1988

Effect of Cooperative Grouping on Stoichiometric Problem-Solving in High School Chemistry.

Joy Bridges Tingle
Louisiana State University and Agricultural & Mechanical College

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Effect of cooperative grouping on stoichiometric problem solving in high school chemistry

Tingle, Joy Bridges, Ph.D.
The Louisiana State University and Agricultural and Mechanical Col., 1988

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UMI
EFFECT OF COOPERATIVE GROUPING ON
STOICHIOMETRIC PROBLEM SOLVING IN
HIGH SCHOOL CHEMISTRY

A Dissertation

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy

in

Department of Curriculum and Instruction

by

Joy Bridges Tingle
B.S., Louisiana State University, 1964
M.N.S., Louisiana State University, 1974
May 1988
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Effects of Cooperative Grouping on Stoichiometric Problem Solving in High School Chemistry

Abstract
Joy Bridges Tingle
Louisiana State University
May 1988
Major Professor: Ron Good

A study of stoichiometric problem solving in chemistry was conducted in three high schools in a rural school district. Students (n = 178) in grades 10-12 solved problems individually or in cooperative groups using a prescriptive problem-solving strategy. This strategy consisted of a statement of the problem, redescription that included not only extraction of the stated and implied information but picture description, prediction, mathematical solution, and check.

The main purpose of the study was to determine empirically whether there was a difference in achievement between students solving problems individually and in cooperative groups. The cooperative groups were heterogeneously based upon proportional reasoning ability as determined by the results of the 2-item proportional reasoning subtest composing the Test of Logical Thinking (TOLT) developed by Tobin and Capie (1981). Secondary questions included (1): the relationship of math stanines, age, sex, and proportional
reasoning ability; (2) attitude differences; (3) characteristics of successful and unsuccessful students problem solving individually and in groups as determined through videotape analyses, classroom observations, and students' written work.

There was no statistically significant difference in performance between regular or honors students of varying proportional reasoning ability solving stoichiometric problems individually or in cooperative groups (p<.05). The prescriptive method was the common factor throughout the study suggesting that it may be a strategy that will enable the gap between the performance of nonproportional reasoners and proportional reasoners to decrease on stoichiometric problems.

No statistically significant attitude differences were found. It should be noted that students were undecided as to how they felt about chemistry before initiating problem solving and they did not form negative attitudes after seven weeks of problem solving. Verbal and written comments indicated that students enjoyed problem solving in groups.

Successful problem solvers, both those in groups and those who solved problems individually, were characterized by confidence and persistence and exhibited a strong conceptual base. Most successful students used the prescriptive method, organizing their problems into steps, sketching pictures, and
making predictions. Successful groups interacted well, assuming responsibility for each other's learning.
CHAPTER 1
INTRODUCTION

During the last decade, problem-solving research has increased greatly primarily due to the emergence of cognitive science. Linn (in press) has stressed the importance of problem-solving research by referring to problem solving as one of the new basics. Furthermore, Lawson (1979) has suggested that one of the major goals of education should be the development of reasoning strategies. In order to address this goal, curriculum developers must depend upon the research efforts of both cognitive scientists and Piagetian researchers in order to identify the specific features of instruction that foster problem solving and the characteristics of learners likely to profit from it.

Initially problem-solving research was domain-independent, resulting in a limited amount of problem-solving research in chemistry. However in the last few years there has been increasing interaction between cognitive scientists and mathematics and science educators. The resulting chemistry research has focused on the identification of problem-solving behaviors of chemistry students (Anamuah-Mensah, 1986; Camacho & Good, 1986; Frank & Herron, 1987; Gorodetsky & Hoz, 1980; Greenbowe, 1983; Nurrenbern, 1979) and teaching strategies that can be used to enhance the

Recent research suggests that success in chemistry problem solving is dependent upon students' proportional reasoning abilities (Bender & Milakofsky, 1982; Gabel & Sherwood, 1983; Gabel, Sherwood, & Enochs, 1984; Herron, 1978; Krajcik & Haney, 1987). Furthermore, experimental evidence has shown that a significant number of college freshman have not attained that level of thought (McKinnon & Renner, 1971; Ward & Herron, 1980; Wheeler & Kass, 1977).

In order to address the proportional reasoning issue, the present study is designed to facilitate formal thought by coupling research on the prescriptive model proposed by Bunce (Bunce & Heikkinen, 1986), Gabel (in press), and Heller and Reif (1984) with cooperative grouping strategies proposed by researchers such as Johnson and Johnson (1987) and Slavin (1980).
PURPOSE OF THE STUDY

The purpose of this study is:

To determine the effect that cooperative groups, heterogeneously based on proportional reasoning ability, have on stoichiometric problem solving in regular and honors high school chemistry.

The following secondary questions will also be addressed:

1. What intercorrelations exist among such variables as mathematical aptitude, age, sex, and proportional reasoning ability?

2. Are attitude differences noted between students of different proportional reasoning abilities assigned to regular or honors classes who solve problems individually or in cooperative groups?

3. Are there differences in the characteristics exhibited by students of different proportional reasoning abilities while problem solving in cooperative groups when compared to problem solving individually?

Chapter III shows how these research questions may be answered.
SIGNIFICANCE OF THE STUDY

Cooperative grouping is not a new idea, but is a strategy that has been neglected for the past 50 years. Recent research has shown that if student-student interdependence is structured carefully and appropriately, students will value more the subject area being studied, achieve at a higher level, and use higher-level reasoning strategies more frequently (Johnson & Johnson, 1987). In addition, students participating in cooperative grouping are characterized by higher levels of motivation, more positive interpersonal relationships, and higher self-esteem.

The importance of cooperative grouping goes beyond increasing achievement and fostering positive attitudes toward subject areas. Cooperative interaction with other people is essential in building and maintaining a career, family, and community life. Schools, however, have promoted the student individually and competitively. Peer relationships have been limited for the most part to extracurricular activities. The implementation of cooperative grouping provides an opportunity to teach those necessary cooperative skills within the curriculum.

Cooperative learning may also aid in making students better thinkers and problem solvers. Many studies have shown that success in chemistry problem solving is dependent upon
students' proportional reasoning abilities (Bender & Milakofsky, 1982; Gabel & Sherwood, 1983; Gabel, Sherwood, & Enochs, 1984; Herron, 1978; Krajcik & Haney, 1987). Piaget (1964) believed that there are four main factors which are necessary for the development of mental structures: (a) maturation, (b) experience, (c) social transmission, and (d) equilibration. The mental structures referred to by Piaget include proportional reasoning. Gabel (in press) has stated that changes in students' proportional reasoning abilities are difficult if not impossible to achieve. In addition, Wheeler and Kass (1977) found that instruction in proportional reasoning ability in chemistry did not appear to enhance general proportional reasoning. Phillips (1978), however, suggests that small group interaction allows for sharing of reasoning stemming from different operational levels providing an avenue for social transmission. Kurtz and Karplus (1979) also showed that it is possible to advance the use of proportional reasoning of many secondary school students by means of a well-designed teaching program as well as student-student interaction with manipulatives. Since cooperative learning is characterized by student-student interaction in small groups, this strategy may provide an opportunity to evoke change in proportional reasoning.
RATIONALE OF THE STUDY

Reif (1984) has pointed to the methodology used by teachers in problem solving as being neither very effective nor efficient. Usually teachers provide examples of problem solutions followed by students spending time practicing related problems. Teachers do not usually question a methodology that results in students doing well with textbook problems. For a majority of teachers the textbook serves as the curriculum guide as well as a prescribed methodology. Since most texts provide models of problems with similar end-of-the chapter problems, that is what students experience.

Most introductory science courses emphasize the ability to recall information and to use it as directed in solving problems (Fasching & Erickson, 1985). Most of the problems merely require students to plug numbers into formulas and perform calculations. Too often the emphasis in problem solving has been on the right answer rather than the process involved in obtaining the answer. Frequently students can not apply the laws and formulas to interpret actual physical events (Resnick, 1983).

Evidence points to successful problem-solving skills requiring a substantial amount of qualitative reasoning (Camacho & Good, 1986; Greenbowe, 1983; Nurrenbern, 1979).
Heller and Reif (1984) found that many students, after formal instruction and receiving good grades in a recent course, could not generate a correct description of fairly routine problems and thus failed to solve them properly. With the emphasis on plugging numbers into a formula to obtain a right answer without the strategic reasoning, problem-solving skills will not improve.

Polya (1945) proposed a general heuristics approach as a way to improve students' problem-solving ability. Polya suggested that if students spent time understanding the problem, devising a plan, and then looking back over their work, they would become better problem solvers. Gagne (1980) supports the position that problem-solving strategies should be explicitly taught stating that there is no advantage for learners to discover strategies rather than being taught them directly. Conflicting evidence exists in studies with chemistry students and the use of heuristics similar to those of Polya. In a study by Bunce and Heikkinen (1986), college students were required to use a specially-designed worksheet that included a statement of the problem in words, a sketch, mathematical solution, and review. The results showed no significant differences in achievement for students who used the worksheets; however there were limitations to this study. Students found these worksheets too time-consuming and no
extra time was provided on tests to use this method. Students resorted to the factor-label method which they found easier and which produced satisfactory results. Another study conducted by Frank and Herron (1987) was similar in nature to the Bunce and Heikkinen study but they found some improvement in student achievement using their heuristics consisting of planning the problem, solving it, and then reviewing it.

At the 1987 National Science Teachers Association Convention, Dorothy Gabel stated that the factor-label method found in most chemistry and physics textbooks had done more to promote rote learning than any other method utilized to teach problem solving. She indicated that most students follow that method without any understanding as to why they do it and why it works. A study of the factor-label method in solving mole problems in chemistry resulted in similar findings (Larkin & Rainard, 1984). Gabel advocated a problem redescription strategy which incorporates a factor-label approach as only one component of problem solving. Reif and Heller (1984) found that the prescriptive model used in their study which included both qualitative and quantitative descriptions concluding with an assessment was sufficient to generate excellent problem descriptions and markedly improved subsequent problem solutions.
In addition to the prescriptive models of Gabel, Bunce, Reif and Heller, qualitative redescription can also be enhanced by the encouragement of continual checks throughout the problem-solving process. The process of prediction involves continuous backward checks toward what is already known and forward checks toward what is likely to happen (Good, 1987). Smith and Good (1984) found that experts in classical genetics made checks often during the problem-solving process. In order to make a prediction, students must focus their attention on relevant concepts and problem-solving strategies. Since prediction is used early in the problem-solving process, it carries with it a degree of personal commitment to find out if it is correct thus necessitating continual checks throughout the problem-solving process (Good, 1987).

Since problem-solving is a process and not a product, the class lecture technique is an ineffective means of teaching this skill (Heller & Reif, 1984). Unfortunately, Project Synthesis (Harms & Yager, 1981) reports that the lecture/discussion is the predominate technique used in the science classroom. Often this technique presents just the information the students are to memorize for recall value only. It also is characterized by students working alone or competitively. Cooperative grouping provides another avenue for teaching problem solving. In both educational and work
settings, peers have a strong influence on productivity. Greater achievement is typically found in cooperative situations rather than in situations where individuals work alone (Johnson, Maruyama, Johnson, Nelson, & Skon, 1981). Cooperative grouping coupled with problem redescription offer the opportunity for student discussion thus enabling them to view problems from a variety of perspectives.

**SUMMARY**

This chapter introduced a proposed strategy designed to increase proportional reasoning ability through the use of prescriptive heuristics in a cooperative learning environment. The significance of the study is discussed in terms of cooperative learning as not only a means for increasing achievement through the development of reasoning skills but in terms of the affective domain of the learner. The rationale focuses on current methodology that has resulted in diminished problem-solving skills citing viable alternative strategies derived from cognitive science and Piagetian research.
CHAPTER II
REVIEW OF THE LITERATURE

This review will describe and analyze literature related to four main aspects of the study: (a) Piagetian research pertaining specifically to proportional reasoning, (b) problem solving generally, (c) chemistry problem solving specifically, and (d) cooperative grouping. Studies will be cited that attempt to link these research areas together.

Piagetian-Based Research

Piaget found that children progress through various stages of mental development and that these stages cannot be circumvented. Children must go through a period of physical manipulation of objects before they can think abstractly. Piaget identified this period of manipulation as concrete operational and the period of abstract thinking as formal operational. Many secondary school students exhibit characteristics of both stages and are referred to as being transitional (Shayer & Adey, 1981). Piaget has stated that the formal operational stage begins to develop between the ages of 11 and 12 years and is completed by the ages of 14 or 15 years.

Research studies have conflicted with Piaget's conclusions. Chiappetta (1976) reviewed Piagetian studies that assessed cognitive levels of secondary students and concluded that the
majority of adolescents in the United States function at the concrete operational level and not at the formal operational level in understanding science content. In a large study in schools of England and Wales (n=12,000), Shayer and Adey found that only 30% of the students who were 16 years old had reached the formal operational stage.

Piagetian developmental stages of thought have been operationally defined in terms of certain reasoning patterns such as proportional reasoning. Karplus, Pulos, and Stage (1983) have defined proportional reasoning as "a term that denotes reasoning in a system of two variables between which there exists a linear functional relationship" which "leads to conclusions about a situation or phenomenon that can be characterized by a constant ratio" (p. 219). A child who makes inferences from data under conditions of a constant ratio equal to a small whole number but is unable to make inferences when the ratio is not equal to a small whole number exhibits reasoning patterns applied at a concrete level as opposed to a formal level of thought. Many studies have revealed that a large fraction of secondary school students do not use proportions successfully to solve simple constant ratio tasks (Kurtz & Karplus, 1979).

Introductory chemistry courses at both secondary and college levels contain many highly conceptual and quantitative
topics requiring students to function at a formal operational level in order to attain comprehension (Goodstein & Howe, 1978; Williams, Turner, Debreulli, Fast, & Berestiansky, 1979). Furthermore, the ability of formal operational students to solve problems involving proportional reasoning appears to be a major factor contributing to the success formal operational students have in chemistry (Krajcik, 1982). A recent study identified test items on a version of the American Chemical Society-National Science Teachers Association High School Chemistry Achievement Examination (ACS exam) that discriminated between formal and nonformal operational students and explored the reasoning patterns required by these items (Krajcik & Haney, 1987). It was found that over 50% of the discriminating test items in the analysis involved the use of proportional reasoning. Since the ACS exam is the best single predictor of the college chemistry grade (Sieveking & Savitsky, 1969), proportional reasoning is essential for student success.

Many researchers have emphasized the need to develop and implement strategies to assist students in moving toward more logical thought. For example, problems involving formal reasoning are grasped more easily when they are initially presented at a concrete level (Kavanaugh & Moomaw, 1981). Thus carefully planned instructional strategies which are
based on a knowledge of the differences in concrete and formal thought processes may produce improvements in instruction which can narrow the gap between the achievement of formal operational students and concrete operational students (Cantu & Herron, 1978).

A review of research on formal reasoning and science teaching (Lawson, 1985) demonstrated that Piagetian research as well as that which has sprung from it, has provided an important background from which to build instructional programs that can assist in helping students to think well. Interest in training studies has not been in accelerating intellectual development, but in discovering whether some sort of educational intervention can be of value, focusing on the key issues of generalizability and retention. The extent to which the training transfers to novel tasks and novel aspects of reasoning depends upon the length and diversity of training experiences and the extent to which students are confronted with thought provoking situations and placed in control of their own actions. These implications of the Lawson review suggested that courses in many disciplines need to become directly concerned with the development of formal reasoning.
Problem Solving

Prior to the 1950's, Gestalt theorists whose philosophy was based upon the mind being shaped by a set of underlying categories or hypotheses believed that understanding the problem as a whole was essential for successful problem solving (Heller & Hungate, 1985). They were interested in sudden insights during problem solving and saw problem solving requiring the integration of previously learned responses in novel ways.

The predominant theory, however, pervading problem-solving research during the first half of the twentieth century was behaviorism initiated by J. B. Watson and perpetuated by psychologists such as B. F. Skinner and E. L. Thorndike (Gardner, 1985). The behaviorists concerned themselves more with general connections between actions performed by the problem solver and conditions under which actions were performed. The emphasis was on a more general domain-independent problem-solving approach.

Jean Piaget's human cognitive developmental research as well as Gestalt psychology kept the "cognitive flame" alive during the period of behaviorism (Gardner, 1985, p. 118). With the advent of computers in the 1950's and the work of such men as George Miller and Jerome Bruner, cognitive science emerged as a creditable field resulting in a new emphasis on
problem solving. Gardner (1985) defines cognitive science as follows:

"A contemporary, empirically based effort to answer long-standing epistemological questions—particularly those concerned with the nature of knowledge, its components, its sources, its development, and its deployment." (p. 6)

Schoenfeld (1985) suggests that the central issues in cognitive psychology can be represented in the following questions:

1. "What is the nature of the knowledge that individuals have at their disposal?"
2. "How is such knowledge organized and accessed for use?" (p. 46)

Initially problem-solving research in cognitive science dealt with well-structured, puzzle-like problems searching for answers to these questions. Recently, however, cognitive psychologists as well as mathematics and science educators have become interested in how the learner thinks in subject areas in which success is dependent on domain-specific knowledge and problem-solving skills (Mayer, 1985; Schoenfeld, 1985).

Since many studies have indicated that successful problem solving requires a substantial amount of qualitative reasoning
consideration must be given to the learner's prior knowledge as well as the learner's reasoning strategies. Reasoning strategies are essential to problem solving (Linn, in press). These strategies enable problem solvers to generate orderly relationships out of their experiences thus generating more meaningful knowledge, (Lawson, 1979). Domain-specific knowledge and reasoning strategies are complimentary; however, possession of one does not ensure that the other is present. Camacho and Good (1986) found that simply having more knowledge did not ensure success when solving chemical equilibrium problems, although greater understanding does increase problem-solving ability.

Domain-specific knowledge, sometimes referred to as declarative knowledge or verbal knowledge (Gagne, 1980), consists of organized principles, concepts, and formulas. Studies of experts solving problems conducted by Heller and Reif (1984) have suggested that knowledge is hierarchically organized, arranged on different levels of detail. In another study conducted by Smith and Good (1984), the problem-solving skills of experts and novices were analyzed as they were asked to think aloud while solving standard textbook problems in genetics. They also found that experts' content knowledge was more hierarchically arranged basing this
finding on the initial amount of time spent with qualitative descriptions.

Chi, Feltovich and Glaser (1981) as well as a later study by de Jong and Ferguson-Hessler (1986) suggested that knowledge is organized by problem types. Once the learner realizes the type of problem from the description, declarative and procedural knowledge needed becomes available. In a study conducted by Chi and others involving expert physicists and novice physics students asked to sort mechanics problems, results indicated that novices sorted problems based on physical objects such as pulleys and inclined planes while experts sorted on the basis of physics principles that were applicable to the problems but were not mentioned in the problem statements. In the de Jong and Ferguson-Hessler study, it was suggested that within problem types, the knowledge is hierarchically arranged.

The problem-solving process involves procedural knowledge or as Gagne refers to it as intellectual skills, knowing how to solve the problem. In studying the problem-solving process, many studies have been conducted to identify differences between successful and unsuccessful problem solvers. Simon and Simon (Heller & Hungate, 1985) analyzed differences between expert and novices as they solved kinematics problems in physics. They found that experts seemed to solve
problems automatically as they worked from the given information to the unknown, while novices worked backwards. Also the novice's approach was algebraic, going straight to a formula to plug in numbers for a solution. The expert's initial approach involved a qualitative description involving a deeper understanding of the domain-specific knowledge that Simon and Simon call "physical intuition" (p. 86). The results of the Smith and Good study (1984) concurred with the Simon and Simon study. In addition, they found that among the strategies used by the experts was a series of checks on the correctness of the solution.

Larkin (Heller & Hungate, 1985) observed physicists solving complex problems in mechanics. This study revealed detailed qualitative descriptions used by the experts initially in solving problems before any equations were generated. First the experts drew sketches representing the physical situation described in the problem and then drew more abstract diagrams representing the problem in terms of concepts from their knowledge of physics. Also during the qualitative phase, experts explored alternative ways to solve the problem at a very general level. The writing of an equation signaled the selection of the approach to be used and the end of the qualitative phase. Novices tended not to understand or perceive problems in terms of fundamental principles and thus
did not construct problem representations that were helpful in obtaining solutions.

Experts acquire their knowledge and develop problem-solving strategies through years of experience. Thus it is highly improbable that novices can be quickly taught to be experts; however a more realistic goal may be "expert novice" performance (Heller & Hungate, 1985, p. 90). A novice at this point would be able to solve problems, but not necessarily by the same processes as the experts. Identifying effective problem-solving processes to teach students is referred to as prescriptive. Heller and Reif (1984) formulated and tested a prescriptive model of effective human problem-solving in the area of mechanics in physics. According to their model, the initial description was in two parts: (a) the basic description that summarized the given information in the problem unknown as well as a diagram or picture and (b) the theoretical description expressed in terms of specific concepts and principles. The prescriptive model specified the exact steps applied to generate the theoretical description. The study was designed to induce novices to generate theoretical descriptions by being placed under external control by the use of detailed step-by-step directions. They found that these learners were not only able to generate explicit and correct descriptions of the motion and interaction of systems in
mechanics problems but also that these descriptions facilitated subsequent construction of correct problem solutions.

Chemistry Problem Solving

Proportional reasoning at the formal operational level is related to students' success in learning chemistry and experimental evidence suggests that a significant number of college freshmen have not attained that level of thought (McKinnon & Renner, 1971; Ward & Herron, 1980; Wheeler & Kass, 1977). In a study (n=276-359) conducted in Australia with high school chemistry students (Chandran, Treagust, & Tobin, 1987), prior knowledge in chemistry and formal reasoning ability were found to be significantly related to chemistry achievement.

In a study of introductory college chemistry students (n=225), proportional reasoning skills were found to have the strongest relationship to performance in both lecture and laboratory classes (Bender & Milakofsky, 1982). Since proportional reasoning plays an important role in metric conversions, mole concepts, and stoichiometry, students weak in this area will encounter difficulties. High school students (n=266) in still another study tended to solve problems involving the mole concept, gas laws, stoichiometry, and molarity relying strictly on algorithmic methods and did not
understand the chemical concepts on which the problems were based (Gabel, Sherwood, & Enochs, 1984). Greenbowe (1983) found that unsuccessful problem solvers focused on an inaccurately balanced equation and used an algorithm, factor-label method, to generate an incorrect answer. Even the students in high-ability classes in high school resorted to using a formula rather than a proportional approach (Anamuah-Mensah, 1986; Gabel & Sherwood, 1983). Students who can use formal operational reasoning patterns are capable of a greater degree of achievement in high school chemistry than students who cannot use these reasoning patterns (Anamuah-Mensah, Erickson, & Gaskell, 1987). Strategies for developing reasoning skills are needed for both concrete and formal operational thinkers if these students are to be successful in chemistry problem solving.

Cooperative Grouping

Different teaching methodologies are needed for those students who have difficulty reasoning at a formal level. Research has shown that students who participate in whole class settings tend to be high formal thinkers (Chandran et al., 1987). It is suggested that in order to cater to the needs of students who are not functioning at a formal operational level, provision should be made for small group work so that all students have an equal opportunity to participate. In addition,
verbalization has the effect of making students think of new ways to view problems and facilitates both the discovery of general principles and their employment in solving successive problems (Gagne & Smith, 1962). In two recent studies with introductory college chemistry students, achievement increased with the group discussion approach (Fasching & Erickson, 1985; Frank & Herron, 1987). Placing students in control of their own actions and in thought provoking situations increases the probability of formal reasoning development (Lawson, 1985).

Johnson and Johnson (1983) demonstrated that a particular type of grouping, cooperative learning, promotes the use of higher reasoning strategies and greater critical thinking competencies. Their work is based upon a theory of cooperation applied to the functioning of small groups proposed by Morton Deutsch. Deutsch's early studies (1949) examined the effects of cooperation and competition upon the group process.

In cooperative learning groups, the membership is typically heterogeneous in ability and personal characteristics with all members sharing responsibility for each other's learning (Johnson, Johnson, Holubec, & Roy, 1984). The key feature that distinguishes cooperative grouping from other learning environments is the interactions among students (Webb, 1982).
A meta-analysis of 122 studies of the effects of cooperative, competitive, and individualistic goal structures on achievement suggests that cooperative grouping is more effective than interpersonal competitive and individualistic efforts (Johnson, Maruyama, Johnson, Nelson, & Skon (1981). With the addition of a required group product the positive effect of the cooperative grouping increases.

A review by Webb (1982) focused on the interaction processes occurring within small groups and their relationship among achievement, cognitive process, and reward structure. Examination of these studies suggested that student ability and reward structure had the most consistent relationship with student interaction. Specifically, helping behavior exhibited by students correlated positively to achievement and this helping behavior was characteristic of heterogeneous ability groups. Rewarding students for the achievement of others in addition to their own achievement promoted cooperation among students and attention to task. In addition, rewarding for achievement of all group members promoted helping behavior.

In a review of 28 primary field projects lasting at least two weeks in which cooperative learning methods were used in elementary or secondary classrooms, the pattern of findings supported the utility of cooperative learning methods in
general for increasing student achievement (Slavin, 1980). The major implications from this review suggest that for high level cognitive learning outcomes, such as identifying concepts and analyzing problems, less structured cooperative techniques that involve high student autonomy and participation in decision-making may be more effective than traditional individualistic techniques. Kurtz and Karplus (1979) also suggested that students be given more autonomy thus more opportunity to look at relations from their own point of view, to raise questions and to seek answers to these questions in their own way. They recommended that provision for this autonomy be in small groups where motivation was higher than when students worked on an individual basis.

Sharan (1980) examined various team-learning methods based upon cooperative learning. He also reported superior performance academically for students working in small groups as compared to those in traditional classrooms; however he stated that these gains were not consistent for all student groups. As an example, Sharan cites one study using a team-learning method referred to as Jigsaw resulting in gains for minority children but not white children.

Reif (1984) has pointed to the methodology used by teachers in problem solving, modeling examples of problem solutions followed by students practicing related problems, as
being neither very efficient nor effective. Current estimates indicate that over 85% of instruction within schools involves lectures, individual seatwork, or competition where students are isolated from one another, "forbidden to interact", and "pitted against each other" (Johnson & Johnson, 1983, p. 125). Whereas cooperation and the importance of peer relationships for constructive socialization and cognitive development have been largely ignored in our society, research has shown peer cooperative group interaction can positively affect students' achievement (Johnson & Johnson, 1983). This is substantiated in a study conducted by Johnson (1986) examining the use of cooperative learning to improve problem-solving skills in mathematics at the elementary grade levels. At the individual student level, groups of four containing elements of peer tutoring and group investigation, students scored significantly higher on a postachievement test than the control not utilizing the grouping strategy.

Most studies of group interaction in science, however, have focused on the laboratory environment. Cooperative, competitive, and individual science laboratory interaction patterns and their effects on student achievement have suggested that cooperative laboratory work with heterogeneous ability grouping improves overall cognitive achievement levels (Okebukola & Ogunniyi, 1984). However,
Lawrenz (1985) found homogeneous grouping in the laboratory more effective than heterogenous grouping in a study conducted in a physical science class for elementary education majors.

A recent study of introductory college chemistry conducted by Frank and Herron (1987) focused on problem-solving strategies implemented within recitation groups that met once a week for an hour. Results of the study suggest that small group interaction in problem solving on challenging problems carefully directed by an instructor can lead to improvement on problem-solving tasks and general achievement in chemistry. Small groups were defined as recitation groups of 25-30 students. Students formed smaller groups of two or three within the recitation group, but that grouping was not a planned part of the study. Frank and Herron suggested that further research is needed in a controlled setting for that particular focus.

Summary

This review of related literature suggests a need to develop strategies to assist students in moving toward more logical thought. Since proportional reasoning ability is directly related to success in chemistry problem solving and a large percentage of high school students are unable to reason proportionally, ineffective methodology must change. Piaget
(1969) suggested years ago that new methods of education must become directly concerned with the development of formal reasoning by considering not only the internal structural maturation, but the influences of experience and the social and physical environment of the child.

Many studies throughout this review have supported the importance of domain-specific knowledge in problem solving; however, just as importantly, procedural knowledge must be considered its complement. In fact, some researchers would establish procedural knowledge in the forefront. Recently Krajcik and Yager (1987) conducted a study to determine the success in introductory college chemistry with and without high school experience in chemistry. This study suggests that pre-mastery of specific concepts may not be as important for success in college chemistry as such variables as motivation, perseverance, and mathematics skills. Furthermore, the study proposed that high school chemistry not be taught in the traditional manner and recommended a deemphasis of content and concepts which would allow chemistry teachers to focus on developing abilities such as understanding proportions and rational thinking.

This review has also emphasized research designed to identify behaviors of successful problem solvers. Overwhelmingly, the qualitative aspect was a dominant
characteristic of successful problem solvers. Prescriptive methods, although time-consuming, are designed to induce the learner to use qualitative descriptions. Rather than relying on strictly algorithmic methods for problem solving, students are encouraged to think about their thinking through a step-by-step prescription.

An increase in the development of formal reasoning can occur not only through the influence of the prescriptive experience but through the learner's social and physical environment as suggested by Piaget. Cooperative grouping provides an avenue for social transmission as well as an alternative to the traditional lecture methodology. In addition, research has supported cooperative learning as a means of increasing student achievement.

By adapting characteristics of successful problem solvers to prescriptive heuristics and then coupling them with the nontraditional environment of cooperative grouping, an opportunity is presented which may narrow the gap between the achievement of formal and concrete operational reasoners. Specifically, in a course such as chemistry, containing many highly conceptual and quantitative topics requiring formal reasoning in order to attain comprehension, the possibility for success may be increased.
CHAPTER III

METHOD

Nature of the Sample

The sample consisted of 178 students ranging from 14.7-19.0 years in age, representing grades 10-12. This study was conducted in the three public high schools in a rural south Louisiana parish for a period of seven weeks commencing at the beginning of the second nine-week session of the 1987-88 school year. Permission was obtained from the superintendent of the school district as well as each student involved in the study (Appendix A).

Both honors and regular chemistry classes comprised the study. In this school system, students are selected to be in honors classes based upon certain criteria: (a) IQ scores and math stanines from their latest California Achievement Test and (b) average grade in science based on the current year and two previous years (Appendix B). Most chemistry honors students elect to skip physical science and complete a biology course in the ninth grade instead, thus scheduling chemistry in the tenth grade. Regular chemistry classes consist mostly of eleventh grade students with a small percentage of seniors. The breakdown of the sample by school is shown in Table 1.
Table 1

Sample

<table>
<thead>
<tr>
<th>High School</th>
<th>Honors</th>
<th>Regular</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>40*</td>
<td></td>
<td>40</td>
</tr>
<tr>
<td>B</td>
<td>43*</td>
<td>48*</td>
<td>91</td>
</tr>
<tr>
<td>C</td>
<td>47*</td>
<td></td>
<td>47</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>90</td>
<td>88</td>
<td>178</td>
</tr>
</tbody>
</table>

Note. The asterisk denotes 2 classes.

Only one teacher in each school took part in the study and the classes of each teacher were randomly assigned experimental treatment and control treatment. By using three different teachers in different schools each assigned experimental treatment and control treatment groups, an attempt was made to minimize the school/teacher variable.

Pilot Study

A pilot study (n = 55) was conducted for a three-week period in two physics classes in one of the three high schools during the beginning of the fall semester, 1987. Physics students were used in the pilot since introductory chemistry classes do not encounter problem solving until later in the semester. As a result of this study, plans to use groups of three, provide more examples of problems adapted to the
prescriptive method, include an attitude instrument, and provide additional instruction on interaction skills were implemented in the dissertation study. (See Appendix C.)

Nature of the Chemistry Problems

In chemistry, proportional reasoning is first encountered with chemical nomenclature and the writing of formulas which are based upon the Law of Definite Proportions and the Law of Multiple Proportions. Atomic masses represent a proportional average of isotopic composition. It is necessary that students recognize the definite ratio given by the empirical formula. The first chemical problem solving encountered by chemistry students in this study, besides density which is solved by a formula, is stoichiometry which is the study of quantitative relationships implied by a chemical reaction. Stoichiometry requires the knowledge of the particulate nature of matter, understanding the mole concept, and the ability to do proportional reasoning (Goodstein & Howe, 1978; Wheeler & Kass, 1977). The problems requiring proportional reasoning that were used in this study included: (a) determining the number of moles and number of particles in the mass of a given substance, (b) determining empirical and molecular formulas, (c) mass-mass problems based on a balanced equation, and (d) limiting reagent problems.
Students' problem sets consisted of the preceding problem types contained in their adopted text, *Merrill Chemistry: A Modern Course* (Smoot, Price, & Smith, 1979, 1987). These sets were limited to no more than four problems due to the use of problem prescription requiring so much time.

**Instruments**

*Test of Logical Thinking*

The Test of Logical Thinking (TOLT) developed by Tobin and Capie (1981) was used to assess the proportional reasoning of the students in the sample (Appendix D). As established by the authors, the 10-item test has a high internal consistency and the two-item subtest on proportional reasoning exhibits sufficient reliability to allow decision making at the subtest level \( r = .82 \). The construct validity of the TOLT was assessed by administering the Mr. Tall/Mr. Short task of proportional reasoning proposed by Karplus to a representative sample of students (Appendix E). All students were administered the TOLT prior to the beginning of the study. The results of the two-item subtest on proportional reasoning were used as the basis for forming heterogeneous groups of three or four within the classes that were randomly assigned to experimental treatment (Table 2). Students were categorized and then randomly placed in groups to ensure that each group would consist of students of differing proportional
reasoning ability. The students in the other classes, serving as the control treatment, solved problems on an individual basis.
Table 2
Heterogeneous Groups Based on Proportional Reasoning

School A

<table>
<thead>
<tr>
<th>Group 1</th>
<th>Group 2</th>
<th>Group 3</th>
<th>Group 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>T, NP, NP</td>
<td>T, NP, NP</td>
<td>P, NP, NP</td>
<td>NP, NP, NP</td>
</tr>
</tbody>
</table>

School B

Class 1

<table>
<thead>
<tr>
<th>Group 1</th>
<th>Group 2</th>
<th>Group 3</th>
<th>Group 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>T, NP, NP</td>
<td>T, NP, NP</td>
<td>P, NP, NP</td>
<td>P, NP, NP, T</td>
</tr>
</tbody>
</table>

Class 2

<table>
<thead>
<tr>
<th>Group 1</th>
<th>Group 2</th>
<th>Group 3</th>
<th>Group 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>P, NP, NP</td>
<td>P, NP, T</td>
<td>P, NP, T</td>
<td>P, NP, T</td>
</tr>
</tbody>
</table>

School C

<table>
<thead>
<tr>
<th>Group 1</th>
<th>Group 2</th>
<th>Group 3</th>
<th>Group 4</th>
</tr>
</thead>
</table>
Note.  P = Proportional  
T = Transitional  
NP = Nonproportional

Science Attitude Survey

A science attitude survey was administered to all students prior to beginning the study (Appendix F). Reliability was estimated to be .92 using Cronbach’s alpha (Borg & Gall, 1983). This survey was modified from a questionnaire, Science Attitude Scale, developed by Aiken (1979) to measure attitudes toward science. This Likert-type questionnaire consists of 24 items designed to assess enjoyment, motivation, importance, and freedom from fear. Three of the six items on each of the four-part scales are worded in a positive direction and three in a negative direction in terms of attitudes toward the subject. A high score registers a strong like for the subject and a low score a strong dislike. For the purposes of this study, the words chemistry and problem solving were substituted for the word science. This science attitude survey was also administered at the conclusion of the study. In addition, students in the honors classes (n = 90) were given the opportunity to write additional comments after completing the survey evaluating the prescriptive method and problem solving individually or in groups.
Chemistry Pretest

A chemistry pretest (Appendix G) consisting of 12 multiple choice items and two word problems requiring a balanced chemical equation was structured to assess prior knowledge of the problems used in this study as well as conceptual knowledge required in solving these problems as indicated by the school district's curriculum guide (Appendix H). The 12 items taken from the 1981 American Chemical Society-National Science Teachers Association High School Chemistry Achievement Examination (ACS exam) were dichotomously scored. With the use of Cronbach's alpha, reliability was estimated as .84. The content validity of the items from the ACS examination has already been established in a study conducted by Krajcik and Haney (1987). The source of the two word problems requiring students to extract pertinent information in order to write a balanced equation was Heath Chemistry (Herron, Kukla, Dispezio, Schrader, & Erickson, 1987).

Chemistry Posttest

A chemistry posttest (Appendix I), the dependent measure, consisted of seven multiple choice items and three questions representing the four identified problem types used in the study selected from the 1985 ACS examination as well as Heath Chemistry (Herron et al., 1987). An estimate of
reliability was determined using Cronbach's alpha ($r = .80$). This test served as one part of the student's midterm examination conducted at the end of the seven-week study. Students were not required to show their work on the multiple choice items, however they could receive bonus credit for using the prescriptive method for the last three questions (Appendix J). The test was dichotomously scored; however student work was checked and if students obtained a wrong answer due entirely to a mathematical error or an error in balancing the equation they received credit for the problem.

Content validity was established by submitting all test items to a chemistry professor as well as a science education professor.

Experimental Design

Analysis of covariance was used to analyze the data based upon categorical independent variables of proportional reasoning ability, type of class structure (honors and regular), experimental variable (type of grouping, individual or cooperative), and the continuous dependent measure (chemistry posttest). The chemistry pretest served as the continuous covariate. The treatment variable, problem prescription, was held constant in each class. Based upon the results of the two-item subtest of the TOLT, proportional reasoning ability was identified as proportional (both items correct),
transitional (one item correct), and nonproportional (both items incorrect). The general linear models procedure was used to compensate for unequal n's per cell (see Table 3).

### Table 3

**Illustration of design**

<table>
<thead>
<tr>
<th>Reasoner</th>
<th>Individual</th>
<th>Grouped</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Regular</td>
<td>Honors</td>
</tr>
<tr>
<td>Proportional</td>
<td>7</td>
<td>12</td>
</tr>
<tr>
<td>Transitional</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Nonproportional</td>
<td>24</td>
<td>23</td>
</tr>
</tbody>
</table>

**Note.** n = 178

Demographic data, sex and age, were obtained from student records as well as math stanines from the California Achievement Test. The stanine is a scale from 1-9 that provides a rough estimate of a student's achievement. In general, scores of 1-3 are considered below average, 4-6 average, and 7-9 above average. Correlations between demographic data, math stanines, and proportional reasoning ability were statistically analyzed.
Think aloud process

The first think aloud tapes were transcribed in the spring of 1957 at the Carnegie Institute of Technology. The goal of the analysis was to define a computer program that would parallel human behavior. A verbal protocol, the transcript of student verbalizations during the course of problem solving, is referred to as a "typical technique" for verifying the information processing approach (Newell & Simon, 1972, p.12). During the last decade the thinking aloud or concurrent verbalization technique (Ericsson & Simon, 1980) has been used successfully to identify strategies and characteristics of successful problem solvers in many research studies including the area of chemistry problem solving (Anamuah-Mensah, 1986; Camacho, 1986; Gabel et al., 1984; Gorodetsky & Hoz, 1980; Greenbowe, 1983; Nurrenbern, 1979).

In an attempt to answer the question concerning the different characteristics exhibited by students of different proportional reasoning abilities in different settings, the think aloud technique was utilized. At the end of the seven-week study, student volunteers of varying proportional reasoning ability from the control treatment as well as the experimental treatment classes were asked to volunteer to solve limiting reagent problems orally, to think aloud, while being
videotaped. Twenty-two teams (n = 55), 10 pairs and 12 groups, represented each class participating in the study.

To ensure that the students representing the control treatment class would talk aloud while problem solving, students were paired. Students were given a choice between (a) one student assuming the role of problem solver, reading and solving the problem aloud, and the other student listening and keeping the problem solver talking (Lochhead & Whimbey, 1987) or (b) both students sharing in the problem-solving process encouraging oral exchange. The original groups representing the experimental treatment were maintained while they were videotaped. Each student team was reminded that the camera could not see what was going on in their minds nor what they were writing on their papers; therefore they must verbalize.

Student teams were assigned one of a three problem set of limiting reagent problems (Appendix K). Students had not been introduced to this type of stoichiometric problem previously but were asked to apply their knowledge of stoichiometric problem solving to this new situation. Even though students had been utilizing the prescriptive method for problem solving, the problem solving strategy employed by the students was their decision.
The videocamera was set up in the back of the chemistry classroom or in the adjoining storeroom in order to preserve the regular environment as much as possible. Student desks were arranged so that the students' backs would not face the camera even though they would normally face one another when problem solving. Videotaping took place during the students regularly scheduled chemistry class. Once the students were given directions, they introduced themselves on camera and then read the problem. At that point they were left unattended until they were finished with the assigned problem. During a 55-minute class period, two to four teams were videotaped.

The videotapes were reviewed extensively. Characteristics of successful and unsuccessful problem solvers were noted as well as similarities and differences between (a) students of varying proportional reasoning abilities and (b) students who had been solving problems on an individual basis and those who had been problem solving in groups. Student groups which obtained the correct answer through a logical process were deemed successful.

To insure reliability of the videotape analyses, the three teachers taking part in the study were asked to view and critique the tapes and submit a written analysis for comparison (Appendix L). In addition, students' written work was analyzed (Appendix M).
Prescriptive method

Prescription in this context means that procedures are specified so that the problem solver can generate useful initial descriptions of problems in both a qualitative and quantitative way with the objective to reduce errors and improve subsequent problem solving. Heller and Reif (1984) found that the prescriptive model used in their study which included both qualitative and quantitative descriptions concluding with an assessment generated excellent problem descriptions and resulted in future improvement in solving problems.

The prescriptive strategy used in this study was adapted from the problem-solving strategies identified through expert-novice research (Camacho & Good, 1986; Chi, Feltovich, & Glaser, 1981; DeJong & Ferguson-Hessler, 1986; Good & Smith, 1987) and from Heller and Reif's prescriptive problem solving study (1984), Bunce's problem solving approach (Bunce & Heikkinen, 1986), and Gabel's problem redescription approach (1987). In addition, prediction was added to the prescription to ensure continuous backward checks toward what is known and forward checks toward the projected outcomes as suggested by Good (1987).

The problem prescription consists of a: (a) statement of the problem, (b) redescription that includes extraction of the
stated as well as the implied information and a picture
description, (c) prediction, (d) mathematical solution, and
(e) check (Table 4).
Table 4

Problem Prescription

I. PROBLEM:
Copy the problem and underline key words or phrases.

II. REDescription: Be sure to include units.
   A. Given: Unknown:

   B. PICTURE: Label the diagram or sketch.

III. PREDICTION OR ESTIMATION:

IV. MATHEMATICAL SOLUTION:

V. CHECK:
Initially students were asked to recopy the problem for two main reasons: (a) copying results in more attention paid to the details of the problem and (b) underlining or circling the main concepts needed to solve the problem can not be done in the textbook. From the circled or underlined concepts, students were asked to list the given information and the unknown using an appropriate variable symbol and the specified units. In addition, they were asked to list information needed to solve the problem not necessarily given in the problem such as the atomic mass, Avogadro's number, etc. The redescription picture may take the form of a diagram and/or a balanced equation. A diagram is often difficult to draw in chemistry, however students were encouraged to draw a cylinder or some type container to represent the standard used in the problem and another cylinder to represent the given substance. Comparative diagrams were quite helpful in assisting students with the process skill of predicting. Once a prediction has been made, a mathematical solution is needed. Students could choose any strategy such as a proportion or the factor-label (unit analysis) technique. Before the problem was complete, students were asked to reassess the problem comparing their prediction with their answer.

In order to establish consistency between classes in this study, the problem prescription was introduced and modeled
for each class using several examples (Appendix N). Students were required to use the problem prescription whenever they were solving problems in class. Since this process was time-consuming, the number of problems assigned for classwork as well as the number of problems contained on a test were decreased accordingly. Homework on chemistry problems during the research study was curtailed since the after-school environment could not be controlled.

Teacher Training

Inservice training for the three teachers was provided in order to insure consistency between schools. Teachers were given verbal instruction in using the prescriptive problem-solving strategy and given samples of each type of problem the students would encounter during the study utilizing the problem prescription (Appendix N). Discussion of cooperative grouping guidelines focused on the book, Circles of Learning (Johnson et al., 1984) which was given to the teachers prior to the inservice. These guidelines are similar to those identified in Slavin's review of cooperative learning (1980): (a) reward interdependence, (b) task interdependence, (c) individual accountability, and (d) teacher imposed structure. The primary component of cooperative grouping, positive reward interdependence where one student's success helps another to be successful, was stressed.
In addition, a handout on cooperative grouping that included specific guidelines and rules of behavior was provided for each student in the experimental treatment classes (Appendix O). Teachers were asked to discuss this information with their students as well as emphasize interaction skills. In order to provide for positive reward interdependence, students were informed that only one problem set would be turned in per group with all members receiving the same grade. In addition, they were informed that bonus points would be awarded to all members of the group if individual scores on the test for each group member resulted in at least a 70% score. Roles (Table 5) were also assigned to ensure interdependence and to assist in increasing collaborative skills, a major objective of cooperative grouping (Johnson & Johnson, 1987).
Table 5

Group Roles

1. Organizer/Time Manager: Makes sure everyone in the group has a role, keeps track of the time, and keeps everyone on task.

2. Encourager/Observer: Makes sure everyone has an opportunity to participate and keeps track of how well everyone is working together.

3. Recorder: Writes down the group's decisions and submits the final problem set to the teacher.

4. Summarizer/Checker: Makes sure everyone in the group understands what is being said and that it makes sense to the group as a whole.

Note. For groups of 3, roles 1 and 2 are combined.

Adapted from Circles of Learning (Johnson et al., 1984)

The teachers' role in cooperative learning was also discussed. Their responsibilities included:

(1) Instructing in cooperative learning

(2) Modeling the problem prescription

(3) Preparing problem sets from textbook-type problems
(4) Assisting students when called upon by asking questions to guide and promote thinking rather than responding with a direct answer

(5) Grading the problem sets

(6) Providing the conceptual background through lecture and lab experiences as indicated by the parish curriculum guide

(7) Preparing, administering, and evaluating tests representative of the problem types experienced by the students.

Teachers were cautioned not to bias the study by identifying positively toward any one group.

Summary

The sample consisted of 178 regular and honors chemistry students. This study was conducted in three high schools using eight classes for a period of seven weeks. These classes were randomly assigned to experimental treatment: (a) students solved problems on an individual basis or (b) students were placed in heterogeneous groups of three or four based upon the students' proportional reasoning ability for problem solving. All students used a prescriptive strategy for problem solving.

Statistical analyses were conducted using a pretest and posttest for chemistry achievement and a pre- and post-attitude measure. Qualitative analyses included videotape
analyses, classroom observations, teacher critiques, and students' written work.
CHAPTER IV
RESULTS
Stoichiometric Problem Solving

The primary purpose of this study was to determine the effect that cooperative groups, heterogeneously based on proportional reasoning ability, have on stoichiometric problem solving in regular and honors high school chemistry. Restated in terms of a null hypothesis, there is no statistically significant difference at the .05 level in the posttest means between students of differing proportional reasoning abilities solving stoichiometric problems individually or in cooperative groups.

A 2x2x3 analysis of covariance was performed on the chemistry posttest consisting of 10 items dichotomously scored. Independent variables consisted of two levels of treatment (individualized and grouped), two levels of type (regular and honors), and three levels of proportional reasoning (nonproportional, transitional, and proportional). The covariate was the chemistry pretest. The General Linear Models (GLM) Procedure adjusted for the unbalanced design due to unequal cells (Table 3).

After adjustment for the covariate (pretest), no statistically significant main effects of treatment, type, and proportional reasoning were found on the posttest.
performance, nor were there significant interactions (p<.05). (See Table 6).

Table 6
Analysis of Covariance for Chemistry Posttest

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Covariate</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pretest</td>
<td>10.66</td>
<td>1</td>
<td>10.66</td>
<td>3.56</td>
<td>.06</td>
</tr>
<tr>
<td>Main Effects</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prp. Reas.</td>
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<td>2</td>
<td>13.20</td>
<td>2.21</td>
<td>.11</td>
</tr>
<tr>
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<td>.23</td>
<td>.08</td>
<td>.78</td>
</tr>
<tr>
<td>Type</td>
<td>4.62</td>
<td>1</td>
<td>4.62</td>
<td>1.55</td>
<td>.22</td>
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<tr>
<td>Interactions</td>
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<td></td>
</tr>
<tr>
<td>Prp*Trt</td>
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<td>2</td>
<td>-</td>
<td>.24</td>
<td>.79</td>
</tr>
<tr>
<td>Prp*Typ</td>
<td>2.33</td>
<td>2</td>
<td>-</td>
<td>.39</td>
<td>.68</td>
</tr>
<tr>
<td>Trt*Typ</td>
<td>.00</td>
<td>1</td>
<td>-</td>
<td>.00</td>
<td>.98</td>
</tr>
<tr>
<td>Prp<em>Trt</em>Typ</td>
<td>16.13</td>
<td>2</td>
<td>-</td>
<td>2.70</td>
<td>.07</td>
</tr>
<tr>
<td>Explained</td>
<td>90.86</td>
<td>12</td>
<td>7.57</td>
<td>2.53</td>
<td>-</td>
</tr>
<tr>
<td>Residual</td>
<td>493.63</td>
<td>165</td>
<td>2.99</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Total</td>
<td>584.49</td>
<td>177</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
Least square means (populations marginal means) are the means that would be expected for a balanced design involving the independent variables of treatment, type, and proportional reasoning with the covariate (Appendix P).

The three-way interaction of proportional reasoning by treatment by type, although statistically nonsignificant at the .05 level, may suggest a trend (Table 6). The least square means for the posttest for proportional reasoning by treatment by type are found in Table 7.

Table 7

<table>
<thead>
<tr>
<th></th>
<th>Individual</th>
<th>Grouped</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Regular</td>
<td>Honors</td>
</tr>
<tr>
<td>NP</td>
<td>3.87</td>
<td>4.81</td>
</tr>
<tr>
<td>T</td>
<td>3.97</td>
<td>4.75</td>
</tr>
<tr>
<td>P</td>
<td>5.08</td>
<td>4.57</td>
</tr>
</tbody>
</table>

The graph of the three-way interaction (Figure 1) illustrates better performance of proportional reasoners in honors classes in a cooperative grouping environment for problem solving (M=5.77). Transitional reasoners in groups
performed better in regular classes (M=4.48), but in honors classes performed better on an individual basis (M=4.75). Nonproportional reasoners' performance was greatest when solving problems individually in honors classes (M=4.81).
Figure 1

Plot of Three-way Interaction of Proportional Reasoning by Treatment by Type for Posttest
Secondary Questions

What intercorrelations exist among the variables mathematical aptitude, age, sex, and proportional reasoning ability?

Math stanines from the students' last California Achievement Test served as an indicator of mathematical aptitude. Pearson Product-Moment Correlations were performed on age, sex, math stanines, and proportional reasoning ability (Table 8). The alpha level was set at .05. A significant negative association was found between math stanines and age and also proportional reasoning ability and age. The math stanines and reasoning ability were lower for the older student. A significant positive association was found between math stanines and proportional reasoning ability with higher math stanines associated with higher proportional reasoning ability. No significant correlations were found between math stanines and sex, proportional reasoning ability and sex, and age and sex.
Table 8

Pearson Correlation Coefficients for Age, Sex, Math Stanines, and Proportional Reasoning Ability (Prp)

<table>
<thead>
<tr>
<th></th>
<th>Sex</th>
<th>Stanine</th>
<th>Prp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>-.0915</td>
<td>-.5386*</td>
<td>-.1980*</td>
</tr>
<tr>
<td>Coefficient</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Significance</td>
<td>.2080</td>
<td>.0001</td>
<td>.0060</td>
</tr>
<tr>
<td>Sex</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coefficient</td>
<td>-</td>
<td>-.0815</td>
<td>-.1013</td>
</tr>
<tr>
<td>Significance</td>
<td></td>
<td>.2703</td>
<td>.1633</td>
</tr>
<tr>
<td>Stanine</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coefficient</td>
<td>-</td>
<td>-</td>
<td>.4078*</td>
</tr>
<tr>
<td>Significance</td>
<td></td>
<td></td>
<td>.0001</td>
</tr>
</tbody>
</table>

*p<.05

Are attitude differences noted between students of different proportional reasoning abilities assigned to regular or honors classes who solve problems individually or in cooperative groups?

A science attitude survey was used as both the pretest and posttest to measure attitudes toward science (Aiken, 1979). This Likert-type questionnaire (Appendix F) consists of 24 items eliciting responses indicating whether the students strongly agreed or disagreed with the items ranging from five to one respectively. A 2x2x3 analysis of covariance was
performed on the total posttest score. Independent variables consisted of two levels of treatment (individualized and grouped), two levels of type (regular and honors), and three levels of proportional reasoning (nonproportional, transitional, and proportional). The covariate was the attitude pretest. The GLM Procedure adjusted for the unbalanced design due to unequal cells (Table 3).

After adjustment for the covariate (pretest), no statistically significant main effects of treatment, type, and proportional reasoning were found for the attitude posttest nor were there significant interactions (p<.05). (See Table 9).
Table 9

Analysis of Covariance for Attitude Posttest

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Covariate</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pretest</td>
<td>30581.23</td>
<td>1</td>
<td>30581.23</td>
<td>215.02</td>
<td>.00</td>
</tr>
<tr>
<td>Main Effects</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prp. Reas.</td>
<td>62.81</td>
<td>2</td>
<td>62.81</td>
<td>0.22</td>
<td>.80</td>
</tr>
<tr>
<td>Treatment</td>
<td>79.54</td>
<td>1</td>
<td>79.54</td>
<td>0.56</td>
<td>.46</td>
</tr>
<tr>
<td>Type</td>
<td>8.07</td>
<td>1</td>
<td>8.07</td>
<td>0.06</td>
<td>.81</td>
</tr>
<tr>
<td>Interactions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prp*Trt</td>
<td>62.54</td>
<td>2</td>
<td>-</td>
<td>0.22</td>
<td>.80</td>
</tr>
<tr>
<td>Prp*Typ</td>
<td>56.21</td>
<td>2</td>
<td>-</td>
<td>0.20</td>
<td>.82</td>
</tr>
<tr>
<td>Trt*Typ</td>
<td>71.51</td>
<td>1</td>
<td>-</td>
<td>0.50</td>
<td>.48</td>
</tr>
<tr>
<td>Prp<em>Trt</em>Typ</td>
<td>592.44</td>
<td>2</td>
<td>-</td>
<td>2.08</td>
<td>.13</td>
</tr>
<tr>
<td>Explained</td>
<td>34513.42</td>
<td>12</td>
<td>2876.12</td>
<td>20.22</td>
<td></td>
</tr>
<tr>
<td>Residual</td>
<td>23894.29</td>
<td>168</td>
<td>142.23</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Total</td>
<td>58407.71</td>
<td>180</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Least square means for attitude for the main effects as well as interactions can be found in Appendix P.

Although not statistically significant at the .05 level, the three-way interaction may suggest a possible trend. Least square means for attitude for the three-way interaction of the
independent variables of treatment, type, and proportional reasoning indicate the most positive attitude for transitional reasoners in grouped honors classes (M=75.5) and the least positive attitude for nonproportional reasoners solving problems individually in regular chemistry classes (M=65.4). See Table 10. The graph of the three-way interaction of treatment, proportional reasoning, and type (Figure 2) illustrates that proportional reasoners in honors classes may have a more positive attitude when solving problems individually than in groups (M=74.7; M=65.4), while proportional reasoners in regular classes may have a more positive attitude when solving problems in groups rather than individually (M=75.3; M=70.2).

Table 10
Least Square Means for Attitude for Proportional Reasoning by Treatment by Type

<table>
<thead>
<tr>
<th></th>
<th>Individual</th>
<th>Grouped</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Regular</td>
<td>Honors</td>
</tr>
<tr>
<td>NP</td>
<td>65.4</td>
<td>74.9</td>
</tr>
<tr>
<td>T</td>
<td>73.3</td>
<td>68.7</td>
</tr>
<tr>
<td>P</td>
<td>70.1</td>
<td>71.1</td>
</tr>
</tbody>
</table>
Figure 2
Plot of Three-way Interaction of Proportional Reasoning by Treatment by Type for Attitude

![Graph showing the three-way interaction of Proportional Reasoning by Treatment by Type for Attitude. The graph displays the means of attitude measures for Grouped and Individual chemistry students, with lines indicating differences in Regular Chemistry and Honors Chemistry.]
Intercorrelations among the 24 items and five scores on the original questionnaire (Aiken, 1979) suggested three factors were being measured: enjoyment or interest, perceived importance or value, and freedom from fear or anxiety toward the specific subject. The motivation variable was found to be related too closely to enjoyment or interest to be a separate factor. A principal factor extraction with orthogonal rotation was performed on the 24 items of the revised questionnaire used in this study (Appendix P). This extraction was performed for both the attitude pre- and post-measures. Comparison of the items for each factor on the pre- and post-questionnaires indicated four items relating to motivation, enjoyment, or interest loaded on factor 1, four items relating to fear or anxiety loaded on factor 2, and only two items relating to importance loaded on factor 3.

Subscales were established for each factor and 2x2x3 ANCOVA's were performed on each subscale. The independent variables of treatment, type, and proportional reasoning remained the same. The covariate was the subscale on the pre-attitude measure. After adjustment for the covariate using the GLM Procedure, there were no significant main effects nor significant interactions using the subscales for motivation and importance. For the subscale of fear or anxiety, there were no significant main effects, but there
were significant interactions of type and proportional reasoning, $F(2,180)=3.16, p<.05$ and treatment and type, $F(1,180)=4.87, p<.05$ (Table 11).

Table 11
Analysis of Covariance for Post-Attitude Subscale Fear and Anxiety

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Covariate</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prescale</td>
<td>409.45</td>
<td>1</td>
<td>409.45</td>
<td>112.20</td>
<td>.00</td>
</tr>
<tr>
<td>Main Effects</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prp. Reas.</td>
<td>16.02</td>
<td>2</td>
<td>16.02</td>
<td>2.19</td>
<td>.11</td>
</tr>
<tr>
<td>Treatment</td>
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<td>1</td>
<td>0.45</td>
<td>0.12</td>
<td>.73</td>
</tr>
<tr>
<td>Type</td>
<td>4.17</td>
<td>1</td>
<td>4.17</td>
<td>1.14</td>
<td>.29</td>
</tr>
<tr>
<td>Interactions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prp*Trt</td>
<td>1.48</td>
<td>2</td>
<td>-</td>
<td>0.20</td>
<td>.82</td>
</tr>
<tr>
<td>Prp*Typ</td>
<td>23.08</td>
<td>2</td>
<td>-</td>
<td>3.16</td>
<td>.04*</td>
</tr>
<tr>
<td>Trt*Typ</td>
<td>17.79</td>
<td>1</td>
<td>-</td>
<td>4.87</td>
<td>.03*</td>
</tr>
<tr>
<td>Prp<em>Trt</em>Typ</td>
<td>1.69</td>
<td>2</td>
<td>-</td>
<td>0.23</td>
<td>.79</td>
</tr>
<tr>
<td>Explained</td>
<td>522.84</td>
<td>12</td>
<td>43.57</td>
<td>11.94</td>
<td>-</td>
</tr>
<tr>
<td>Residual</td>
<td>613.09</td>
<td>168</td>
<td>3.65</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Total</td>
<td>1135.93</td>
<td>180</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

*p<.05
Since fear or anxiety is a negative attitude, the smaller means denote a greater fear or anxiety while the larger means denote a positive attitude due to less fear or anxiety.

In honors chemistry classes, the fear or anxiety of transitional students was greater than for other students of differing proportional reasoning ability in either type class (M=5.9 versus M=7.2-8.0; Table 12, Figure 3).

Table 12
Least Square Means for Fear or Anxiety for Proportional Reasoning by Type

<table>
<thead>
<tr>
<th>Type</th>
<th>Regular</th>
<th>Honors</th>
</tr>
</thead>
<tbody>
<tr>
<td>NP</td>
<td>7.20</td>
<td>7.35</td>
</tr>
<tr>
<td>T</td>
<td>7.62</td>
<td>5.94</td>
</tr>
<tr>
<td>P</td>
<td>7.52</td>
<td>7.97</td>
</tr>
</tbody>
</table>
Figure 3
Plot of Two-way Interaction of Proportional Reasoning by Type for Fear or Anxiety
In regular chemistry classes the fear or anxiety of grouped students was less than that of students solving problems individually (M=7.9 versus M=7.0). The opposite was true in honors classes with the fear or anxiety of students solving problems individually being less than that of grouped students (M=7.4 versus M=6.8; Table 13, Figure 4). Since fear or anxiety is a negative attitude, the smaller means denote a greater fear or anxiety while the larger means denote a positive attitude due to less fear or anxiety.

Table 13

Least Square Means for Fear or Anxiety for Type by Treatment

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Individual</th>
<th>Grouped</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regular</td>
<td>7.02</td>
<td>7.88</td>
</tr>
<tr>
<td>Honors</td>
<td>7.40</td>
<td>6.77</td>
</tr>
</tbody>
</table>
Figure 4
Plot of Two-way Interaction of Type by Treatment for Fear or Anxiety
Elicited responses from attitude surveys.

Students in the honors chemistry classes were given the option of writing comments on their attitude survey answer sheets. In the individualized classes (control treatment), 48% (24/50) of the students chose to write comments as compared to 72% (33/46) of the students working in groups (experimental treatment). Over half (57.6%; 19/33) of the grouped students cited enjoyment as illustrated by the following excerpts:

T: "I have thoroughly enjoyed the group method of problem solving which we have employed so far this year. I feel that it should be used more widely, perhaps in all classes of chemistry. The group method has enabled our group to put our knowledge together to work the problems. Individually we would not have been able to absorb the concentrated amount of information given to us all at once."

NP: "I find chemistry an interesting and necessary part of my education; however, it does have its difficulty, but that makes it more challenging and thus enjoyable."
P: "I have enjoyed the program very much. I have learned a lot so far and I'd like to continue learning how to solve word problems. I think that working in groups taught us to work better with our classmates."

NP: "Chemistry is fun, but hard. Working in a group makes it a lot easier to learn and help each other."

T: "I enjoyed working in groups because you know that if you do a problem and get it wrong someone is there to help you find your error. In class the teacher doesn't have time to work with us individually and to correct all the errors."

Only 15% (5/33) of the students stated that they did not enjoy working in groups as indicated by the following excerpts:

P: "I didn't like working in groups and I found I was more motivated and excelled better working alone, although I was able to help the other members in my group."

P: "I didn't like working in groups. For myself, it is much easier to understand things working alone. I could have advanced myself farther without group work."
P: "I didn't like the idea that we were put in groups because it is harder to take a test because each person in the group depends on another and you don't quite learn enough. I suggest groups for the test."

Some students working individually expressed a desire to work in groups as illustrated by the following comments:

NP: "Doing the chemistry is interesting to me, but not getting help from others makes me feel lost. I wish we could get help from others while doing the equations."

T: "I like not being grouped because we are responsible for ourselves, but grouping would be beneficial in that we would learn and understand faster."

P: "We should all work in groups. I don't like working individually."

Other comments focused on the use of the prescriptive method. This method included a: (a) statement of the problem, (b) redescription that included extraction of the stated as well as the implied information and a picture description, (c) prediction, (d) mathematical solution, and (e) check (Appendix N). Very few students working in groups commented on this strategy, however most of these comments were from
proportional reasoners and were characterized as being negative.

P: "I found it easier to skip all the unnecessary estimations and such."

P: "I thought the process is useless except to waste time."

P: "I didn't like having to do all the steps in solving a problem."

Only one student, a non-proportional reasoner, working in a group commented positively, "The procedure helped me understand the chemical problem solving better."

On the other hand, most non-proportional reasoners working individually wrote positive statements concerning the use of the prescriptive method as indicated in the following excerpts:

NP: "I have enjoyed the method of problem solving. It makes the problem easier to understand and to do. I also liked it because it helps develop your thinking skills."

NP: "I like the problem-solving method and found it was pretty easy."

NP: "The procedure worked somewhat on me. I realized how important it is to think on your own in chemistry. However, I have not mastered the thinking part just yet."
One student analyzed the value of the prescriptive method for students by stating:

"When learning to work new problems, the prescription method is helpful because it more or less explains where each piece comes from and where each piece goes. When I have learned to do the problems, this method becomes unnecessary."

Many students indicated that the degree of difficulty of the problems was high, but that the prescriptive method and/or grouping made the problems easier.

Are there differences in the characteristics exhibited by students of different proportional reasoning ability while solving problems in cooperative groups or individually?

In order to answer this question, 22 student teams were asked to solve limiting reagent stoichiometric problems while being videotaped at the end of the seven week study (Appendix K). Students had not been introduced to this type of problem previously but were asked to apply their knowledge of stoichiometric problem solving to this new situation. Students from the control treatment (n=22) were paired while solving the problems and the proportional reasoning of each noted. The original groups representing the experimental treatment were maintained while they were videotaped (n=33).
Even though students had been utilizing the prescriptive method for problem solving, the problem-solving strategy employed by the students was their decision. Successful problem solvers were defined as those able to derive a correct answer based upon logical rationalizations such as writing a balanced chemical equation and relating the mole ratio to the actual mole quantities in the problem. An answer was considered correct if the student made only a careless math error.

After extensive review of the videotapes by the researcher, characteristics of successful and unsuccessful problem solvers as a whole were noted and associated with students of varying proportional reasoning abilities. This section also analyzes and synthesizes videotapes, students' written work (Appendix M), and classroom observations of students who had been solving problems individually as compared to those who had been solving problems in groups. The teachers in this study reviewed the videotapes and submitted a written report evaluating the classroom observations, students' work, and the study as a whole (Appendix L). Only one teacher specifically mentioned the evaluation of the videotapes.

**Successful and unsuccessful problem solvers.**

Eight of the 22 student teams (36%) were successful in solving a limiting reagent problem. These teams consisted of
three pairs (n=6) and five groups (n=15). In all cases a
proportional reasoner (P) or a transitional reasoner (T) was
represented in the group.

When appropriate, successful problem solvers began each
problem by writing a balanced equation and determining the
mole ratio from the equation. They organized their problem by
stating the given information and the unknown and labeling
each quantity. Some students drew pictures and used them to
estimate the actual mole quantities from the atomic masses
of the elements involved in the problem as specified by the
prescriptive method. These students broke their problem into
steps and one group actually wrote the words step 1, step 2,
etc. Camacho also reported similar observations of successful
students breaking the problem into steps (1986).

Conceptually successful problem solvers understood the
relationship between a balanced chemical equation and the
given mass quantities, while unsuccessful students had
difficulty distinguishing between the coefficients and the
actual mole quantities. For example, one student group
balanced an equation and then converted the given masses for
the two elements in question to moles in order to determine
which element was in excess. In each case, the mole value
determined was less than one mole.
Student A: "We can use the 2(Al):3(Cl) mole ratio to find the one in excess."

Student B: "It should be one extra mole of chlorine."

Student A: "If we don't have a mole, we can't have a mole left over."

Student B related the coefficients to the actual quantities given in the problem and not to the mole ratio. Also this student inferred a 1:1 mole ratio, therefore reasoning that there would be one mole of chlorine in excess. Similarly, Anamua-Mensah (1986) found that a large number of high school students in his study failed to understand the meaning of the coefficients in balanced chemical equations and interpreted all relationships between reactants and products as a 1:1 ratio.

Successful problem solvers exhibited confidence throughout the problem-solving process as contrasted by a lack of confidence for unsuccessful problem solvers. Successful problem solvers verbalized without questioning each strategy employed. In contrast, an unsuccessful student who had helped solve a problem incorrectly ended by saying, "Probably got it wrong." In still another group that was unsuccessful, confidence was the issue in the following excerpt:

Student A: "I still don't think that's right."
Student B: "Maybe it's Cl; maybe it's both of them."

Student A: "I don't understand this. It seems like the problem should be longer."

Unsuccessful problem solvers not only were weak in chemistry content but also exhibited a lack of basic understanding in mathematics. For example, students subtracted unlike quantities (e.g., moles minus grams) to determine the excess in the problem. In a problem where 35 grams of both sodium and chlorine were given, students were asked to determine which one would be in excess after the reaction was over. Students in one group determined that since it took 35.5 grams for one mole of chlorine they could subtract the .5 needed for chlorine from the sodium and there would still be some sodium left over. Another group found the excess by converting the grams of sodium and chlorine to moles and then subtracting the two unlike quantities. In still another example involving a simple ratio of 1:5, students chose to multiply by the difference of four.

Unsuccessful problem solvers used trial-and-error trying to relate previously worked problems to the limiting reagent problem. In most cases, they were unable to remember a previously solved problem that could be used as in the following excerpt:

Student A: "Let's try to do something with the mole ratio."
Student B: "I don't understand what to do."

Student A: "Let's find the mass of the product.
Maybe that will help."

Most unsuccessful students, regardless of the problem and before determining what was being asked for in the problem, immediately converted mass to moles. They then tried to decide how to solve the problem by using a trial-and-error strategy. In two cases, students attempted to solve a mass-mass problem as an empirical formula determination. Nurrenbern (1979) also found that students trying to solve limiting reagent problems exhibited the strategy of forcing the problem information into some previously memorized form or relationship despite inappropriateness of form or relationship.

A summary of the observed characteristics of successful and unsuccessful problem solvers can be found in Table 14. These characteristics represent the researcher's analysis as well as teacher critiques (Appendix L) and students' written work (Appendixes M).
<table>
<thead>
<tr>
<th>Successful</th>
<th>Unsuccessful</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Wrote a balanced chemical equation</td>
<td>1. No balanced chemical equation used</td>
</tr>
<tr>
<td>2. Determined a mole ratio from the coefficients</td>
<td>2. Did not use the coefficients to determine a mole ratio or used them as the actual mole quantities for the problem</td>
</tr>
<tr>
<td>3. Utilized the prescriptive method</td>
<td>3. Did not use the prescriptive method</td>
</tr>
<tr>
<td>a. Stated the given information</td>
<td></td>
</tr>
<tr>
<td>b. Used pictures for predictions</td>
<td></td>
</tr>
<tr>
<td>c. Broke problem into steps</td>
<td></td>
</tr>
<tr>
<td>4. Mathematical errors were due to carelessness</td>
<td>4. Conceptual mathematical errors</td>
</tr>
</tbody>
</table>
Table 14 continued:

5. Related the problem to previously solved problems
6. Labeled quantities with appropriate units
7. Exhibited confidence
8. Persistent

5. Used trial-and-error strategy, sometimes forcing data into some inappropriate problem type
6. Labeling rarely occurred
7. Lack of confidence
8. Gave up easily

Individual problem solving.

Most students who had been problem solving individually for seven weeks continued to do so when paired for videotaping (11 pairs). These students either worked independently with very little interaction or assumed the role of lecturer, evoking few or no comments from the other student. One student completely ignored the other student as he methodically solved the problem successfully. The other student interrupted to ask if his equation was balanced. He corrected his mistake without acknowledging the other student's assistance.

In all cases involving the pairing of a proportional reasoner (P) and a nonproportional reasoner (NP), the P assumed the leading role (n=5 pairs). When a transitional reasoner (T) and a NP or P were paired, the T became the leader (n=5 pairs). In a
particular case, the T exhibited very good reasoning and used an analogy in an attempt to help the other student understand a problem seeking the element that would contain the largest number of atoms if equal amounts of two different elements were given. The reasoning skill of this student is illustrated by the following excerpt:

T: "Oxygen would have more atoms than chlorine. It would be about 2 moles in 30 grams of oxygen and about .9 moles for chlorine."

NP: "I think it's the opposite. How did you get .9?"

T: "If you multiply $6.02 \times 10^{23}$ by .9 and multiply 2 by $6.02 \times 10^{23}$, you will have more oxygen atoms."

NP: "How'd you get that again?"

T: "Suppose we have two different kinds of marbles, lead and glass, and we want 602 marbles. It will take different weights to get that number of marbles. This one would weigh less and this one would weigh more (pointing to the glass and lead respectively). (He paused and repeated again.) It's oxygen that has more atoms."

NP: "How can we get that again? Does one mole equal one atom?"
T: "No! If we put one mole of oxygen in a jar, that's 16 grams equal to \(6.02 \times 10^{23}\) and 35.5 g of chlorine in a jar, that's equal to one mole and \(6.02 \times 10^{23}\) atoms."

NP: "Is that one atom?"

T: "No, chlorine is more dense, but oxygen has more atoms."

This dialog continued, but to no avail. The NP did not exhibit an understanding of mole and even when he agreed with the T at the end of the explanation. The viewer inferred that the student really did not understand why oxygen had more atoms. The T exhibited a sound conceptual background with the ability to relate abstract concepts to concrete experiences such as with the marbles and jars. His patience with the NP seemed endless.

In the only case where two T's were paired, these students vied for the lead and very little was accomplished. In fact, their problem-solving time was spent determining whether an element was diatomic in nature and distinguishing between superscripts and subscripts rather than attempting to solve the limiting reagent problem.

Most students who had been solving problems individually were not as persistent as students who had been solving problems in groups as reported by one of the teachers. They
exhibited anxiety and frustration tending to seek help more often from the teacher without continuing to work on their own. Often these students were observed in nonproblem-solving activities while waiting for assistance from the teacher.

**Group problem solving.**

Most students who had been working in groups interacted well. Three out of five of the successful groups exhibited cooperative behavior. In these groups, students assumed responsibility for other students' learning. This phenomenon was illustrated as a P tried to include a shy NP by asking her questions and explaining to another NP group member the concept of scientific notation. Initially one NP observed as the other group members worked through the problem.

P: “You understand?”

NP1: “How do you know to use Avogadro’s number?”

After a brief explanation of Avogadro’s number, the P resumed the task of finding which element was in excess with the other students looking on and offering some assistance. He finally asked in his teacher role:

P: “Which one had more?”

NP1: “Oxygen”

P: “Great!”
Another NP returned to the topic of Avogadro's number.

NP2: "Which is bigger, 10^{23} or 10^{24}?"

The P expanded the numbers on the paper and then asked her to indicate which was larger and she responded correctly. The P smiled and added further information.

P: "If it were more negative, then the opposite would be true."

As illustrated in the preceding excerpt, the P accepted responsibility for the group's learning and provided positive encouragement through facial and verbal expressions.

Interaction among group members was characterized by students using questions to involve other group members and to check strategies as illustrated by the following excerpt:

NP: "Aren't we supposed to look at the amu to find it?"

P: "Don't we have to use the factor-label method?"

T: "We need to use Avogadro's number because you are looking for atoms."

NP: "Wouldn't chlorine have more atoms (than oxygen) because it's heavier, amu more?"

The NP lacked confidence as evidenced by the use of questions to check each step of the problem.

In many groups it was difficult to identify a leader in that they all shared the responsibility of problem solving equally.
In one of the successful cooperative groups, a NP took the initial lead but soon it became very difficult to distinguish a leader in the group. These students each worked independently but compared and checked each other's work throughout the process. They were very well-organized, working in steps and labeling all their work. Each student seemed to have specific assigned tasks such as inputing the initial data into the calculator, checking the result, and retrieving atomic masses from the periodic table. They were also characterized by persistence and confidence.

Persistence was characteristic of most groups evidenced more often with the use of prediction as part of the prescriptive method. If a group arrived at a mathematical solution that did not agree with their prediction, the students would work diligently to expose the incongruency. During this process group interaction was at its peak.

Two successful groups were not characterized by cooperative interaction while being videotaped. The T in one group read the problem and immediately responded with a correct answer before the other two NP's had an opportunity to contribute to the process. In the other group, the P worked through the problem without hesitation while the other group members, P and NP, looked on and tried to keep up. There was no interaction among group members. The P student who
worked the problem independent of the other group members had commented on his attitude survey that he preferred working alone, but was able to help other members in his group.

Weak conceptual backgrounds were predominant in the unsuccessful groups. These groups did not know where to begin and even failed to write chemical equations where needed. Furthermore, most students did not organize their problems and tried to find an answer through trial and error without necessary intermediate steps. Rarely did any group try to use the prescriptive method to help them understand the problem in a qualitative way. The usual beginning was with the question, "Don't we need amu's first?" or "Don't we need to use the factor-label method?" These students were looking for some type of algorithm to find an immediate answer rather than qualitatively thinking through the problem.

Table 15 summarizes the observed characteristics from the videotapes and classroom observations of students who solved problems individually or in groups. Successful groups exhibited more of these characteristics than unsuccessful groups especially in organization and the use of questions to check their work.
Table 15

**Observed Characteristics of Individual and Grouped Problem Solvers**

<table>
<thead>
<tr>
<th>Individual*</th>
<th>Grouped</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Very little interaction when paired</td>
<td>1. Interacted well</td>
</tr>
<tr>
<td>2. Leader surfaced immediately</td>
<td>2. Difficult to identify a leader</td>
</tr>
<tr>
<td>3. P or T assumed lecturer role</td>
<td>3. Questions used to involve group members and checking for concurrence</td>
</tr>
<tr>
<td>4. Gave up easily and sought help more often</td>
<td>4. Persistent</td>
</tr>
<tr>
<td>5. Organization lacking</td>
<td>5. Well-organized with a division of tasks for group members</td>
</tr>
<tr>
<td></td>
<td>6. Assumed responsibility for each other's learning</td>
</tr>
</tbody>
</table>

*Students who solved problems individually were paired for the videotaping.*
Teacher evaluations.

Teachers participating in the study were asked to evaluate the videotapes of their students as well as the study as a whole (Appendix L). Only one of the teachers specifically mentions the videotape analysis.

Teachers indicated that most of their students were conditioned to memorize formulas. They found that the prescriptive method encouraged students to reason and analyze the stoichiometric problems which resulted in improved conceptual understanding. Even though the prescriptive process was time consuming for the student as well as the teacher, one teacher indicated that it enabled her to gain a better understanding of the students' grasp of the chemistry content and problem-solving skills. Another teacher reported that almost all of her students in the honors classes learned how to solve the problems using this method. More negative comments regarding the prescriptive method were reported by students who solved problems individually in honors classes. Predominantly, these students were proportional reasoners. They complained about it being time consuming and even stated that it was "stupid."

Picture descriptions and predictions were cited as the most difficult parts of the prescriptive method. This was particularly true if more than one process was involved in the
problem such as in mass-mass problems. One teacher did indicate that when predicted answers and mathematical solutions did not agree, interaction of the group members increased as they shared their expertise in order to determine the reason for the inconsistency. Also another teacher reported that some students became so proficient with prediction that they were able to determine the correct answer without seeking a mathematical solution.

When analyzing individual students paired for videotaping with students who had been working in groups, one of the teachers expressed more positive outcomes for groups. She found students who had been solving problems on an individual basis exhibiting more anxiety and frustration, not interacting well with each other, and one student entirely dependent upon the other or seeking outside help from the teacher. Frequently these students were not able to determine the most appropriate method to solve the problem and were not step orientated. Groups on the other hand were more confident, more persistent, and more efficient problem solvers. These students exhibited enjoyment and enthusiasm as they interacted with each other.

Overall teachers indicated that the time allotted for the study was too short to expect major changes in performance. They indicated they would continue to use these strategies
expressing confidence in their success. One teacher reported that "a combination of prescription procedure for solving problems and of groups with one analytical thinker in each was very successful."

Summary.

Analysis of the posttest means between students of differing proportional reasoning abilities solving stoichiometric problems individually or in groups resulted in a nonsignificant statistical difference ($p<.05$). A similar nonsignificant statistical difference occurred between post-attitude means, however there were statistically significant interactions of type (regular and honors) by proportional reasoning and type by treatment (individual and group) for the fear/anxiety subscale of the attitude measure derived from factor analysis ($p<.05$). The greatest fear/anxiety occurred for transitional students in honors classes. Students in regular classes solving problems individually experienced more fear/anxiety than those in groups, while the opposite occurred in honors classes.

Differences between the characteristics of successful and unsuccessful problem solvers working individually and in cooperative groups were evidenced in videotape analyses, classroom observations, and students' written work. Teacher critiques were also used. Overall successful problem solvers
were well-organized utilizing the prescriptive method and exhibited an understanding of the mole concept. Most successful problem solvers were proportional reasoners or were members of groups containing proportional reasoners. Most grouped students interacted well sharing their ideas and assuming responsibility for each other's learning. Finally, teachers evaluated the prescriptive method as well as the cooperative grouping strategy as effective means for teaching stoichiometric problem solving.
CHAPTER V
DISCUSSION, LIMITATIONS, and IMPLICATIONS

The primary purpose of this study was to determine the effect that cooperative groups heterogeneously based on proportional reasoning have on stoichiometric problem solving in high school chemistry. Discussion of the results, limitations, and implications of this study are presented in this chapter.

Discussion

The results of the statistical analysis indicate that students experienced similar success on the posttest regardless of whether they were in a regular or honors class or whether they solved problems individually or in groups. Students of varying proportional reasoning ability also experienced similar success on the chemistry posttest.

The Prescriptive Method

The common denominator utilized in this study was the prescriptive problem-solving method. Every student was introduced to the method through the modeling of specific examples of each type of stoichiometric problem identified in this study (Appendix N). Students were requested to use this method each time they solved problems including on tests. The number of problems assigned was decreased to compensate for this time-consuming process. This procedure was designed to
encourage students to approach the problems qualitatively and in an organized fashion. It provided a strategy for students problem solving alone or in groups in lieu of the traditional model in which the teacher demonstrated how to solve example problems followed by assignment of similar problems for practice. Teachers were able to spend more time assisting students individually as well as evaluating their progress rather than spending most of their time in front of the class.

The results of this study suggest that the prescriptive method may have enabled students to experience similar success regardless of the setting. Evidence from the videotape analysis indicated the prescriptive method was the predominate strategy used by successful problem solvers. These students organized their problem into steps according to the individual components of the prescriptive method. They drew pictures to assist in making predictions with some students taking measures to ensure accuracy by drawing their pictures to scale. Students seemed to consider their prediction as a personal reflection of their ability, resulting in a commitment to check it with their mathematical solution. This inference is consistent with the work reported by Good (1987). When congruency did not occur, these students worked diligently to uncover the source of the inconsistency. This phenomenon resulted in a rethinking of the problem-solving
process which should eventually result in better problem solvers as supported by Polya (1945).

One of three teachers in this study reinforced the merit of the prescriptive method commenting that "requiring students to sketch what is given in a problem and develop a solution encourages them to reason and analyze." Even though she found grading problems utilizing this method very time consuming, she felt that it was an excellent indicator of students' understanding of the concepts involved. She suggested that the prescriptive method be utilized at an earlier age before the students are "conditioned to memorize formulas and steps to solutions without understanding."

The value of the prescriptive method was assessed by students on the attitude surveys through their written comments. Non-proportional reasoners indicated that the prescriptive method made problem solving easier, citing that it made them think, while many proportional reasoners indicated that many of the steps were unnecessary and "a waste of time." Bunce and Heikkinen (1986) found similar results with students classified as possessing logical mathematical reasoning choosing not to use their time-consuming problem-solving approach to the same extent as students with lower reasoning skills. The students in this study who needed the prescriptive method and understood it
were also the students who used it and benefited from its use. Unfortunately many students were unable to use the method due to their weak conceptual background (e.g., inability to write a chemical equation). On the other hand, students who were able to determine how to solve the problem with very little or no difficulty felt they had no need to qualitatively describe the problem. For the latter students, the assigned problems were really only exercises. One proportional reasoner summarized the merit of the prescriptive method when he suggested that it was helpful when working new problems; however when he had learned how to solve the problems the method became unnecessary.

Stoichiometric problem solving proved to be difficult for most students in this study regardless of proportional reasoning ability or setting as evidenced by a mean score for the posttest of 4.5 out of a possible score of 10 and student comments citing a high level of difficulty. Greenbowe (1983) and Nurrenbern (1979) reported similar findings. For most students who were successful, the prescriptive method provided a strategy to link what they knew and what they were being asked to find. For many students extracting the given data, identifying the unknown, writing a balanced equation, and sketching a picture of the mole quantity in question enabled them to visualize the problem, rethink it without the
extraneous words, and thus make a plausible prediction. In some cases, the prediction and mathematical solution were identical.

The expert-novice problem-solving research of the past decade has identified many characteristics of successful problem solvers. Since it is highly improbable that novices can be quickly taught to become experts (experts acquire their knowledge and develop problem-solving strategies through many years of experience), the challenge lies in identifying effective problem-solving processes to teach the novice. The use of the prescriptive method in this study enabled students to incorporate problem-solving strategies utilized by successful problem solvers thus identifying it as an effective tool for stoichiometric problem-solving.

**Cooperative Grouping Strategy**

Results of this study also suggest that the cooperative grouping strategy was comparable to individualized problem solving based upon similar chemistry posttest means. Strategies must be varied in order to keep students interested and motivated. One teacher commented that she planned to use grouping the rest of the year, however not exclusively because "the students tended to become restless and uninterested after several weeks of using the same method of instruction." Research on learning styles of students suggests that a variety
of instructional strategies be used in the classroom so that students will have an opportunity to learn through their preferred style (Kuerbis, 1988). Since over 85% of instruction within schools involves lectures, individual seatwork, or competition (Johnson & Johnson, 1983), effective alternate strategies are essential. Cooperative grouping offers another means for teaching chemistry problem solving that can be adapted to any type of class, regular or honors. It also provides an active environment for students to practice solving problems rather than through seatwork or reception learning, neither of which provide adequate stimulation for the development of formal reasoning skills (Nurrenbern, 1979). Also Gagne and Smith (1962) proposed verbalization as a means to encourage student thinking facilitating the discovery of general principles and their use in solving successive problems.

The outcome of the cooperative grouping strategy was two-fold. Besides cooperative grouping serving as an alternative problem-solving strategy, it served as a means for teaching interaction skills. Most students did not instinctly know how to work effectively with other students as evidenced by teacher comments and poor interaction between student pairs who had been solving problems throughout the study on an individual basis. On the other hand, most students
participating in cooperative grouping cited enjoyment and interest as positive outcomes of this strategy. These factors foster higher levels of motivation and more positive interpersonal relationships as found in the research studies by Johnson and Johnson (1987) and Kurtz and Karplus (1979). Students were encouraged to work together by requiring a group product as well as bonus points dependent upon a minimum score by each group member on the test. Most students working in groups learned to share their expertise, with the more capable students accepting responsibility for the other group members' learning.

**Intercorrelations among Mathematical Aptitude, Age, Sex, and Proportional Reasoning Ability**

A significant negative correlation was found between math stanines and age and also proportional reasoning ability and age (p<.05). Honors students scheduled chemistry in tenth grade while regular chemistry contained mainly juniors and seniors. Since one of the criteria for honors selection was math stanines, it is reasonable to expect that younger students would have higher math stanines than the older students. Based upon the results of the TOLT, more honors students were identified as proportional reasoners than regular chemistry students thus resulting in a negative correlation with age. Even though Piagetian research suggests that there would be
more proportional reasoners in a sample of older students, in this study the students being compared are not similar on the basis of math stanines and the difference in age of most students in the two groups is only one year. Since fewer proportional reasoners and students with lower math stanines are found in the regular chemistry classes, it is difficult to form heterogeneous groups within those classes. The elimination of honors classes would result in the desegregation of high-ability students thus increasing the possibility for heterogeneous grouping. The results of this study showed no statistically significant difference in the success on stoichiometric problem solving experienced between honors and regular chemistry classes. However other factors not addressed in this study such as the year chemistry is scheduled by honors students should be explored before the elimination of the honors program should be considered.

There were no statistically significant correlations between sex and math stanines, sex and proportional reasoning, and sex and age (p<.05). Conflicting research exists concerning the correlation of math ability and sex. Some studies such as the one conducted by Farrell and Farmer (1985) showed gender-related differences in favor of males in first-order proportional reasoning but no gender-differences for multiple proportional reasoning. Other studies affirm the
results of this study (Karplus & Pulos, 1983; Wheeler & Kass, 1977).

Since there was a positive correlation between math stanines and proportional reasoning ability (p<.05), heterogeneous groups could be formed based upon math stanines rather than determining the student's proportional reasoning through the administration of a test thus providing another option for teachers in determining the composition of the groups.

**Attitude Differences**

There were no statistically significant main effects of treatment, type, and proportional reasoning for the post-attitude measure (p< .05). The maximum score that could be obtained on the measure was 120 indicating a strong like for chemistry, while 24 was the lowest score indicating a strong dislike. If students were undecided on every question, their score would be 72. The mean score on the post-attitude survey was 71.2 suggesting that most students were undecided as to their attitude about chemistry even after spending seven weeks problem solving. These students had not engaged in chemistry problem solving prior to this study and during the seven weeks had not developed a dislike for problem solving even though their success was minimal. In addition, the attitude of these students had not changed significantly
regardless of the type of class or whether they solved problems individually or in groups.

Although not statistically significant, proportional reasoners in honors classes had a more positive attitude when solving problems individually than in groups. Proportional reasoners in honors classes that were grouped affirmed this possibility by comments indicating a dislike for working in groups and the feeling that they could advance themselves farther working alone. Many students in honors classes are highly competitive and grade conscious. One product per group with each member of the group sharing the same grade was not viewed as advantageous to the top achievers in the class. Proportional reasoners in regular classes however had a more positive attitude when solving problems in groups. These students did not have as many competitors within the class and perhaps felt more comfortable working in groups. Also in the regular classes, the top students were afforded an opportunity to become more accepted by their peers by sharing their expertise with their group members.

Significant interactions of type and proportional reasoning occurred for the subscale identified as fear or anxiety (p<0.05). In honors classes, the fear or anxiety of transitional students was greater than other students of differing proportional reasoning abilities in either type class. Students in honors
classes have been grouped together for several years. Proportional reasoners are generally those students who have been successful in mathematics (positive correlation with math stanines) and are thus confident with less anxiety, but transitional students may still be trying to "measure up." Since these students have been identified as honors, they may still be striving to be as successful as other students in their class. They may be under pressure to make A's and thus experience more anxiety. Non-proportional reasoners may not have been as successful as the other students over the past few years in mathematics and may be content to assume the lower end of the spectrum perhaps excelling in non-mathematical courses.

Significant interactions of treatment and type also occurred for the fear or anxiety subscale (p < .05). In regular classes the fear or anxiety of grouped students was less than that of students solving problems individually. The opposite was true for honors classes. Students in regular classes were able to share their expertise and in particular obtain assistance from a proportional or transitional reasoner in most cases. When regular students were solving problems individually, they had to depend upon themselves or share the teacher's expertise with all other class members thus experiencing more anxiety or fear. Honors classes contained
more proportional and transitional reasoners which increased the probability of success on an individual basis (Bender & Milakofsky, 1982; Gabel & Sherwood, 1983; Gabel, Sherwood, & Enochs, 1984; Herron, 1978; Krajcik & Haney, 1987).

Successful and Unsuccessful Problem Solvers

Overall the successful groups and pairs contained students who exhibited a strong conceptual background as evidenced by their success in writing balanced chemical equations, determining ratios and making their predictions from them. More importantly, these students were confident and persistent and in most cases they were able to teach the other members of their groups how to solve the problems by modeling, asking questions, and using analogies as they worked through the problems in an organized fashion. In every case these students were identified as being proportional or transitional reasoners.

Teams that exhibited cooperative behavior had the advantage of sharing the expertise of all group members while problem-solving success for teams exhibiting little interaction depended upon one individual’s conceptual base.

Not only a weak conceptual understanding but also mathematics deficiencies such as subtracting unlike quantities or treating a ratio as a difference contributed to teams being unsuccessful. Even though 50 percent of the
teams exhibited cooperative behavior, their weak conceptual base resulted in the use of trial-and-error strategy without success. Camacho (1986) cited the use of this strategy by unsuccessful novices.

This analysis suggests that the criteria of selection for successful problem solving should be based upon conceptual understanding as exhibited by student performance rather than upon proportional reasoning alone. Recent advances in problem-solving research as reported by Bransford, Sherwood, Vye, and Rieser (1986) concur with this suggestion as pointed out in this excerpt:

"Thinking abilities are not simply added on top of existing domain-specific competencies. Instead, competencies in a domain and the ability to think about that domain seem to develop hand in hand."
Limitations

1. Cooperative grouping was not being used in the secondary schools in this district, thus students had to learn how to work with other students in addition to learning how to solve chemistry problems. For some students, interaction skills were not easily learned and resulted in non-productive problem-solving sessions.

2. Cooperative groups are characterized by being heterogeneous in ability. In the regular chemistry classes, homogeneous groups resulted due to an insufficient number of proportional reasoners.

3. The post-chemistry test was part of the students' midterm examination. The time scheduled for this test was immediately prior to the Christmas holidays. Also there were time constraints in two of three schools with the time allowed for the exam ranging from 1.5 hours to 2 hours. Since the prescriptive method required more time, some students opted for a mathematical solution only, as was also found in the Bunce and Heikkenin study (1986).
4. Even though research has indicated that studies that last a period of time of 5 to 10 weeks result in effective problem-solving instruction (Curbelo, 1984), this period is too short to effect change from a memorization mode to a critical thinking mode (supported by teacher comments). Also it takes time for students to:
   a. Internalize problem-solving strategies learned in groups.
   b. Learn how to interact positively with other students.
   c. Evoke change in proportional reasoning.

5. This study considered problems that dealt with only one topic in chemistry, stoichiometry. The results may not be generalizable to other problem types.

Implications

The results of this study have several implications for high school chemistry teachers and future research.

**High School Chemistry Teachers**

As a result of this research study and teacher evaluations, consideration should be given to the following suggestions:

1. The use of the prescriptive method for problem solving especially when students encounter a new type of problem.
2. The use of cooperative grouping as an alternative approach for teaching problem solving.
3. More time devoted to conceptual development on a qualitative basis.
4. The use of cooperative grouping to promote interaction skills.
5. The use of videotaping to analyze students' problem-solving behaviors.
6. The decrease in the quantity of assigned problems with greater emphasis on the problem-solving process.

Future Research

Cooperative grouping research needs to be continued in the area of problem solving especially at the secondary level where students are beginning to think formally. Since this study suggests that cooperative grouping is a viable alternative strategy for chemistry problem solving, other factors should be considered such as:

1. Whether problem-solving characteristics of successful groups become internalized.
2. The effect problem-solving in cooperative groups has on retention.
3. The use of cooperative grouping in identifying and changing misconceptions.

Heller and Reif (1984) found that the prescriptive method used in their study was sufficient to generate excellent
problem descriptions and improve subsequent problem solutions. Their work as well as that of Gabel (in press) and Bunce and Heikkinen (1986) was supported by this study.

Research should continue to determine:

1. Whether the prescriptive method can be effective with younger students in promoting critical thinking skills in lieu of memorizing formulas.

2. Whether the prescriptive method promotes retention.

3. Whether the prescriptive method can be adapted to other chemistry problems besides stoichiometry.

The preceding suggestions are based upon the statistical results of this study as well as the videotape analyses, student and teacher comments, and personal observations of these classes.
REFERENCES


APPENDIX A
Permission Forms
Consent Form

I hereby acknowledge that I am voluntarily participating in Joy B. Tingle's dissertation study. I recognize that this research is a study of chemistry problem solving and that I may be audio and/or videotaped while solving problems. I also understand that the report of this study will not identify me by name nor will it have a negative effect on my evaluation in the course.

______________________________  _________________________
Student Signature               Date

______________________________  _________________________
Parent/Guardian Signature       Date
Joy B. Tingle  
412 Carthage Drive  
Houma, LA 70360  
July 16, 1987

Paul W. Fournier, Superintendent  
Terrebonne Parish School Board  
P. O. Box 5097  
Houma, LA 70361

Dear Superintendent Fournier:

I have recently completed my coursework and general examinations required for my doctorate in curriculum and instruction. My dissertation lies in the domain of chemistry problem solving. Research suggests that unless students can reason proportionally, success in chemistry is questionable. Many studies have shown that over 50% of college freshmen have difficulty reasoning proportionally. We can thus infer that the percentage would be higher in secondary school. My dissertation study includes two strategies designed to increase problem solving skills: heterogeneous cooperative grouping based upon initial proportional reasoning skills and prescribed directions for problem solving that emphasize qualitative redescription.

I am writing to gain permission to conduct my proposed study in the public high schools in Terrebonne Parish using three classes of chemistry per school working with three teachers. I have spoken to each teacher and they are extremely interested in trying new ideas designed to assist students in becoming better problem solvers. A pilot study with students in a Chemistry II class will be needed during the first nine weeks since first year chemistry students do not encounter many problems during the initial grading period.

I assure you that I will follow all regulations pertaining to the use of students in research as well as acknowledge the teachers and school system for their contribution. I will conduct the research during my leave of absence as well as bear all costs of the project.
The applicability of this research to other problem solving areas provides an opportunity to expand the focus beyond chemistry. If successful in this research, I hope to be involved in such an effort.

I appreciate the support you have given me in the past and look forward to hearing from you soon.

Sincerely,

Joy B. Tingle
Science Curriculum Specialist
APPENDIX B
Honors Criteria
**Ranking Guide**  
(For placement of students in ability grouped classes.)

**Key for assigning points:**

<table>
<thead>
<tr>
<th>Class</th>
<th>Regular Point Value</th>
<th>High Level Point Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>4</td>
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</tr>
<tr>
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</tr>
<tr>
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<table>
<thead>
<tr>
<th>Percentile IQ</th>
<th>Stanine Point Value</th>
<th>Percentage IQ</th>
<th>Stanine Point Value</th>
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<td>25-40</td>
<td>4</td>
<td>98-99</td>
<td>9</td>
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**Weighted Grades**  
(Add points for each subject needed.)

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<thead>
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<th>NAME</th>
<th>IQ (3 x Point Value = _)</th>
<th>WEIGHTED IQ (3 x Avg Stanine = _)</th>
<th>WEIGHTED STANINES (2 x Sum of 3 Subj Grades = _)</th>
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</tr>
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<tbody>
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<td>Lang</td>
<td>Math</td>
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</tr>
</tbody>
</table>

**SCHOOL_________________________ Grade Level_________
Compiled by__________________________
Date______________________________
Instructions for Initial Placement

1. List all students in the grade level alphabetically in the first column of this form.

2. From each student's cumulative record, obtain student's grades for the subject(s) concerned and his IQ and stanine scores on California Achievement Tests. Record and use this information as described in the following steps.

3. Record student's IQ in the "IQ" column. Obtain student's score for "Weighted IQ" column by adding the value points (shown above the columns) for his IQ scores on the three most recent California Achievement Tests.

4. If student does not have scores from 3 different achievement tests, use scores available to estimate an average IQ. Multiply value points for IQ average by three to obtain score for "Weighted IQ" column.

5. Obtain student's score by subject for "Weighted Stanines" section by adding the value points for his stanines in the subject, taken from the three most recent California Achievement Tests.

6. If student does not have scores from three different achievement tests, use scores available to estimate an average stanine in each subject. Multiply these average stanines by three to obtain scores for each part of the "Weighted Stanines" section.

7. Obtain student's scores for "Weighted Grades" section by adding quality points for his average grade in each specified subject for the current year and two previous years. Then double the sum.

Example: Assume a ninth grade student in regular math has a current average of B, and averages of A in the 6th grade and B in the 7th. You would add 3 + 4 + 3 and double the sum, thus obtaining 20 as his math score for the "Weighted Grades" part.

If grades are not available for all three years, use what you have to estimate an average grade for each subject. Then multiply the quality points for the average grade by three and double the total.

6. Total student's points for "Weighted IQ," "Weighted Stanines," and "Weighted Grades" to obtain a composite score or index number for each subject needed. Follow the chart below.

To calculate composite scores or index numbers for different subject areas, use grades and stanines as follows: (average when necessary)

<table>
<thead>
<tr>
<th>SUBJECT AREA</th>
<th>USE GRADES FOR:</th>
<th>USE STANINES FOR:</th>
</tr>
</thead>
<tbody>
<tr>
<td>English, and</td>
<td>English Avg.</td>
<td>Language Avg.</td>
</tr>
<tr>
<td>Reading</td>
<td>Reading</td>
<td></td>
</tr>
<tr>
<td>Mathematics</td>
<td>Mathematics</td>
<td>Mathematics</td>
</tr>
<tr>
<td>Science</td>
<td>Science</td>
<td>Mathematics</td>
</tr>
<tr>
<td>Social Studies</td>
<td>Social Studies</td>
<td>Reading Avg.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ref. Skills</td>
</tr>
<tr>
<td>Foreign Language</td>
<td>Foreign Language (or Reading and English)</td>
<td>Language Avg.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Reading</td>
</tr>
</tbody>
</table>

7. Use scale below to place students in high level (H), regular (R), or low level (L) classes.

<table>
<thead>
<tr>
<th>Class</th>
<th>Range of Scores</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>2 - 33</td>
</tr>
<tr>
<td>R</td>
<td>34 - 53</td>
</tr>
<tr>
<td>H</td>
<td>54 - 84</td>
</tr>
</tbody>
</table>
APPENDIX C
Pilot Study
Pilot Study

A pilot study (n = 55) was conducted for a three-week period in two physics classes representing the entire physics population in a public high school in a rural south Louisiana parish during the beginning of the fall semester, 1987. Physics students were used in the pilot since introductory chemistry classes do not encounter problem solving until later in the semester.

Prior to beginning the study, the TOLT was administered. Forty-six percent of the students in one class (12/26) and 48% of the students in the other class (14/29) responded correctly to the proportional reasoning items. These results are similar to the findings in a study conducted by McKinnon and Renner (1971) with college freshman. Using the results of the TOLT, students in one class were randomly placed in heterogeneous groups of four based upon proportional reasoning ability when solving physics problems. Each group contained two students who had answered both proportional reasoning items correctly (proportional reasoners), one student who had answered one item correctly (transitional reasoner), and one student who had answered both incorrectly (nonproportional reasoner). In order to satisfy student questions as to how the groups were determined, students were informed that the groups were based upon proportional reasoning ability, but individual
results of the TOLT were not made available. The control treatment class was required to solve physics problems on an individual basis.

Inservice for the teacher was provided to acquaint her with cooperative grouping and problem prescription and to clarify her role in working with both physics groups. Whole class instruction for both classes included conceptual information mandated by a parish curriculum guide in physics addressing the concepts of speed, velocity, and acceleration as well as problem prescription.

Problem sets consisting of velocity and acceleration problems were completed in both classes during class time so that afterschool problem solving would not become a factor in the study. Even though this type of problem involved plugging numbers into a formula, proportional reasoning was involved in predicting an answer based upon an initial situation.

Classroom observations as well as analyses of the verbal protocols revealed a change in attitude between the control treatment and experimental treatment classes. Due to a last minute substitution of personnel, students in both classes were antagonistic toward the teacher and uncooperative. The students resisted everything that the teacher did that was not similar to the techniques employed by their last year chemistry teacher who was supposed to be their physics
teacher. These students made negative comments about the
teacher and often refused to complete any of the assignments.
After grouping one class, students began to enter the room
asking in a polite and eager way if they were going to be able
to work problems in groups that day. The other class continued
to be antagonistic throughout the study.

Classroom observations and verbal protocols also suggested
the following:
1. The time on task was greater in the groups as evidenced
by students conversing with each other about the
problems in question as opposed to some students
working alone, who looked out of the window and even
slept in class.
2. Students working problems individually complained more
about using the prescription than the students working
in groups.
3. Both classes had difficulty with prediction, but the
teacher indicated that the students in groups tended to
predict better on the test than the other students.
4. Students in groups tended to derive formulas more often
than plugging numbers into a memorized formula.
5. Groups of four often divided themselves into two groups
of two or one student was left out of the interaction.

As a result of the pilot study, plans to use groups of three
were implemented in the dissertation study. More examples of
problems adapted to the prescriptive method were provided
with an emphasis on prediction. Interaction skills were
stressed often with students emphasizing the functioning of
the group as a whole.
Directions

A series of eight problems is presented. Each problem will lead to a question. Record the answer you have chosen and reason for selecting that answer.

<table>
<thead>
<tr>
<th>Problem</th>
<th>Best Answer</th>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Put your answers to questions 9 and 10 below:

9. TJD SAH   10. BDGC
   ___     ___  ___     ___  ___     ___  ___     ___  ___     ___  ___     ___  ___     ___  ___     ___  ___     ___  ___     ___  ___     ___  ___     ___  ___     ___  ___     ___  ___     ___  ___     ___  ___     ___  ___     ___  ___     ___  ___     ___  ___     ___  ___     ___  ___     ___  ___     ___  ___     ___  ___     ___  ___     ___  ___     ___  ___     ___  ___     ___  ___     ___  ___     ___  ___     ___  ___     ___  ___     ___  ___     ___  ___     ___  ___     ___  ___     ___  ___     ___  ___     ___  ___     ___  ___     ___  ___     ___  ___     ___  ___     ___  ___
Item 1  Orange Juice #1

Four large oranges are squeezed to make six glasses of juice. How much juice can be made from six oranges?

a. 7 glasses
b. 8 glasses
c. 9 glasses
d. 10 glasses
e. other

Reason:
1. The number of glasses compared to the number of oranges will always be in the ratio 3 to 2.
2. With more oranges, the difference will be less.
3. The difference in the numbers will always be two.
4. With four oranges the difference was 2. With six oranges the difference would be two more.
5. There is no way of predicting.

Item 2  Orange Juice #2

How many oranges are needed to make 13 glasses of juice?

a. 6 1/2 oranges
b. 8 2/3 oranges
c. 9 oranges
d. 11 oranges
e. other

Reasons:
1. The number of oranges compared to the number of glasses will always be in the ratio 2 to 3.
2. If there are seven more glasses, then five more oranges are needed.
3. The difference in the numbers will always be two.
4. The number of oranges will be half the number of glasses.
5. There is no way of predicting the number of oranges.
Suppose you wanted to do an experiment to find out if changing the length of a pendulum changed the amount of time it takes to swing back and forth. Which pendulums would you use for the experiment?

a. 1 and 4  
b. 2 and 4  
c. 1 and 3  
d. 2 and 5  
e. all

Reason:

1. The longest pendulum should be tested against the shortest pendulum.

2. All pendulums need to be tested against one another.

3. As the length is increased the number of washers should be decreased.

4. The pendulums should be the same length but the number of washers should be different.

5. The pendulums should be different lengths but the number of washers should be the same.
Suppose you wanted to do an experiment to find out if changing the weight on the end of the string changed the amount of time the pendulum takes to swing back and forth. Which pendulums would you use for the experiment?

a. 1 and 4  
b. 2 and 4  
c. 1 and 3  
d. 2 and 5  
e. all

Reason:

1. The heaviest weight should be compared to the lightest weight.

2. All pendulums need to be tested against one another.

3. As the number of washers is increased the pendulum should be shortened.

4. The number of washers should be different but the pendulums should be the same length.

5. The number of washers should be the same but the pendulums should be different lengths.
A gardener bought a package containing 3 squash seeds and 3 bean seeds. If just one seed is selected from the package what are the chances that it is a bean seed?

a. 1 out of 2
b. 1 out of 3
c. 1 out of 4
d. 1 out of 6
e. 4 out of 6

Reasons:

1. Four selections are needed because the three squash seeds could have been chosen in a row.
2. There are six seeds from which one bean seed must be chosen.
3. One bean seed needs to be selected from a total of three.
4. One half of the seeds are bean seeds.
5. In addition to a bean seed, three squash seeds could be selected from a total of six.
A gardener bought a package of 21 mixed seeds. The package contents listed:

3 short red flowers
4 short yellow flowers
5 short orange flowers
4 tall red flowers
2 tall yellow flowers
3 tall orange flowers

If just one seed is planted, what are the chances that the plant that grows will have red flowers?

a. 1 out of 2
b. 1 out of 3
c. 1 out of 7
d. 1 out of 21
e. other

Reason:

1. One seed has to chosen from among those that grow red, yellow or orange flowers.

2. 1/4 of the short and 4/9 of the tall are red.

3. It does not matter whether a tall or a short is picked. One red seed needs to be picked from a total of seven red seeds.

4. One red seed must be selected from a total of 21 seeds.

5. Seven of the twenty-one seeds will produce red flowers.
Item 7

The Mice

The mice shown represent a sample of mice captured from a part of a field. Are fat mice more likely to have black tails and thin mice more like to have white tails?

a. Yes
b. No

Reason:

1. 8/11 of the fat mice have black tails and 3/4 of the thin mice have white tails.

2. Some of the fat mice have white tails and some of the thin mice have white tails.

3. 18 mice out of thirty have black tails and 12 have white tails.

4. Not all of the fat mice have black tails and not all of the thin mice have white tails.

5. 6/12 of the white tailed mice are fat.
Item 8

Are fat fish more likely to have broad stripes than thin fish?

a. Yes

b. No

Reason:

1. Some fat fish have broad stripes and some have narrow stripes.

2. 3/7 of the fat fish have broad stripes.

3. 12/28 are broad striped and 16/28 are narrow striped.

4. 3/7 of the fat fish have broad stripes and 9/21 of the thin fish have broad stripes.

5. Some fish with broad stripes are thin and some are fat.
Three students from grades 10, 11, and 12 were elected to the student council. A three member committee is to be formed with one person from each grade. All possible combinations must be considered before a decision can be made. Two possible combinations are Tom, Jerry and Dan (TJD) and Sally, Anne and Martha (SAM). List all other possible combinations in the spaces provided.

(Delete spaces are provided on the Answer Sheet than you will need.)

STUDENT COUNCIL

<table>
<thead>
<tr>
<th>Grade 10</th>
<th>Grade 11</th>
<th>Grade 12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tom (T)</td>
<td>Jerry (J)</td>
<td>Dan (D)</td>
</tr>
<tr>
<td>Sally (S)</td>
<td>Anne (A)</td>
<td>Martha (M)</td>
</tr>
<tr>
<td>Bill (B)</td>
<td>Connie (C)</td>
<td>Gwen (G)</td>
</tr>
</tbody>
</table>

Item 10

The Shopping Center

In a new Shopping Center, 4 store locations are going to be opened on the ground level.

A BARBER SHOP (B), a DISCOUNT STORE (D), a GROCERY STORE (G), and a COFFEE SHOP (C) want to move in there. Each one of the stores can choose any one of four locations. One way that the stores could occupy the 4 locations is BDGC. List all other possible ways that the stores can occupy the 4 locations.

(Delete spaces are provided on the Answer Sheet than you will need.)
APPENDIX E
Mr. Tall/Mr. Short
THE RATIO PUZZLE

The figure at the left is called Mr. Short. We used large round buttons laid side-by-side to measure Mr. Short's height, starting from the floor between his feet and going to the top of his head. His height was four buttons. Then we took a similar figure called Mr. Tall, and measured it in the same way with the same buttons. Mr. Tall was six buttons high.

Now please do these things:

1. Measure the height of Mr. Short using paper clips in a chain provided. The height is ________

2. Predict the height of Mr. Tall if he were measured with the same paper clips. ________

3. Explain how you figured out your prediction. (You may use diagrams, words, or calculations. Please explain your steps carefully.)

        [Space for answers]
APPENDIX F
Attitude Survey
Attitude Survey

Directions: Please indicate how you feel about each statement by marking your answer sheet according to the following scale:

1 = Strongly agree
2 = Agree
3 = Undecided
4 = Disagree
5 = Strongly disagree

1. Chemistry is not a very interesting subject.
2. I want to develop my science skills and study chemistry more.
3. Chemistry is a very worthwhile and necessary subject.
4. Chemistry makes me feel nervous and uncomfortable.
5. I have enjoyed studying physical chemistry this semester.
6. I don't want to take any more chemistry than I have to.
7. Other subjects are more important to people than chemistry.
8. I am very calm when solving word problems.
9. I have seldom liked solving word problems.
10. I am interested in taking more classes like this one.
11. Chemistry helps to develop the mind and teaches me to think.
12. Chemistry problem solving makes me feel uneasy and confused.
13. Chemistry is enjoyable and stimulating to me.
14. I am not willing to take more than the required amount of chemistry.
15. Chemistry is not especially important in everyday life.
16. Trying to understand chemistry doesn't make me anxious.
17. Chemistry is dull and boring.
18. I plan to take as much chemistry as I can during my education.
19. Chemistry has contributed greatly to the advancement of civilization.
20. Chemistry is one of my most dreaded subjects.
21. I like trying to solve new problems in chemistry.
22. I am not motivated to work very hard on chemistry lessons.
23. Chemistry is not one of the most important subjects for people to study.
24. I don't get upset when trying to do chemistry problems.
|   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| 1 |   |   |   | 13|   |
| 2 |   |   |   | 14|   |
| 3 |   |   |   | 15|   |
| 4 |   |   |   | 16|   |
| 5 |   |   |   | 17|   |
| 6 |   |   |   | 18|   |
| 7 |   |   |   | 19|   |
| 8 |   |   |   | 20|   |
| 9 |   |   |   | 21|   |
|10 |   |   |   | 22|   |
|11 |   |   |   | 23|   |
|12 |   |   |   | 24|   |

Chemistry Pretest
APPENDIX G
Chemistry Pretest
CHEMISTRY PRETEST

Directions: All student responses are to be recorded on the answer sheet. There is only one best answer to every question. Hand calculators are permitted. Please show any scratch work on the answer sheet. This is not for a grade but do the best that you can.

1. Which set consists only of compounds?
   (1) Na, Ca, He
   (2) H_2O^+, Cl^-, I^-
   (3) NaCl, CH_4, Br_2
   (4) H_2S, CuCl_2, KI

2. What is the mass of one mole of calcium phosphate, Ca_3(PO_4)_2?
   (1) 215 g
   (2) 278 g
   (3) 279 g
   (4) 310 g

3. An unknown compound was found to contain only carbon and hydrogen in a mass ratio of 6.0 g C to 1.0 g H. What is the empirical (simplest) formula of this compound?
   (1) CH
   (2) CH_2
   (3) C_6H
   (4) CH_6

4. Based on the position of the elements in the periodic chart, the most likely formula for strontium nitride is
   (1) Sr_2N_5
   (2) Sr_5N_2
   (3) Sr_2N_3
   (4) Sr_3N_2

5. What is the correct name for Fe(NO_3)_2?
   (1) Iron(II) nitrate
   (2) Iron(II) nitrite
   (3) Iron(III) nitrate
   (4) Iron(III) nitrite

6. The expression
   Cu + 2 H_2SO_4 \rightarrow CuSO_4 + 2 H_2O + ?
can be balanced by adding which missing product?
   (1) H_2
   (2) S
   (3) SO_2
   (4) H_2SO_3

7. How many moles of oxygen, O_2, are needed to produce 9 moles of carbon dioxide, CO_2?
   (1) 15
   (2) 6
   (3) 3
   (4) 4

8. Approximately how many molecules are in 11 g of carbon dioxide, CO_2, gas?
   (1) 1.5 \times 10^{23}
   (2) 3.0 \times 10^{23}
   (3) 6.0 \times 10^{23}
   (4) 2.4 \times 10^{23}
9. A substance with a molecular weight of 92 consists of equal numbers of S and N atoms. What is the formula of the substance?

(1) SN  (2) S₂N₂  (3) S₃N₃  (4) S₄N₄

10. The formula for ytterbium sulfate is Yb₂(SO₄)₃. What is the formula for ytterbium chloride?

(1) YbCl₂  (3) Yb₂Cl₂
(2) Yb₂Cl₃  (4) YbCl₃

11. When this expression is balanced, 

\[ 2 \text{C}_3\text{H}_6 + \text{O}_2 \rightarrow \text{CO}_2 + 6\text{H}_2\text{O} \]

what is the coefficient of oxygen, O₂?

(1) 6  (2) 9  (3) 12  (4) 18

12. What mass of calcium hydroxide, Ca(OH)₂, is obtained from 18.7 grams of calcium oxide, CaO?

\[ \text{CaO} + \text{H}_2\text{O} \rightarrow \text{Ca(OH)}_2 \]

(1) 18.7 g  (3) 56.1 g
(2) 24.7 g  (4) 74.1 g
Directions: Write a balanced chemical equation for the following problems below.

13. A student placed aluminum metal into a water solution of hydrogen chloride. All of the aluminum reacted to form aluminum chloride and hydrogen gas. No precipitate was observed. The student later evaporated the water to leave solid aluminum chloride.

14. Once ignited, magnesium burns brilliantly with an intense flame producing a white powder, magnesium oxide.
APPENDIX H
Chemistry Curriculum Guide
## IV. CHEMICAL SHORTHAND

| A. Elements and Symbols; Atomic Number |
| B. Compounds and Formulas; Atomic Weight and Formula Weight |
| C. Oxidation Numbers |
| D. Polyatomic Ions |
| E. Diatomic Molecules |
| F. Binary Compounds |
| 1. Nomenclature |
| 2. Empirical/Molecular Formulas |
| 3. Coefficients |

### G. Reactions

1. Reactants/Products
2. Steps in Balancing
3. Classification
   a. Composition
   b. Decomposition
   c. Single Replacement
   d. Double Replacement
4. Energy in chemical changes (Exothermic/Endothermic)

## COMPETENCY/PERFORMANCE OBJECTIVE

IV. The student will be able to:

* **A.** Recognize the symbols for elements with atomic numbers.

* **B.** Distinguish between symbol and formulas; atomic weight and formula weight.

* **C.** Write a simple formula of chemical compounds using oxidation numbers (atomic numbers 1 through 30).

* **D.** Identify polyatomic ions in a formula and use them in writing a formula.

* **E.** Identify $H_2$, $O_2$, $N_2$, $Cl_2$, $F_2$, $Br_2$, and $I_2$ as diatomic molecules.

* **F 1.** Use Greek prefixes or Roman numerals in naming simple binary compounds.

* **F 2.** Differentiate between empirical and molecular formulas.

* **F 3.** Define a formula unit.

* **G 1.** Balance equations representing four different classifications of reactions.

* **G 2.** Distinguish between exothermic and endothermic.

* **Minimum Competencies**
V. THE ATOM

A. Atomic Theory
   1. Origin
   2. Law of Definite Proportions
   3. Dalton's Hypothesis
   4. Law of Multiple Proportions

B. Atomic Structure
   1. Protons, neutrons, electrons
   2. Atomic No./Mass No.
   3. Isotopes
   4. Size and Dimension

V. THE ATOM

A. Atomic Theory
   1. Discuss the origin of the atomic theory.
   2. State the Law of Definite Proportions.
   3. List components of Dalton's Hypothesis.

B. Atomic Structure
   1. Differentiate among the properties: charge, relative mass, location of the electron, proton, and neutron.
   2. Determine the atomic and mass numbers of atoms.
   3. Select isotopes from a list of elements using the atomic numbers and atomic mass numbers.
   4. Compare the approximate dimensions (radii or diameters) of the nucleus and the atom.
### COURSE OUTLINE

<table>
<thead>
<tr>
<th>VIII. STOICHIOMETRY AND THE MOLE</th>
<th>VIII. COMPETENCY/PERFORMANCE OBJECTIVE</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Avogadro's Number and the Mole</td>
<td>VIII. The student will be able to:</td>
</tr>
<tr>
<td></td>
<td>*A. State Avogadro's number.</td>
</tr>
<tr>
<td>B. Chemical Calculations</td>
<td>B 1. Define formula mass.</td>
</tr>
<tr>
<td>2. Percentage Composition</td>
<td>*B 3. Determine the number of moles and number of particles in the mass of a given substance.</td>
</tr>
<tr>
<td></td>
<td>*B 5. Determine the molecular formula given the molecular mass and the empirical formula.</td>
</tr>
</tbody>
</table>
APPENDIX I
Chemistry Posttest
Dependent Measure

Multiple-Choice:

1. How many grams of water will be formed when 32 grams of hydrogen and 32 grams of oxygen are mixed and allowed to react?

\[ 2\text{H}_2 + \text{O}_2 \rightarrow 2\text{H}_2\text{O} \]

(A) 18  (B) 2.0  (C) 36  (D) 64

*ACS Concept: Mass/mass - Limiting reagent

2. The equation representing the complete combustion of vitamin C is:

\[ \text{C}_6\text{H}_8\text{O}_6 + 5\text{O}_2 \rightarrow 6\text{CO}_2 + 4\text{H}_2\text{O} \]

What is the number of moles of oxygen needed for the complete combustion of 3 moles of vitamin C?

(A) 0.600  (B) 5.00  (C) 15.0  (D) 160

*ACS Concept: Mole/mole ratio

3. The molecular formula for glucose is \( \text{C}_6\text{H}_{12}\text{O}_6 \). What is the empirical formula?

(A) \( \text{CHO} \)  (C) \( \text{C}_3\text{H}_6\text{O}_3 \)

(B) \( \text{CH}_2\text{O} \)  (D) \( \text{CH}_2\text{O}_3 \)

*ACS Concept: Molecular/Empirical Formulas

4. Consider the equation:

\[ 2\text{Al(OH)}_3 \rightarrow \text{Al}_2\text{O}_3 + 3\text{H}_2\text{O} \]

When 15.0 grams of aluminum hydroxide, \( \text{Al(OH)}_3 \) is decomposed, how many grams of water will be formed?

(A) 3.86 g  (B) 5.19 g  (C) 4.20 g  (D) 22.5 g

*ACS Concept: Mass/Mass
5. Consider the equation: \(2\text{NO} + \text{O}_2 \rightarrow 2\text{NO}_2\)

Given 10 molecules of NO and 8 molecules of oxygen, how many molecules of \(\text{NO}_2\) can be formed?

(A) 10  (B) 20  (C) 16  (D) 18

*Heath Chemistry  Concept: Molecules/Moles  Limiting Reagent

6. Acetylene gas is used for welding. Acetylene contains 30 grams of carbon for each 2.5 grams of hydrogen. What is the empirical formula?

(A) \(\text{C}_2\text{H}_2\)  (B) \(\text{C}_2\text{H}\)  (C) \(\text{CH}\)  (D) \(\text{CH}_2\)

*Heath Chemistry  Concept: Empirical Formula

7. A compound that has the empirical formula \(\text{CH}\) and the molecular mass of 78 amu would have the molecular formula of ___.

(A) \(\text{CH}\)  (B) \(\text{C}_3\text{H}_6\)  (C) \(\text{C}_6\text{H}_6\)  (D) Not enough information

*Heath Chemistry  Concept: Molecular Formula
Use the prescriptive method to solve the following problems.

8. Determine the empirical formula for a compound that is 79.9% copper and 20.1% sulfur.

*Heath Chemistry Concept: Empirical Formula

9. Methyl alcohol, CH₃OH, combines with oxygen to form carbon dioxide and water. How many grams of oxygen are required to burn 34.5 grams of methyl alcohol?

*Heath Chemistry Concept: Mass/mass

10. How many moles of iron (III) chloride, FeCl₃, could be made with 1.81 x 10²³ atoms of chlorine and the appropriate number of iron atoms?

*Heath Chemistry Concept: Atoms/Moles

*Source
APPENDIX J
Student Work from Posttest
Determine the empirical formula for a compound.

Known:
79.9% copper
30.1% sulfur

79.9 g

\[
\text{Cu} \\
1 \text{ mol} \\
0.35 g
\]

3% of a mol

\[
16.49 \text{ g Cu} \\
83.19 \text{ g S}
\]

\[
\frac{16.49}{83.19} = 0.2 \text{ mol}
\]

There will be more Cu than S.

\[
79.9 \text{ g Cu} \times \frac{1 \text{ mol}}{63.59 g} = 1.26 \text{ mol}
\]

\[
\frac{1.26}{0.2} = 6.3 \text{ mol}
\]

\[
20.15 \text{ g S} \times \frac{1 \text{ mol}}{32.1 g} = 0.626 \text{ mol}
\]

\[
\frac{0.626}{1.26} = 0.5
\]

\[
\boxed{\text{Cu}_2\text{S}}
\]

There are more Cu than S.
Determine the empirical formula for a compound that is 19.9% copper and 20.1% sulfur.

Given: 19.9 g copper
20.1 g sulfur

Unknown: empirical formula

<table>
<thead>
<tr>
<th>Substance</th>
<th>Mass (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper</td>
<td>19.9</td>
</tr>
<tr>
<td>Sulfur</td>
<td>20.1</td>
</tr>
</tbody>
</table>

\[
\text{Cu: } \frac{19.9}{19.9} = 1 \quad \text{and} \quad \text{S: } \frac{20.1}{32.1} = 0.63
\]

Prediction: the empirical formula will be \( \text{Cu}_2\text{S} \).

Check: As predicted, the empirical formula is \( \text{Cu}_2\text{S} \).
Methyl alcohol, $\text{CH}_3\text{OH}$, can burn with oxygen to form carbon dioxide and water. How many grams of oxygen are required to burn 34.5 g of methyl alcohol?

**Given:**

$$2\text{CH}_3\text{OH} + 3\text{O}_2 \rightarrow 2\text{CO}_2 + 4\text{H}_2\text{O}$$

**Unknown:** grams of Oxygen

- 32.0 g O₂
- 32.0 g O₂
- 32.0 g O₂

32.0 g CH₃OH

64 g CH₃OH

About 52 grams of oxygen

$$\frac{96}{64} = \frac{64}{x}$$

$$\frac{64x}{64} = \frac{336}{64}$$

$$x = 51.75$$

**Good Thinking**

Results agree with prediction.
14.) Methyl alcohol, CH₃OH, combines with Oxygen to form carbon dioxide and water. How many grams of Oxygen are required to burn 34.5 g of methyl alcohol?

Given:

\[ 2\text{CH}_3\text{OH} + 3\text{O}_2 \rightarrow 2\text{CO}_2 + 4\text{H}_2\text{O} \]

\[ \text{mole CH}_3\text{OH} = 32.0 \text{ g CH}_3\text{OH} \]

\[ \text{mole ratio} = 3:2 \]

\[ \text{1 mole O}_2 = 32.0 \text{ g O}_2 \]

\[ 1.16 \text{ moles CH}_3\text{OH} \text{ is the prediction.} \]

\[ 1.5 \text{ moles O}_2 \]

\[ \text{Excellent} \]

\[ \frac{34.5 \text{ g CH}_3\text{OH}}{32.0 \text{ g CH}_3\text{OH}} \]

\[ \frac{3 \text{ moles O}_2}{2 \text{ moles CH}_3\text{OH}} \]

\[ \frac{32.0 \text{ g O}_2}{1 \text{ mole O}_2} \]

\[ 51.8 \text{ g O}_2 \text{ would be required to burn 34.5 g CH}_3\text{OH.} \]

ON BACK for # 45
APPENDIX K
Limiting Reagent Problem Set
Limiting Reagent Problem Set

Directions: Use an explanation based upon the prescriptive method to solve the following problems.

1. Which, if either, has more atoms, 30 grams of oxygen or 30 grams of chlorine? Explain your answer.

*Goodstein & Howe Concept: Grams/moles/atoms

2. 35 grams of chlorine are reacted with 35 grams of sodium to form NaCl. Is there exactly enough of each or will sodium be left over or will chlorine be left over? Explain your answer.

*Goodstein & Howe Concept: Mass/Mass Limiting Reagent

3. If 15.5 grams of aluminum are reacted with 46.7 grams of chlorine gas, then aluminum chloride, AlCl₃, is formed.
   a. Which reactant is in excess?
   b. Calculate the number of grams of excess.
   c. Calculate the mass of aluminum chloride produced.

*Heath Chemistry Concept: Mass/mass Limiting Reagent

*Source
APPENDIX L
Teacher Critiques
Teacher Critiques

School A

"As a teaching tool, the prescriptive plan was somewhat effective. Students have very poor reasoning skills. They've been conditioned to memorize formulas and steps to solutions without understanding why a procedure is followed. Requiring students to sketch what is given in a problem and develop a solution encourages them to reason and analyze.

Students resisted using the plan because it was time consuming and they lacked the patience needed. While some students were able to grasp an understanding after some time, many remain unsure and unable to design a solution. Perhaps this method should begin much sooner.

The students in a group were more efficient in problem solving and were more willing to work. They also experience less frustration than the students working individually.

Much time was required to grade problem sets using the plan, however as an indicator of students' understanding of concepts, it was excellent."
School B

"While participating in this program, I have come to realize that grouping will have many advantages. Although there were no extreme changes in this short period of time, I did see the frustration level of the students decrease considerably. Those students in groups who are generally poor problem solvers became more confident while attempting to solve the problems.

Throughout this study, however, I did note a difference between my honors and regular classes. The ability to group the material seemed to take much longer in the regular grouped class than it did in the ungrouped honors class. The length of retention was also greater for the ungrouped honors class than it was for the grouped regular class.

More time should be given to this program. If this is done, I feel that there will be a significant difference in the performance level of the students in the groups. I intend to utilize this program for the remainder of the year. However, I do not feel that it should be used exclusively. The students tended to become restless and uninterested after several weeks of using this same method of instruction.

In viewing the videotapes of each class, I found that the groups had very good interaction with one another. In
some instances the students would tend to allow one of the students to explain the problems. The other students would recognize the explanation and would offer suggestions that would enhance the discussion. I also found that when in a group situation, if the answer did not agree with the prediction, the group would work with each other to discover what they had done incorrectly. In determining the correct process, the group would utilize the knowledge of all the students. At this point they did not leave it up to only one person to explain.

The groups also tried to be sure that everyone had the same results using the steps provided. The problem that the students most often experienced was that they were not able to understand how to make their predictions when it involved more than one process. The groups were always eager to share their information. That information may have been only to complete the calculation on the calculator.

When the groups were not successful in solving the problem, they sometimes became quiet or would begin to talk about other subjects. At this point they would need reassurance and instruction in the process by the instructor. The groups did not tend to give up as quickly as the those that were not grouped.
The students who were not grouped tended to experience moments of anxiety and frustration with each other. They were not able to interact with one another as well as those that were grouped. The students that were not grouped were not able to determine the best way to solve the problem as often as those that were grouped. They were not as step orientated as those in a group. These students looked to the other to explain the problem. In the classroom, these students relied on the instructor to help him get through the initial steps. They were less able to think through the problem whether they were in an honors class or not if they were not grouped.

All of these viewpoints were seen in some extent in both the groups and the individual students. Whether the students were in a group or not, they all did their best to perform as effectively as possible throughout the duration of this program."
School C

"It was with a great deal of enthusiasm that I agreed to cooperate with Joy Tingle on her research for her doctorate studies. There has been a great deal of emphasis placed on problem solving recently on the national level and I was anxious to try some of these new ideas in my classroom. Working in groups is always a challenge and working in groups to solve problems really sounded like an excellent opportunity to put into practice some of these new motivational and problem solving techniques.

Ms. Tingle selected my two physics classes as the subjects in her preliminary study. She tested both classes for their analytical thinking skills then divided one class into groups of four with one analytical thinker in each group. The other class was asked to work individually with only the aid of the instructor and the text. Each class was requested to follow the same prescription procedure in solving problems. No work was allowed outside of class. The class which was grouped seemed to progress more rapidly and to gain more insight into the concept of the problem. This group just simply seemed to enjoy physics more and were more enthusiastic. The class which was not grouped often complained about having to follow the prescription procedure and just wanted to solve the problems by putting the facts.
given into a formula and getting 'the answer'. The picture was one of the most difficult parts of the procedure for both classes to group.

After the preliminary study, two of my chemistry classes were also tested to identify the analytical thinkers in each class. Again one class was divided into groups of four with one analytical thinker in each group. The grouped class benefited from their discussions and were able to grasp the concept of the mole and mass-mass relation more quickly and easily. The class which was not grouped was not as eager to try to visualize the mole by drawing pictures and often said it was just plain stupid. Again instead of trying to visualize the concept they just wanted to plug everything into a formula and get the answer. Some students however, became so proficient at doing their drawings and making estimations they did not even need to use the formula to get the correct answer. By the end of the study almost all the subjects, grouped and ungrouped could solve their chemistry problems using the prescription procedure, although there were a few who never completely mastered the method of estimating.

The major drawback in this method was that not all students in the groups participated equally. Some students relied on the analytical thinker in their group to solve the
problem, then copied or signed their names to the group assignment for a group grade. When evaluation time came they could not do the work on their own. The other students in the group also resented the fact that they could get away with this. Several incentives were tried to overcome this problem and worked in most cases.

Although the prescriptive procedure required more time to solve each problem, because of the drawings and estimations, the subjects seemed to gain a better understanding of the overall concept of the mole and of the relationship between masses in a chemical reaction. A combination of the prescription procedure for solving a problem and of groups with one analytical thinker in each was very successful in my classes and I plan to use this technique in the future. This prescription procedure of problem solving can be utilized by the students in other classes in high school and college as well as for solving problems in their everyday lives."
APPENDIX M
Student Work from Videotapes
1. O - $16.0\times30g = 480$ atoms in $30g \text{O}$.
   Cl - $35.5\times30g = 1065$ atoms in $1065g \text{Cl}$.
   Chlorine has more atoms than oxygen.

2. Na 230  
   Cl - 35.5  
   $\frac{58.5}{70.0} \div 11.5 \times 2 = 5.75$  

5.8g of Na and 5.8g of Cl will be left over.

No understanding.

Adding and subtracting unlike quantities.
1. \[ \text{Oxygen} \quad \begin{array}{c} 16g \\ \text{1 mole} \end{array} \quad \rightarrow \quad \begin{array}{c} 30g \\ \text{2 mole} \end{array} \quad \text{Chlorine} \quad \begin{array}{c} 35.49g \\ \text{1 mole} \end{array} \quad \rightarrow \quad \begin{array}{c} 30g \\ \text{6/7 mole} \end{array} \]

\[ \text{= Oxygen} \]

2. \[ \text{Cl}_2 + 2\text{Na} \rightarrow 2\text{NaCl} \quad (1:2) \]

\[ \quad \begin{array}{c} 70g \\ \text{1 mole Na} \end{array} \quad \begin{array}{c} 23g \\ \text{1 mole Cl}_2 \end{array} \]

\[ \begin{array}{c} 35g \\ \text{1 mole} \end{array} \quad \begin{array}{c} 70g \\ \text{5 mole} \end{array} \]

\[ \text{Sodium will be left} \]

3. \[ \text{2Al} + 3\text{Cl}_2 \rightarrow 2\text{AlCl}_3 \quad (2:3) \]

\[ \quad \begin{array}{c} 70g \\ \text{1 mole Al} \end{array} \quad \begin{array}{c} 23g \\ \text{1 mole Cl}_2 \end{array} \]

\[ \begin{array}{c} 15.5g \\ \text{1 mole} \end{array} \quad \begin{array}{c} 27g \\ \text{57 mole} \end{array} \]

\[ \begin{array}{c} 46.7g \\ \text{1 mole} \end{array} \quad \begin{array}{c} 70g \\ \text{187 mole} \end{array} \]

\[ \text{Al} = 1 \times 27 = 27 \]

\[ \text{Cl} = 3 \times 35 = 105 \]

\[ = 132 \]
11. 15.5 grams of aluminum are reacted with 46.7 grams of chlorine gas, then aluminum chloride, AlCl₃, is formed.

\[
A. \ 2\text{Al} + 3\text{Cl}_2 \rightarrow 2\text{AlCl}_3
\]

\[
1. \ 15.5\,\text{g Al} \quad \rightarrow \quad 1\text{mol Al} = 0.574\,\text{mol Al}
\]

\[
2. \ 46.7\,\text{g Cl} \quad \rightarrow \quad 1\text{mol Cl} = 1.32\,\text{mol Cl}
\]

Step 2. Mole Ratio

2 moles Al : 3 moles Cl

Step 3

\[
0.574\,\text{mols Al} \quad \rightarrow \quad 0.861\,\text{mols Cl}
\]

Step 4. Compare: 0.861 moles Cl to moles of Cl in step 1.

1.861 moles Cl to 1.32 moles Cl

0.574 mol Al will react with 0.861 mol Cl, but 1.32 moles Cl is available. Cl is in excess.

The limiting reactant is Al.
APPENDIX N
Sample Problems
Problem Prescription
Moles From a Given Mass

I. PROBLEM: Copy the problem and underline key words or phrases.

How many moles are represented by 11.5 g of C₂H₅OH?

II. REDESCRIPTION: Be sure to include units.
A. Given: Unknown:

   11.5 g C₂H₅OH
   46.0 g C₂H₅OH

   ? moles of C₂H₅OH

B. PICTURE: Label the diagram or sketch.

   ![Diagram showing 11.5 g and 46.0 g](image)

III. PREDICTION OR ESTIMATION:

   Approximately 1/4 mole or .25 mole

IV. MATHEMATICAL SOLUTION:

   \[
   \frac{11.5 \text{ g}}{46.0 \text{ g}} \times \frac{1 \text{ mole}}{1 \text{ mole}} = \frac{0.249 \text{ mole}}{1 \text{ mole}}
   \]

   or

   \[
   \frac{11.5 \text{ g}}{46.0 \text{ g}} = \frac{0.249 \text{ mole}}{1 \text{ mole}}
   \]

V. CHECK: Answer makes sense with prediction
Problem Prescription
Empirical Formula

I. **PROBLEM:** Copy the problem and underline key words or phrases.

What is the empirical formula for a compound if a 2.50 g sample contains 0.900 g of calcium and 1.60 g of chlorine?

II. **REDESCRIPTION:** Be sure to include units.

A. Given: Unknown:

| .900 g Ca | \( \text{Ca}_x \text{Cl}_x \) |
| 1.60 g Cl |

Ca + Cl = 2.50 g

1 mole Ca = 40.1 g
1 mole Cl = 35.5 g

B. PICTURE: Label the diagram or sketch.

III. **PREDICTION OR ESTIMATION:**

\( \frac{1}{40} \text{ mole Ca} \quad \frac{1}{20} \text{ mole Cl} \)

\# moles Cl > \# moles Ca < 1

IV. **MATHEMATICAL SOLUTION:**

\[
\begin{align*}
\frac{40.1 \text{ g}}{1 \text{ mole}} &= \frac{.9 \text{ g}}{1 \text{ mole}} \\
&\quad \quad \quad \frac{35.5 \text{ g}}{1 \text{ mole}} = \frac{1.6 \text{ g}}{1 \text{ mole}}
\end{align*}
\]

\[
\begin{align*}
\frac{.9 \text{ g}}{40.1 \text{ g}} &= \frac{.0224}{1 \text{ mole}} \quad \text{or} \quad \frac{1.6 \text{ g}}{35.5 \text{ g}} &= \frac{.045}{1 \text{ mole}}
\end{align*}
\]

Ratio: \( 0.0224 \quad \text{or} \quad 1 \quad \text{CaCl}_2 \)

\[
\frac{.045}{2}
\]

V. **CHECK:** Answer makes sense with prediction

\# moles Cl > \# moles Ca & > 1 mole
I. **PROBLEM:** Copy the problem and underline key words or phrases.

How many grams of a zinc chloride are required to react with 15.0 g of aluminum metal? The products are aluminum chloride and zinc metal.

II. **REDESCRIPTION:** Be sure to include units.

A. **Given:**

- Unknown:
  - \( m = 15 \text{ g Al} \)
  - 1 mole Al = 27 g
  - 1 mole ZnCl\(_2\) = 96.4 g

\[ 3 \text{ ZnCl}_2 + 2 \text{ Al} \rightarrow 2 \text{ AlCl}_3 + 3 \text{ Zn} \]

B. **PICTURE:** Label the diagram or sketch.

1 mole Al

\[ 27 \text{ g} \]

.5 mole ZnCl\(_2\)

\[ 15 \text{ g} \]

1 mole ZnCl\(_2\)

\[ 96.4 \text{ g} \]

Mole Ratio

\[ 3 : 2 \]

III. **PREDICTION OR ESTIMATION:**

Mole Ratio: \(.75 \text{ moles ZnCl}_2 : .5 \text{ mole Al} \)

Since 96.4 g is almost 100 g, .75 moles would be approximately 75 g ZnCl\(_2\)

IV. **MATHEMATICAL SOLUTION:**

\[
\begin{align*}
15 \text{ g Al} & \quad 1 \text{ mole Al} & 3 \text{ moles ZnCl}_2 & 96.4 \text{ g ZnCl}_2 \\
27 \text{ g Al} & \quad 2 \text{ moles Al} & 1 \text{ mole ZnCl}_2 & \text{ZnCl}_2 \\
\hline
& & & 80.3 \text{ g} \\
\end{align*}
\]

V. **CHECK:** Answer makes sense with prediction
APPENDIX O
Rules of Behavior
Rules of Behavior
Cooperative Grouping

Guidelines:

1. One copy of each problem set per group with signatures of members of the group will be turned in for grading. The grade will be shared by group members.
2. Everyone in the group is responsible for learning how to work the problems since tests will be given on an individual basis.
3. On each test, if all members of the group score at least a 70% or better, then 5 extra points will be given to everyone in the group.
4. Students will assume the following roles when working in groups. These roles will be alternated each week. If someone is absent, combine roles such as a and b.
   a. Organizer/Time Manager: Makes sure everyone in the group has a role, keeps track of the time, and keeps everyone on task.
   b. Encourager/Observer: Makes sure everyone has an opportunity to participate and keeps track of how well everyone is working together.
   c. Recorder: Writes down the group’s decisions and submits the final problem set to the teacher.
   d. Summarizer/Checker: Makes sure everyone in the group understands what is being said and that it makes sense to the group as a whole.

General Rules:

1. Move into groups according to the diagram with as little noise as possible. Once in groups, there will be no moving around. Members of the group must face each other.
2. Talk only to members of your group or teacher. Only one member of the group should talk at a time.
3. Use each other’s name.
4. No "put-downs"; criticize ideas not people.
5. Everyone must participate; think and plan out loud; everyone’s ideas are worth listening to.
APPENDIX P
Statistical Data
Statistical Data and Interpretations

The comparison of means between students solving problems individually and those solving problems in cooperative groups (Table P-1) indicates the mean representing the individual problem solving is slightly higher (M=4.51) than the group (M=4.42). The mean of the posttest for honors students was higher than for students in regular classes (M=4.66; M=4.27). Proportional reasoners' posttest mean was higher than the means for transitional and nonproportional reasoners (M=4.93; M=4.24 and M=4.24).

Table P-1

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Type</th>
<th>Proportional Reasoning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ind Group</td>
<td>Reg</td>
<td>Hon</td>
</tr>
<tr>
<td>4.51</td>
<td>4.27</td>
<td>4.66</td>
</tr>
</tbody>
</table>

The two-way interaction of type by treatment (Table P-2) resulted in the highest posttest mean for honors students solving problems individually (M=4.71) with the lowest mean for students in regular chemistry classes that were grouped (M=4.24). For the two-way interaction of type by proportional reasoning (Table P-3), the posttest mean for proportional reasoners was the highest mean in honors classes (M=5.17) and the lowest mean occurred for nonproportional reasoners in
regular chemistry classes (M=3.90). The two-way interaction of treatment by proportional reasoning (Table P-3) resulted in the highest posttest mean for proportional reasoners solving problems cooperatively (M=5.03), while the lowest means occurred for transitional students solving problems in groups (M=4.11).

Table P-2

Least Square Means for Posttest for Type by Treatment

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Individual</th>
<th>Grouped</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regular</td>
<td>4.31</td>
<td>4.24</td>
</tr>
<tr>
<td>Honors</td>
<td>4.71</td>
<td>4.62</td>
</tr>
</tbody>
</table>

Table P-3

Least Square Means for Posttest for Proportional Reasoning by Type and Proportional Reasoning by Treatment

<table>
<thead>
<tr>
<th>Type</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>NP</td>
<td>3.90</td>
</tr>
<tr>
<td>T</td>
<td>4.23</td>
</tr>
<tr>
<td>P</td>
<td>4.69</td>
</tr>
</tbody>
</table>
Least square means for attitude for the main effects (Table P-4) indicate the most positive attitude for grouped students (M=72.1) and transitional reasoners (M=72.1) with very little difference noted between honors and regular (M=71.6; M=71.1).

Table P-4

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Type</th>
<th>Proportional Reasoning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ind Group</td>
<td>Reg</td>
<td>Hon</td>
</tr>
<tr>
<td></td>
<td>NP</td>
<td>T</td>
</tr>
<tr>
<td>70.6</td>
<td>72.1</td>
<td>71.1</td>
</tr>
<tr>
<td></td>
<td>71.6</td>
<td>70.5</td>
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<tr>
<td></td>
<td></td>
<td>72.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>71.4</td>
</tr>
</tbody>
</table>

The least square means for attitude for the two-way interaction of treatment by type (Table P-5) showed in a more positive attitude for regular chemistry students solving problems in groups (M=72.6) with regular chemistry students solving problems individually having the least positive attitude (M=69.6). For the two-way interaction of type by proportional reasoning (Table P-5), a more positive attitude was indicated for honors proportional reasoners (M=72.5). Transitional students solving problems in groups had a more positive attitude (M=73.2) in the two-way interaction of treatment by proportional reasoning (Table P-6).
### Table P-5

**Least Square Means for Attitude for Type by Treatment**

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Individual</th>
<th>Grouped</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regular</td>
<td>69.6</td>
<td>72.6</td>
</tr>
<tr>
<td>Honors</td>
<td>71.6</td>
<td>71.7</td>
</tr>
</tbody>
</table>

### Table P-6

**Least Square Means for Attitude for Proportional Reasoning by Type and Proportional Reasoning by Treatment**

<table>
<thead>
<tr>
<th>Type</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Regular</td>
</tr>
<tr>
<td>NP</td>
<td>70.9</td>
</tr>
<tr>
<td>T</td>
<td>72.1</td>
</tr>
<tr>
<td>P</td>
<td>70.3</td>
</tr>
</tbody>
</table>
A principal factor extraction with orthogonal rotation was performed on the 24 items of the revised questionnaire used in this study. This extraction was performed for both the attitude pre- and post-measures. The criterion for factor extraction was a minimum eigenvalue of one and in each case three factors were extracted as in the original questionnaire; however fewer items loaded for each factor. Comparison of the items for each factor on the pre- and post-questionnaires indicated four items relating to motivation, enjoyment, or interest loaded on factor 1, four items relating to fear or anxiety loaded on factor 2, and only two items relating to importance loaded on factor 3.
Table 19

Factor Loadings for Three-Factor Principal Factors Extraction and Orthogonal Rotation for Attitude Pretest and Posttest

<table>
<thead>
<tr>
<th>Items 1-24</th>
<th>Factor 1</th>
<th>Factor 2</th>
<th>Factor 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
<td>Pre</td>
</tr>
<tr>
<td>Enjoyment</td>
<td>.77</td>
<td>.00</td>
<td>.00</td>
</tr>
<tr>
<td>Motivation</td>
<td>.61</td>
<td>.00</td>
<td>.00</td>
</tr>
<tr>
<td>Importance</td>
<td>.00</td>
<td>.00</td>
<td>.00</td>
</tr>
<tr>
<td>Fear</td>
<td>.00</td>
<td>.00</td>
<td>.63</td>
</tr>
<tr>
<td>Enjoyment</td>
<td>.74</td>
<td>.00</td>
<td>.00</td>
</tr>
<tr>
<td>Motivation</td>
<td>.73</td>
<td>.80</td>
<td>.00</td>
</tr>
<tr>
<td>Importance</td>
<td>.49</td>
<td>.00</td>
<td>.00</td>
</tr>
<tr>
<td>Fear</td>
<td>.00</td>
<td>.00</td>
<td>.83</td>
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<tr>
<td>Enjoyment</td>
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<td>.00</td>
<td>.00</td>
</tr>
<tr>
<td>Motivation</td>
<td>.75</td>
<td>.77</td>
<td>.00</td>
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Label: Motivation, Fear, Importance

*Items loading on more than one factor and those under .50 were replaced by .00.
VITA
JOY BRIDGES TINGLE

VITA

Present Position

Science Curriculum Specialist, K-12
Terrebonne Parish School System
P.O. Box 5097
Houma, LA 70361
Phone: (504) 876-7400 Ext. 27

Personal Data

Married: 1967 to Michael J. Tingle
Children: Suzanne (1971) and Michelle (1976)
Social Security Number: 438-78-9055
Residence: 412 Carthage Drive
          Baton Rouge, Louisiana 70360
Phone: (504) 868-5062

Professional Interests

Designing and teaching physical science courses
   for elementary and secondary teachers
Research in elementary and secondary science teaching
   and learning

Education

B.S. Science Education, Louisiana State University,
   Baton Rouge, 1967 (Physics Major and Chemistry
   Minor)
M.N.S. Masters of Natural Science, Louisiana State
   University, Baton Rouge, 1974
Ph.D. in Curriculum and Instruction with a minor in
   Natural Science, Louisiana State University,
   Dissertation: Effect of cooperative grouping on
   stoichiometric problem solving in high school
   chemistry
Employment History

1969-71  General Science, Chemistry, and Physics Teacher, Department Chairperson, Central High School, Baton Rouge, LA
1972-73  Life Science and Physical Science Teacher, Montegut Middle School, Montegut, LA
1973-74  Biology and ISCS Teacher, Supervising Teacher, University Laboratory School, Baton Rouge, LA
1974-79  Chemistry I, II and Physics Teacher, Department Chairperson, Terrebonne High School, Houma, LA
1979-Present  Science Curriculum Specialist, Terrebonne Parish School System, Houma, LA
1986-87  Sabbatical Leave, Graduate Assistantship Louisiana State University, Baton Rouge, LA

Special Experience

Supervision of student teachers and interns (Internship program for the new alternate postbaccalaureate certification program)
Development of a physical science course for elementary education majors
Development and implementation of parish wide sex education program
Development and implementation of laboratory safety program for the parish
Development and implementation of science curriculum guides, K-12, for the parish
Consultant for reviewing and rewriting of the science curriculum guides, K-12, for the State of Louisiana
Development and implementation of an environmental science program for high school
Development and implementation of Biology II and Chemistry II programs
Served on walk-through teams for the Criteria of Excellence as part of the Special Program to Upgrade Reading (SPUR)
Developed and conducted workshops in the following areas:
1. Science process skills
2. Problem solving
3. Environmental science
4. Simple and effective chemistry demonstrations for: elementary, middle school, and high school teachers
5. Sex education
6. Science project/fairs
7. Cooperative grouping

Reviewer for Charles E. Merrill Publishing Co. high school physics textbook and elementary science series
Served on state textbook adoption committees for elementary science and environmental science

Professional Honors

Recipient of the Delta Kappa Gamma State Scholarship (1986-87)
Recipient of the Delta Kappa Gamma International Scholarship (1987-88)
Honorarium to be awarded by Bermuda Secondary School for the review of science curriculum, evaluation of science teachers, and recommendations - Invitation extended 2/88

Professional Organizations

Delta Kappa Gamma Sorority
Finance Chairman 1980-82
Parliamentarian 1982-84
First Vice-President 1984-86
Louisiana Science Teachers Association
President 1983-84
Executive Board 1982-Present
National Association of Research in Science Teaching
National Science Teachers Association
Served on regional convention planning committee 1985
Southern Association for the Education of Teachers in Science
Terrebonne Association of Science Teachers and Educators (Founder)
**Publications**


**Workshops and Papers Presented at Professional Meetings**


**Courses Taught**

Secondary: General Science, Physical Science, Biology, Chemistry I and II, Physics

University: Secondary Science Teaching Methods
Freshman Chemistry Laboratory
Candidate: Joy Bridges Tingle

Major Field: Education (Science)

Title of Dissertation: EFFECT OF COOPERATIVE GROUPING ON STOICHIOMETRIC PROBLEM SOLVING IN HIGH SCHOOL CHEMISTRY

Approved:

[Signatures]

Major Professor and Chairman

Dean of the Graduate School

EXAMINING COMMITTEE:

[Signatures]

Date of Examination:

April 20, 1988