	95	20	15	10	14	4
106	10	35	22	11	13	12	-1
107	11	20	12	7	2	5	3
108	12	75	13	9	13	14	1
109	11	70	13	4	9	11	2
110	10	65	10	12	9	14	5
111	11	35	6	14	12	11	-1
112	11	100	5	16	2	6	4
113	11	25	7	9	8	9	1
114	10	105	18	12	8	14	6

APPENDIX B

APPENDIX B

Description of equipment and interview to be employed by the investigator in determining the stage of logical thought processes for each subject is contained in Appendix B.

Conservation of quantity. The subject is presented two balls of clay. The examiner asks the individual to make the two balls of clay exactly alike. Each ball must be just as big and just as heavy as the other. The examiner then flattens one ball or rolls it into a sausage shape and asks if there is still the same amount of clay in each piece. He also asks if each piece of clay would, when placed in a container of water, make the water rise to the same level.

Conservation of volume. The subject is presented two graduated cylinders filled with water to the same level and two metal rods of the same size and volume but of different weights. He is asked if one of the metal sections would make the water rise to a higher level when placed in a graduated cylinder than would the other. He is asked to place the heavier rod in the water and to predict how high the lighter rod would make the water rise. If he predicts incorrectly, he is asked to explain why the rods, having unequal weight but equal size both make the water rise to the same level.

Reciprocal implications. The subject is presented an apparatus similar to a billiard table. He is asked to hit targets with a marble impelled by a plunger apparatus. He must hit the target by rebounding the marble off one side of the table. The investigator moves the target to various places on the table to see if the individual can deduce that the angle of incidence equals the angle of reflection, or if he works only by trial and error. He is asked to make a diagram of the path the marble must take to hit a target, and if he can state a rule governing its behavior.

Separation of variables. The subject is presented an array of metal rods secured to a base in such a way that their length can be varied. The rods are of differing thickness, material, and shape. The individual is given a supply of different masses to place at the ends of the rods to test their flexibility. He is asked to enumerate the variables involved and to determine which variables have an effect on the flexibility of a metal rod.

Operations of exclusion. The apparatus consists of a pendulum constructed in such a way that the length of the string and weight of the bob can be varied. Other variables are the height of release and impetus imparted at the time of release. The subject is asked to determine which variable or variables determine the frequency of oscillation of the pendulum. He must exclude all variables except length of string, which is the determining factor.

Elimination of contradictions. The subject is presented a tub of water and an array of objects. Some of the objects float and some of them sink when placed in water. The subject is asked to predict which of the objects will float and which objects will sink. He is then asked to state a rule governing this phenomenon. The objects are then placed in the water. The subject is asked to explain any deviations from his predictions. His attention is called to two of the objects. One object is large, relatively light, and resting on the bottom. He is asked to explain this apparent contradiction.

Instrument for Recording Piaget Task Performance

Student's Name____________________No.__________A - B

School____

Conservation of Quantity:

1. Does the student conserve quantity with a change in form? ______________________________

2. Does the student conserve volume when asked if each piece of clay, when placed in a container of water, will make the water rise to the same level? ______________________________

Conservation of Volume:

1. Does the student predict correctly what happens to water level in the cylinder when the position of the metal rod is changed? ________________

Reciprocal Implications:

Stage

______IIa Subject displays internalized action integrated with other action to form general reversible systems. Subject recognizes some angular motion;

______IIb Subject formulates relations existing between inclination of plunger and that of the line of reflection;

______IIIa Subject expresses equivalence of angles of inclination and reflection;

______IIIb Subject expresses generality of hypothesis as well as its necessary equivalency.

Elimination of Contradiction:

______IIa Subject uses multiple explanations and classifies based on his own criteria;

______IIb Subject exhibits preliminary relating of weight to volume;

______IIIa Subject hypothesizes but does not verify; Subject exhibits ideas of proportionality;

______IIIb Subject relates weight of object to weight of equivalent volume of water and expresses confidence in generality of law.

Separation of Variables:

______IIa The subject is capable of differentiated classification, serial ordering and correspondences but can not separate out the experimentally relevant variables.

______IIb Subject exhibits ability to use multiplications between asymmetrical relations but is still unable to verify the action of one factor by leaving all the other known factors constant.

______IIIa Subject, from the beginning, formulates an hypothesis and attempts to verify it.

______IIIb Subject organizes a systematic proof conforming to the schema "all other things being equal" for all of the relevant factors.

Operation of Exclusion:

______IIa Subject is able to order serially and to use correspondences but is not able to separate variables;

______IIb Subject accurately orders the effect of weight but still cannot separate variables;

______IIIa Subject uses searching behavior but is unable to focus search on a single point or factor which he wishes to analyze; the subject lacks exclusion;

______IIIb Subject is able to isolate all of the variables present by the method of varying a single factor while holding "all other things equal"; Subject excludes the three factors which do not play a causal role.

APPENDIX C

APPENDIX C

The Instructional Strategies

The study required the teachers to employ two different instructional strategies for teaching selected processes and concepts of chemistry. One strategy (quantitative) involved student use of mathematics to attain objectives. The other strategy (qualitative) required the use of non-mathematical descriptions presented by the teacher to help students attain the objectives. One intact chemistry class in each of the two participating schools was taught by the quantitative strategy. A second intact chemistry class in each of the two schools was taught by the qualitative strategy. Both strategies were taught by the same teacher in each school. Both strategies were developed by the two teachers and the investigator.

As previously indicated, both the quantitative and the qualitative strategies were designed to teach the same chemistry processes and concepts. But the two strategies were different in several essential aspects:

1) Students in the quantitative strategy groups worked selected exercises in a programmed mathematics instructional booklet, Arithmetic for

Science Students (Young, 1968). Students in the qualitative strategy groups did not work the selected mathematics exercises;

2) Students in the quantitative strategy groups were taught mathematical concepts in addition to those presented in the instructional booklets. Students in the qualitative strategy groups did not receive the described mathematical instruction;

3) Students in the quantitative strategy groups did investigations and used mathematics to make all calculations needed for preparing solutions and interpreting experimental results. Students in the qualitative groups performed non-mathematical investigations and observed teacher demonstrations to develop non-mathematical interpretations of phenomena;

4) Students in the quantitative strategy groups were involved in class discussions of their investigations and the related mathematical calculations. Students in the qualitative groups conducted class discussions of demonstrations and investigations using non-mathematical interpretations.

Table 29 includes the behavioral objectives, mathematics concepts, chemistry concepts, and learning activities for both strategies. The laboratory investigations were found in the students' laboratory manual of the text materials. Some of the mathematics exercises were adapted from an article on quantitative principles in general chemistry by Taylor (1959).

Table 29

Behavioral Objectives, Mathematics Concepts, Chemistry Concepts, and Learning Activities

Behavioral Objectives: The pupil will make accurate measurements in chemistry.

The pupil will determine the (quantitative) properties of various materials.

Concepts and Skills Mathematics	Concepts and Skills Chemistry	Chem. Inv.	Math.* Exer.	Strategies Quantitative	Strategies Qualitative
The metric system	Observations and interpretations	#2	1	#2 and #4	#2 and #4
Labeling numbers				Subjects do as written	Subjects do as written
	a. Measurements in chemistry	#4			
	b. The properties of matter				

Behavioral Objective: The pupil will make chemical calculations using very large and very small numbers, exponentials, and the concepts of significant numbers.

Concepts and Skills Mathematics	Concepts and Skills Chemistry	Chem. Inv.	Math.* Exer.	Strategies Quantitative	Strategies Qualitative
An introduction to exponentials and significant numbers	Chemical calculations	#7	2	#7 and #10	#7 and #10
	a. The mole concept	#10		Subjects do as written. Use mathematics in class discussion.	Teachers demonstrate reactions. Use non-mathematical description in lectures.
	b. Avogadro's concept				
	c. Chemical calculations using very large and very small numbers				
	d. Gases				
	e. Solutions				

Table 29--Continued

Behavioral Objectives: The students will make chemical calculations using the one-constant linear relationship and the concept of the slope.

The students will make chemical calculations using the two-constant linear relationship and the concept of the slope.

Concepts and Skills Mathematics	Concepts and Skills Chemistry	Chem. Inv.	Math.* Exer.	Strategies Quantitative	Strategies Qualitative
One-constant linear relationships and slopes Two-constant linear relationships and slopes	Investigating chem. reactions a. Weight of starting materials (chemical reactions) b. Yield c. Equivalent weights d. Charles-Gay Lussac's Law e. Law of Definite proportions f. Law of multiple proportions g. The concept of absolute zero h. The molecular weight of soluble solids i. Reaction rates j. Relationship between the Fahrenheit and Centigrade temperature scales k. Heats of reactions l. Oxidation-reduction m. Reaction of ions in solution	#16 #17 #18 #19 #20 #21 #22 #23	3 4 5	#16, #17, #18, and #23. Subjects do as written. Use mathematics in class discussions. #19, #20, #21, and #22. Subjects do as written	#16, #17, #18, and #23. Teachers demonstrate reactions and use non-mathematical description in lectures. #19, #20, #21, and #22. Subjects do as written

*Quantitative groups only

Table 29--Continued

Behavioral Objective: The pupil will make chemical calculations using the inverse linear relationship.

Concepts and Skills Mathematics	Concepts and Skills Chemistry	Chem. Inv.	Math.* Exer.	Strategies Quantitative	Strategies Qualitative
Inverse Linear Relationships	Dulong and Petit Law	#25	6 7	#25 Subjects do as written. Use mathematics in class discussion.	Teacher demonstrates reactions and use non-mathematical descriptions in lectures
	Variation of freezing point with concentration				
	Boyle's Law equation				
	Chemical Bonding				

*Quantitative groups only