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Evaluating student success in the Chemistry in the Community (ChemCom) program

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EVALUATING STUDENT SUCCESS IN THE CHEMISTRY IN THE COMMUNITY (*ChemCom*) PROGRAM

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ABSTRACT

EVALUATING STUDENT SUCCESS
IN THE CHEMISTRY IN THE COMMUNITY
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The purposes of this study were to determine relationships between student success in *ChemCom*, cognitive developmental levels, proportional reasoning abilities, math classes completed, and year in high school. The degree of abstract and proportional reasoning required on the *ChemCom* exam was determined.

Lawson's Classroom Test of Scientific Reasoning determined cognitive developmental levels. The *ChemCom* exam tested student achievement. ANOVA and Tukey-Kramer unplanned comparisons of means were used to analyze the results. The *ChemCom* exam was analyzed and compared using the ACS DivCHED Examination Institute item statistics.

A significant difference was found between students at a formal level and those at lower cognitive levels. Students who had higher levels of proportional reasoning skills and more math classes did significantly better. No significant difference was found dependent on high school year. Achievement on the *ChemCom* exam was not dependent upon cognitive developmental level or proportional reasoning abilities.

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CHAPTER 1

INTRODUCTION

This study began as a search for answers as to why high school students who were having problems succeeding in chemistry were usually having problems succeeding in their math classes. To help these students achieve a better understanding of high school chemistry, a switch was made to the American Chemical Society's Chemistry in the Community (*ChemCom*) program because it was promoted as having more of a qualitative approach to chemistry rather than a quantitative approach (Nelson, 1988). While student success improved, a correlation was still seen between the students' success in chemistry and math.

A search of the literature indicated that students had problems with many chemical concepts because these concepts are considered abstract topics. These topics required a type of reasoning that Jean Piaget called formal operational (Herron, 1975). Research has shown that about 50% of high school students operate at the concrete operational level (Blosser, 1988; Goodstein and Howe, 1978; Herron, 1975; Wheeler and Kass, 1977). The literature search also identified proportional reasoning as being an important formal operational skill necessary for success in chemistry (Goodstein and Howe, 1978; Herron, 1975; Krajcik and Haney, 1987; Lawson and Bealer, 1984; Wheeler and Kass, 1977).

An assumption was made that since the *ChemCom* program approached high school chemistry from a science, technology, and society context with a minimum of quantitative topics, students would be more successful learning chemistry. To test this assumption, a study was conducted. The study classified students according to developmental levels and looked for correlations between year in school, math levels, and their capabilities of using proportional reasoning. The American Chemical Society-

National Science Teachers Association Cooperative Examination, Chemistry in the Community Achievement exam, 1991, (the *ChemCom* exam) from the ACS DivCHED Examinations Institute was used as the vehicle to measure student success in chemistry.

Statement of the Problem

Specifically, the purposes of this study were:

(1) to determine the relationship between student success in the *ChemCom* program and student cognitive developmental levels; (2) to determine the relationship between student success in the *ChemCom* program and students' proportional reasoning skills; (3) to determine the relationship between student success in the *ChemCom* program and the level of the high school math course that the students were taking; (4) to determine the relationship between student success in the *ChemCom* program and the year in high school that the students were ; and (5) to determine the degree of abstract and concrete thinking needed for success on the *ChemCom* exam.

Hypotheses

The hypotheses tested in this study, stated in null form, were:

1. There would be no significant difference in student success on the *ChemCom* exam dependent on concrete, transitional or formal Piagetian cognitive developmental level.

2. There would be no significant difference in student success on the *ChemCom* exam dependent on their proportional reasoning ability.

3. There would be no significant difference in student success on the *ChemCom* exam dependent on level of math course completed.

4. There would be no significant difference in student success on the *ChemCom* exam dependent on the year in high school.

Delimitation of the Problem

The subjects in this study were students at an urban, ethnically diverse public high school. During the 1993-1994 school year the make-up of the student body, as determined by the school administrators, was 22% Hispanic, 8.6% African-American, 7.7% Filipino, 29.7% Asian, 1.7% Native American, and 30.3% White (See Appendix A). Many of the students were of mixed ethnicity. There was one foreign exchange student from Croatia. Complete data were obtained for 105 students, as described in Chapter 3. This sample contained one freshman, 11 sophomores, 81 juniors, and 12 seniors. Fifty-two out of the 105 students were female. Most of the students had chosen the *ChemCom* class as their chemistry class.

All subjects were administered Anton Lawson's Classroom Test of Scientific Reasoning (Revised pencil-paper edition, 11/87) in the middle of March 1994 to determine the level of cognitive development. All students were tested within a three day period. Testing at this time in the school year limited the number of students dropping from the study due to movement in and out of the classes. No students were transferred into or out of the classes after this date. Any changes in the level of cognitive development of the subjects would be less than if they had been tested at the beginning of the school year. The students also recorded on their test booklets the math class that they were currently enrolled in.

The *ChemCom* exam was administered to the students as their final exam during the week of June 12, 1994. Although the classes had not completed the entire *ChemCom* program, the teachers had covered the first four units which ACS believes to be vital and provides the foundation basic to the rest of the course. The teachers selected the appropriate questions to be used for these four units to measure student achievement.

Basic Assumptions

It was assumed that the level of achievement on formal concepts would be affected by the students' developmental levels. Another assumption was that Lawson's Classroom Test of Scientific Reasoning was valid for use with English Second Language students because the statements were simple and pictures were used to help illustrate what was being asked for. This assumption led to the assumption that the assignment of Piagetian levels was valid for all of the subjects.

Another assumption was that even though two different teachers had taught the *ChemCom* program, there would be no effect on student achievement due to their collaboration in planning and presenting the course. Course grades would not be reflective of student development because a number of the students, while being capable of achieving, were unmotivated and refused to complete the assigned work. Several of the students reported that they were only in the class to be with their friends and that they did not do and turn in homework assignments. Many of the students reported that they did not study for quizzes and tests. Several others had severe attendance problems and did not even attempt to make up missed work.

Definition of Terms

The following are definitions of terms used in this study:

Abstract concepts--"concepts that have imperceptible examples and/or imperceptible attributes. Such concepts cannot be learned through direct, concrete experience" (Herron, 1978, p.166).

ChemCom--Chemistry in the Community, a curriculum developed by the American Chemical Society.

Concrete concepts--"concepts that have perceptible examples and perceptible attributes because they are easily perceived" (Herron, 1978, p. 166).

Concrete-operational thinking or reasoning (empirico-inductive)--stage of development, concrete operations based on observations and collected data. These operations include classification, conservation of mass, arranging data in serial order and determining one-to-one relationships among sets of data (Goodstein and Howe, 1978, p. 171).

Formal-operational thinking or reasoning (hypothetico-deductive)--stage of development, formal operations ...can use symbols, deal with abstractions and theories, can extrapolate, hypothesize and generalize. At this level, relationships can be mathematically interpreted and proportional thinking is done (Goodstein and Howe, 1978, p. 171).

Math analysis--math class in high school formerly called precalculus.

M-capacity--"...the number of schemes one can 'attend to' at one time." (Tourniaire and Pulos, 1985, p. 191) "...mental capacity (or mental space) defined as the set measure of Piaget's field of centration (field of attention)..." (Lawson, 1985, p. 573).

Proportional reasoning--thinking or reasoning that involves the use of ratios and proportion or is looking at relationships between variables (Goodstein, 1983; Lawson et. al., 1978; and Tourniaire and Pulos, 1985).

Pseudo-examples--"...perceptible entities that are used to focus attention on critical and variable attributes of an abstract concept" (Bednarek, 1991, p. 9).

Science/Technology/Society Curricula (STS)--curricula that encompass a science theme directly related to everyday experiences and decisions made by society. (Smith and Bitner, 1993)

CHAPTER 2

LITERATURE REVIEW

This section consists of a literature review about:
(1) the nature of formal reasoning, (2) the relationship between formal reasoning, mathematics, and chemistry, (3) the philosophy and goals of *ChemCom*, and (4) the results of recent research into the effectiveness of *ChemCom* .

In many schools, students cannot enroll in chemistry unless they have passed Algebra I with a C-grade or better and are concurrently enrolled in Geometry (personal observations of the researcher and Smith and Bitner, 1993). When one questions experienced chemistry teachers about these pre-requisites, the two main reasons given for them have been the practice that occurs in logical thinking from geometry proofs and especially the practice at seeing relationships and quantitatively dealing with them in the algebra classes.

Nature of Formal Reasoning

Chemistry, as it is currently taught in high schools, is a very abstract subject. Examples of the abstract concepts are the electron, element, atom, molecule, density, the mole, acidity, polarity, and molecular shape and geometry. The content as well as the approach taken in teaching chemistry requires students to be operating at Piaget's formal operational thinking level. According to Piagetian theory, the formal operational thinking level is the highest level of mental structure and development (Biestel, 1975; Lawson, 1985; Pallrand, 1979). Piaget determined that it was reached between eleven and fifteen years of age and developed through the use of objects (Biestel, 1975; Lawson, 1985). In formal operational thinking, students think beyond the present or in terms of what might happen (Herron, 1975). They can form theories and conceptualize. Students are capable of verbal reasoning, do not need concrete objects to reason, and can control variables.

Concrete operational students relate directly to objects and not with verbally stated hypotheses. At this stage, inferences are made using direct extrapolations from observations made from sensory events. Concrete concepts only require concrete reasoning to comprehend. Their structuring and organizing of the problems come from activity that is concrete oriented and with objects and events of real observations in the immediate past (Herron, 1975). They deal directly with concrete reality and the content of the problem, not the form of relations within it (Beistel, 1975). The concrete operational student cannot think in terms of possibilities or potential and is not able to understand abstract concepts that depart from concrete events. They have not learned to conceptualize and theorize (formal operational skills) in chemistry or mathematics. According to Beistel (1975), concrete students can become formal operational thinkers by careful experimentation and extensive, careful questioning which leads the student to deduce the principles. Table 1 provides a few examples of competencies that chemistry students can and cannot do.

Research (Cantu and Herron, 1978; Chandron, Treagust and Tobin, 1985; Goodstein and Howe, 1978; Tobin and Capie, 1981) shows that many adolescents, as well as adults, are limited in their ability to use formal reasoning. Formal reasoning ability is an important factor in cognitive achievement (Tobin and Capie, 1981). Thus some high school students find chemistry difficult to learn since many of them are still at a concrete operational stage.

Table 1

Competencies Chemistry Students are Expected to do [s]

Things that concrete operational students: CAN DO	CAN'T DO
1. Any routine measurement.	1. Measurement of density, heat of reaction, and other derived quantities not directly observable.
2. Measure density by taking mass and volume.	2. Compare the densities of two or more substances.
3. Construct cooling curves of pure substances.	3. Explain why the plateau occurs in the cooling curve during the phase change.
4. From the definition of molarity prepare 1000 ml of a 1 M solution.	4. From the definition, prepare 25 ml of a 2.5 M solution.
5. Place various metals into a solution containing a metal ion and use the data to construct an activity series.	5. Use data from a series of experiments where some metals only appear as ions while others appear as metals to construct and activity series.

[s] Herron, 1975, p. 148

The Relationship of Formal Reasoning with Mathematics and Chemistry

In an annotated bibliography on factors affecting achievement in high school chemistry courses, Bednarek (1991) found three major factors. These factors were cognitive abilities, instructional methods and teaching strategies. Many researchers have studied cognitive ability. The results showed that many high school students do not think on the Piagetian formal-operational level (Cantu and Herron, 1978; Lawson, 1985; Pallrand, 1979; Tobin and Capie, 1981; Tourniaire and Pulos, 1985).

Since so many students are not formal thinkers, many of them are not likely to learn abstract concepts meaningfully. Cantu and Herron (1978) investigated an instructional strategy using psuedoexamples for teaching both concrete and formal science concepts. Pseudoexamples were illustrations, diagrams, and models used as visible items to focus attention on attributes of abstract concepts. They viewed this as being the same method applied to teaching concrete concepts using examples and nonexamples. The philosophy was that pseudoexamples provided direct information about a concept thus reducing the need for students to use hypothetical-deductive reasoning in distinguishing between examples and nonexamples. This would make abstract concepts more understandable to concrete operational students.

Pseudoexamples used were illustrations or supplementary labeled drawings that would focus attention on critical characteristics of the concepts. Line drawings were used for lessons on the ideal gas. Pictures of models were used for isomers, while diagrams and chemical symbols were used for the acid-base lessons.

Their results showed a significant difference in achievement for concrete- and formal-operational students. While the concrete-operational students did learn the concrete concepts better with this instructional strategy, they learned any of the formal concepts poorly. The formal- operational students learned significantly more than the concrete-operational students even on the concrete concepts. Cantu and Herron made the following conclusions:

1. No matter whether the concepts are concrete or abstract, formal-operational students will achieve more than the concrete-operational students.

2. Concrete-operational students will show satisfactory achievement when concrete concepts are taught.

3. The use of pseudoexamples with formal concepts will enhance the achievement of all students.

4. No teaching strategy will eliminate the differences in achievement between concrete- and formal-operational students. Procedures should be developed to enhance the intellectual development of all students.

Formal reasoning ability, prior knowledge, and memory capacity are among the cognitive factors research has shown to have an influence on chemistry achievement. A number of researchers have established a positive linear relationship between formal reasoning ability and success in chemistry (Chandron, et al., 1985). Prior knowledge forms links with new knowledge through the comprehension of and the inter-relationships among the concepts. Prior knowledge is considered by some to be the most important single factor influencing learning. Variation in short term memory space, known as "chunking" may have an effect, also. The chunks can have different sizes. Memory capacity determines the number of schemes a student can keep activated simultaneously. Students are able to "chunk" more effectively and more selectively if they are formal thinkers.

Chandron, Treagust, and Tobin (1985) investigated these three cognitive factors with high school chemistry students. Their research showed that both formal reasoning and prior knowledge had effects on achievement. Formal reasoning had the greatest significant direct effect on achievement and had an indirect effect through prior knowledge. Memory capacity showed no significant effect. They concluded that formal reasoning ability and prior knowledge were significant predictors of success. They suggested that achievement could be improved by insuring that essential pre-requisite knowledge was known before new material was covered. They also suggested that abstract concepts be introduced in a concrete way through mastery learning and small group work so that all students are actively participating.

BouJaoude and Giuliano (1991) indicated that earlier research had shown prior knowledge had a greater significant effect than logical thinking ability on achievement, the opposite of Chandron, Treagust, and Tobin's results. BouJarde and Giuliano (1991) conducted a study on these factors. Their results upheld previous findings showing formal reasoning ability was the second greatest predictor of success in chemistry.

Staver and Halstead (1985) indicated that Herron believes that students who use concrete reasoning patterns can only make inferences that are direct extrapolations from observations. They cannot make inferences twice removed from their observations (Herron, 1975; Staver and Halstead, 1985). Therefore students who are concrete thinkers need concrete concepts in order to comprehend and reason. Staver and Halstead (1985) designed a study to investigate the use of concrete models during evaluation. This study was constructed to separate the effect of model usage from the cognitive demands of the questions. As expected, results showed that students' reasoning capabilities had a significant effect on student performance. However, the use of models during testing had no significant influence although there was some improvement for some of the students. The results of this study were opposite to the findings of a similar study done by Gabel and Sherwood (1983). Staver and Halstead concluded that the students' knowledge along with their reasoning capabilities and the test conditions influenced how they learned new information. The effectiveness of model use during testing was dependent on reasoning patterns. This included spatial reasoning which was not being tested for. Thus the use of models may be a hindrance rather than a help in processing information.

In another study on the use of concrete methods, Goodstein and Howe (1978) addressed the question of whether the use of concrete exemplars improved learning in chemistry. Since prior research had shown students could not express chemical concepts in their own words due to a lack of understanding, they investigated the relationship improvement had with the level of the student's thinking. Following Herron's (1975) suggestion, they used concrete props wherever possible to model the abstract concept of stoichiometry. When results were analyzed, it was obvious that concrete operational students had not profited from the use of the concrete models and exemplars, but the formal operational students had. Goodstein and Howe stated that the experimental results did not support the view that concrete, "hands-on" methods would help any student. Concrete methods had not helped concrete level students in their investigation. They concluded, "Concrete level students cannot learn concepts which require advanced formal operational thinking, no matter how the concepts are taught" (Goodstein and Howe, 1978, p. 365).

Herron (1975) made an observation that any concept involving a ratio, such as density, molarity and reaction rates, was very difficult for many students. These topics are quantitative. Goodstein (1983) has commented that a majority of students in many introductory chemistry classes cannot deal with the quantitative aspects of chemistry. Added to the problem is the fact that more math is required in the chemistry courses now being taught. There are two types of mathematical relationships between variables being utilized. These are proportional relationships and additive-subtractive relationships. Proportions integrate well with dimensional analysis. Applications of these relationships should be focused on the relationships between variables and not on rote formulas. Unfortunately, in secondary mathematics, the concept of relationships is not the focus, rather the mechanics of algebra and geometry are the focus (Goodstein, 1983). Blosser (1988), in a Science Education Digest prepared for the Educational Resources Information Center, makes the point that chemical problem solving involves quantitative skills. The problem solving strategies taught and needed involve formal operational skills. Proportional reasoning and logical-deductive thinking are two of these necessary skills.

Krajcik and Haney (1987) conducted an investigation to establish which reasoning patterns were essential for success in high school chemistry. Investigated were hypothetical, proportional, probabilistic, propositional and combinatorial reasonings. In analyzing the American Chemical Society exam administered to the students, they determined that proportional reasoning ability was a major factor in student achievement on the test. Since the American Chemical Society exam represented what high school chemistry students were expected to learn, they concluded that proportional reasoning played an important role in chemistry achievement. In addition, they found that formal-operational students showed significant achievement while the concrete-operational students did not. They suggested that teachers need to adjust their teaching strategies and provide numerous activities to help students develop proportional reasoning skills.

Gabel and Sherwood (1983) conducted a study on the effect instructional strategies had on problem solving success. Strategies used were analogies, the factor-label method (now called dimensional analysis), proportional reasoning, and diagram use. These strategies involved both visual and verbal instruction. They also looked at mathematics anxiety levels. Most problems could be solved algorithmically but some transfer problems were included.

Students with high math anxiety scored significantly lower than students with low math anxiety. Students with high reasoning ability scored significantly higher than students with low reasoning ability. The results confirmed prior research according to Gabel and Sherwood (1983). Another finding was that students with high math anxiety and low proportional reasoning ability did better with the non-mathematical methods of analogies and diagrams than with material mathematical in nature. They determined, in addition, that dimensional analysis was the best method in general while a proportional approach was the worst except for the gas laws where it worked the best. Since students' proportional reasoning ability develops with time, the best approach for low reasoning ability students would be to take chemistry later after they had more exposure to and success with problem solving.

In another study, Friedel, Gabel, and Samuel (1990) investigated math anxiety, along with spatial visualization skills and proportional reasoning. The method of teaching was highly dependent on the use of analogies. Their study confirmed the importance of proportional reasoning to student success. Their findings upheld the previous study's determination of the negatively correlated effects of math anxiety with student achievement in science. The results also led them to the conclusion that spatial visualization was important for student achievement in chemistry. Other findings were the lack of transfer in problem solving and the failure of analogies as an appropriate teaching method as used in their study.

In an earlier study, Gabel, Sherwood, and Enochs (1984) investigated the general problem solving skills students used to solve problems involving the mole, stoichiometry, molarity, and the gas laws. The students were examined for their understanding of the problem, for devising and carrying out a plan for solving the problem, then for evaluating what they had done. One of the findings was that successful problem solvers used algorithms or algorithms coupled with reasoning strategies. Students with high reasoning abilities used systematic approaches for moles and stoichiometry. High proportional reasoning students were more successful at solving problems. But, the majority of the students relied strictly on the use of algorithmic techniques rather than using reasoning skills, regardless of their capabilities. Yet proportional reasoning students used reasoning techniques more frequently. Little transfer was shown in solving variations of the problems taught. They concluded that low proportional reasoning students may only be able to use the algorithmic approach.

Another study of proportional reasoning ability in chemistry was done by Wheeler and Kass (1977). The chemical concepts studied were nomenclature, formula writing and stoichiometry. After analyzing the data, they affirmed other researchers' findings that 50% or more of high school chemistry students were not at a formal-operational thinking level. Their results supported Piaget's assertion that students need to be at the formal-operational level to be successful at proportional reasoning (Wheeler and Kass, 1977). "The relationships observed suggest that chemical proportionality, like metric proportionality, may be an intrinsically higher level of ordering experience involving the matching of relations" (Wheeler and Kass, 1977, p. 22). Their data also confirmed proportional reasoning ability had a significant correlation with achievement and proportional reasoning ability was related to cognitive ability. Chemical instruction in proportional reasoning did not increase the ability in a non-chemistry context; that is, no transfer occurred.

From this review of the research literature investigating achievement in chemistry, it is apparent that a major factor in student success is cognitive ability (Bruce and Lawrenz, 1991; Friedel et al., 1990; Gabel and Sherwood, 1983; Gabel et al., 1984; Goodstein and Howe, 1978; Herron, 1975; Krajcik and Haney, 1987). Chemistry content and teaching approaches require formal reasoning ability, and a majority of high school chemistry students are not at a formal reasoning level. Formal reasoning ability is a major factor in cognitive achievement. Research has determined that proportional reasoning is a formal operational thinking skill as well as a mathematical relationship.

Shemesh (1988) investigated a math unit of ratio and proportion and its relationship with formal reasoning. He stated that previous work had shown that performance of written tasks of formal reasoning was influenced by prior learning and should not be used as a sole indicator of formal reasoning. To determine the validity of this, he designed the study to test younger students who had not attained formal reasoning ability on proportional reasoning tasks. To restrict achievement to learning and not cognitive developmental change, the teaching was limited to three weeks with fifth grade students.

After analyzing the data, it was apparent that the experimental group significantly improved their ability to solve $X/Y = k$ type problems. Students can be taught appropriate proportional algorithms. They also showed a realization of relationships between quantities, ratio recognition and application to establish proportional relationships. Since neither group could solve Piaget's balance beam task which requires multiplicative compensation of variables in a physical system, Shemesh concluded that $X/Y = k$ tasks only serve to separate those who are proficient using proportional tasks' algorithms from those who are not. The ability to solve proportional reasoning problems was not a good indicator of formal reasoning ability. Ratio and proportion problem solving can be taught to fifth graders. Proportional tasks do not necessarily separate formal from non-formal thinkers due to prior learning which could have an effect on test performance. Another conclusion was that failure to solve proportional tasks was not an indication of lack of formal reasoning ability but more probably the forgetting of learned algorithms. He suggested that true reasoning ability was the group of reasoning patterns left after learned school algorithms have been forgotten.

Harrison, Brindley, and Bye (1989) conducted a study that assessed the effects of a concrete process oriented teaching method for teaching fractions and ratios. According to them, students at a formal operational level should be able to convert decimals to fractions and vice versa. Students should be able to make comparisons of different sized units and use symbolic representations of fractional relationships and operations. They should also be capable of second order proportional thinking, be capable of using symbolic representations of proportional relationships, and be able to explain them. Special attention was paid to building with concrete materials through structured activities towards the abstract ideas. Students explored with concrete materials, followed by systematic experimentation where they kept records, formulated questions, and then reported their results. They then applied the results to practical situations. Time was allowed for student reflection and discussion.

Harrison et al. (1989) stated that according to Skemp's theory of intelligent learning, second order mental operations are dominant in relational thinking. With this kind of thinking, newly encountered concepts are related to an existing scheme that is appropriate or modifies an existing scheme to a more appropriate one. In assessing their results, they found that only the transitional and formal level students in the experimental group showed significant improvement. The concrete level students did not. The experimental transitional students showed significant gains in both fractions and ratios while the formal level students had significant gains in ratios only. The experimental students even reported enjoyment of the lessons and a lower anxiety towards the topic.

Science classes are deeply interwoven with mathematics. Science teachers frequently introduce science concepts as well as analyze them using mathematics. Full comprehension of many labs requires understanding of mathematical relationships according to Bruce and Lawrenz (1991). All math skills required in chemistry should have been covered by the eighth grade, yet many students have not mastered the basic skills by the time they begin algebra, geometry and especially chemistry. Basic skills needed in chemistry that should have been mastered by sixth grade are: operations with fractions, operations with decimals, estimation of length, mass, and volume, metric conversions and common sense estimation of units in the metric system. By the ninth grade, students should have mastered the basic skills of operations with exponents, simple algebra, proportional word problems, and unit problems. Some examples of these basic skills and their uses in chemistry are provided in Table 2.

Table 2

Chemistry Related Math Skills[s]:

Math skill	Uses in Chemistry
1. Operations with fractions	volume measurements, density, titrations, gram/mole problems, balancing equations
2. Operations with decimals	heats of reaction, specific heat problems, density, gram/mole problems, molarity
3. Simple algebra	molarity, % composition, gas law problems
4. Proportion word problems	mole/gram problems, balancing equations molarity, density, titration problems

[s]: Bruce and Lawrenz, 1991

Bruce and Lawrenz (1991) conducted a study to determine how well high school chemistry students did on these basic mathematical skills needed in chemistry. They found that the students' basic math skills were inadequate; 59% of the students could not complete even half of the test. When looking at the students' math background, they found that students who had completed Algebra I answered 27% of the questions correctly, while those who had completed geometry had a 45% success rate, and students who had completed Algebra 2 had a 54 % success rate. Bruce and Lawrenz concluded that the approach to mathematics teaching as outlined in the 1988 National Council of Teachers of Mathematics (NCTM) Standard should be followed; problem solving skills should be emphasized. Math and science should be integrated since there is a good deal of correlation between Algebra 2 and chemistry. They suggested an approach to teaching chemistry that was less quantitative and more descriptive.

As to where proportional relationships should be taught, Goodstein (1983) stated they should be taught before the chemistry course as the students need time to learn and understand the logic of the process before applying them to the unfamiliar variables found in chemistry. She referenced two earlier studies where rate concepts and hands-on activities done with ninth and tenth grade students caused substantial improvement in the students' skill at solving proportional problems. She proposed that problem solving skills should be taught in eighth grade math and science classes. The algebra course should include a section on how equations expressed relationships between variables. The science class should emphasize the concept of rates and proportions using density, speed and concentration, for example. Topics such as dimensional analysis should then be taught by focusing on the relationships between the variables as rates which express a direct proportional relationship rather than as ratios.

In Breaking the Science Barrier, Tobias and Tomizuka (1992) state that "science builds each concept directly on the preceding ones" (p. 4). Mathematics instruction also does this. Physical scientists consider math to be "the framework for thinking in science" (p. 31). Math helps to construct models of natural phenomena; it is used to take measurements and to make predictions. According to Tomizuka (1992) in Breaking the Science Barrier, one of the most important habits in chemistry is to think algebraically about relationships. Algebra not only displays functional relationships but also helps with visualization of relationships through the plotting and sketching of those relationships on a graph.

According to Kurtz and Karplus (1987), research has shown that a large number of high school students cannot use proportions to solve simple ratio tasks (proportional reasoning). Since proportional reasoning is so important for consumer mathematics, trigonometry, and linear functions as well as scientific applications, they conducted a study investigating the effects manipulatives had in achieving proficiency in proportional reasoning. Their subjects were pre-algebra students in the ninth and tenth grades. On analyzing the data, they found substantial gains in student achievement. But the students who were taught using a specially prepared pen and paper version of the manipulative activities made substantial gains too while the control groups did not. Students showed more interest when the manipulatives were used. They concluded that the students could improve their proportional reasoning abilities if well-designed programs were used where instructions went from concrete hands on activities to applications followed by the abstractions. When they analyzed the data for formulating algebraic equations with the new procedures, they found that manipulatives were not successful.

Tourniaire and Pulos (1987) hold the position that proportions is a difficult concept for students even though it is used in everyday situations as well as in science and math. They state that the concept of proportions is difficult and is acquired late according to Newton and Pallrand (Tourniaire and Pulos, 1987). Yet Adi and Pulos (1980) maintain that proportions are a pre-requisite to many high school math concepts . Many adults have not mastered the concept. There are two kinds of ratios; one compares ratios of quantities of the same number. The other compares quantities of differing natures and this is a functional method and a more abstract view of ratios.

The development of proportional reasoning (Tourniaire and Pulos, 1987) goes through several stages; the first is additive which is an equality of difference. The pre-proportionality stage uses additive strategies, but differences are not constant. The logical proportion stage is the understanding of the logical relationships among the four terms in the proportion. The change to multiplicative strategies of logical proportion is slow and complex. Proportional reasoning cannot be acquired all at once. Comparing ratios, while arithmetically easier, is an advanced method and develops some time after proportional techniques are mastered. Adi and Pulos (1980) maintain that thought patterns develop within conceptual schemes and not across them. Thought patterns that are similar can develop across related schemata. Formal thought is not a structured whole, nor is it operationally well defined.

The Piagetian theory considers proportional reasoning to be part of the formal operational stage (Tourniaire and Pulos, 1987). Controlling variables is formal reasoning too. In correlational studies, results support correlational thinking as being a formal reasoning skill. In Pascual-Leone's neo-Piagetian theory of M-capacity, or the number of schemes the mind can handle at one time, M-capacity is necessary but not necessarily sufficient to acquire proportional reasoning at some stage in development (Tourniaire and Pulos, 1987). Lawson (1985) states that Pascual-Leone theorized that the mental capacity (mental space) grows linearly between ages three to sixteen. Research does not show consistent results with M-capacity (Tourniaire and Pulos, 1987). Other studies have shown age and IQ to be highly related to proportional reasoning development. Tourniaire and Pulos (1987) suggest proportional reasoning requires both knowledge gained in school and some general reasoning ability. Proportional reasoning ability is more complex than often thought.

The acquisition of basic quantitative reasoning skills such as proportional, probabilistic, and correlational reasoning has been studied by a number of researchers (Lawson and Bealer, 1984; Lawson et al., 1978). These skills are viewed as central to both mathematical and scientific literacy (Lawson and Bealer, 1984). They are required to deal with basic quantitative data analysis even in everyday life such as comparing prices of items, computing odds, and evaluating links between such things as smoking and cancer and diet and cancer. The results of these studies showed student skills increased dramatically through adolescence. The changes seen with age suggest that acquisition of reasoning skills is not due to specific learning in math and science. Thus Lawson and Bealer (1984) conducted a study to correlate acquisition of reasoning skills with learning and/or development, that is does taking a specific course cause acquisition of reasoning skills?

After analyzing their results Lawson and Bealer (1984) concluded that improvement in quantitative reasoning was not due to specific course instruction since there was a greater increase than expected between grades where the reasoning skills had not been taught. They suggested specific instruction might be necessary but not sufficient to apply the reasoning to different contexts. Instead a process of equilibration occured where the individual's mental structures interacted with external experiences to modify and then to internalize the incomplete and inadequate mental structures. After internalization, the student could then apply the reasoning to different problems. Therefore, improvement with age came from a gradual acquisition of concepts initiated by specific instruction that was then internalized and used later when concepts were encountered in other classes. In conclusion, they suggested math and science courses did little in the short term to help students acquire and apply quantitative reasoning skills. And students who had not acquired these reasoning skills generally avoided courses where they were needed.

Restructuring of current programs should be done so that basic reasoning skills are acquired prior to more advanced classes.

There are two views of algebra (Carpenter, Corbitt, Kepner, Lindquist and Reys, 1982). One view is that algebra is a collection of skills and methods for solving equations. The second view sees algebra as a study of relationships. According to Carpenter et al. (1982), a major function of algebra is the abstract representation of arithmetic concepts. Many students have not mastered the level of symbolism used in a given course. In the 1978 National Assessment of Student Performance in Algebra, algebraic symbolism representation, translation and manipulations were assessed. The assessment was actually a test of retention of algebraic skills and concepts.

This assessment by Carpenter et al. (1982) found that the more math a student had had, the better the student's performance. Student performance was poor in the use of functional notation and translations of information to algebraic form, although performance improved with increasing exposure to algebra. The students also showed poor performance when asked to complete tables or graphs and to identify a rule and write it symbolically. The high school students could not manipulate rational expressions. There was a lack of student knowledge of the relationship between graphs and linear equations. The researchers suggested more work using actual scientific and social science data, in other words, real life applications. About half of the students identified the relationships between variables. When asked to manipulate formulas and solve for an unisolated variable, less than 25 % of the students could solve the problem.

According to Carpenter, et al. (1982), "Student performance in algebra had not reached the point of mastery even for most students with two years of algebra and a year of geometry" (p. 530). The performance of students with a year of general, business or consumer math was 5-10 percentage points below the mean. They concluded that many of these high school students were still operating at a concrete reasoning level and were resorting to memorized manipulations. Another conclusion was that if the addition of supplementary concrete examples and developmental activities do not increase performance then algebraic concepts may be too difficult at the freshman level and the formal reasoning tasks of algebra need to be postponed.

Bloland and Michael (1984) investigated the relationship and predictive validity of age, a standardized algebra prognosis test and objective measures of cognitive development. The results of their study showed a negative correlation with age, that is the older the student in algebra, the more poorly the student was doing. They confirmed that age and score on an algebra prognosis test appeared to be the most promising predictors of success in algebra. There was a significant association of developmental level with success in algebra. Significant differences were found between students determined to be concrete thinkers and formal thinkers. Bloland and Michael determined that Piagetian developmental level would show considerable validity in forecasting student achievement in first year algebra. This would be especially true if used as a single predictor of success.

"The first year algebra course generally is considered to be the cornerstone of the students' program of study in mathematics during the high school years" (Bloland and Michael, 1984, p. 926). Prior studies had shown that previous grades in mathematics appeared to be the most valid predictor of success. Other studies had revealed that acquisition of formal reasoning was necessary to learn the complex, abstract concepts and skills found in algebra. Other research, as with science, had shown many high school students do not operate at a fully developed formal level. Prior to the study of Bloland and Michael (1984), few researchers had used Piaget's developmental levels as a predictor of success in algebra. Those that had, indicated a positive relationship between formal reasoning level and success in algebra.

In a study on inductive and deductive programmed instruction, Sakmyser (1974) found that algebra and reading abilities as well as cognitive styles affected student achievement. In analyzing her data, Sakmyser found no significant difference in achievement between the two groups. She did find that students with high reading abilities showed significant achievement in the deductive group, while students with high algebra abilities showed significant achievement in the inductive program.

A study correlating student scores in mathematics, science and other school subjects was done by Khouj (1982). He did this study because a case has been made that academic achievement in a given subject affects the student's success in other subjects. He suggested that given an overlap between content and concepts of two subjects, the academic achievement in one affects the academic success in the second. After analyzing his data, Khouj found a very significant relationship between algebra and chemistry and algebra and geometry with algebra showing the greater correlation. He also found a correlation between chemistry, biology and English. Khouj concluded that the significant correlation between math and science was probably due to an overlap of concepts and content. The correlation with other subjects was most likely due to general intellectual abilities and study habits.

Gabel and Sherwoods'(1984) investigation on the use of analogies found some interesting problems related to algebra. Students were hindered by the use of scientific notation, multiple step problems, division, and fractional quantities. Yet the students could solve problems that used multiplication and very large numbers not put into scientific notation.

In a study investigating the basic skills needed for success in chemistry, Hurov (1987) found reading skills had a greater correlation with student success than either critical thinking skill or computational skills. In fact, no relationship could be found between math skills and achievement in chemistry. However, she did not rule out math or critical thinking skills as predictors of students' chemistry achievement.

Unfortunately not much research has been done in the area of geometry and proof writing (Senk, 1982, 1985). More research needs to be done to identify cognitive and affective prerequisites. Two of the current researchers are Senk and Hoffer. According to both, writing geometric proofs is difficult for most students. And much time in geometry is spent on proof writing. Doing proofs requires higher order cognitive processes (Senk, 1985). In doing proofs, students learn to analyze the form of an argument and develop better reasoning abilities, that is logical skills (Hoffer, 1981). However, Hoffer believes that there are other areas in geometry that could greatly benefit students. These are visual-spatial reasoning, drawing skills that give concrete practice in proportionality and relationships between variables, and applied skills of mathematical modeling in business, geography, agriculture and the sciences.

According to the van Hiele theory (Senk, 1985; Hoffer, 1981; van Hiele, 1986), higher order thinking skills are needed for achievement in geometry, especially for doing proofs. Students pass through five discrete levels of thinking. All students pass through the levels in the same order, but not at the same rate. Hoffer describes the levels from 1-5 as recognition, analysis, ordering, deduction, and rigor. In the van Hiele model, students understand relationships between figures and the importance of accurate definitions at level 3. Level 3 (ordering) is a transitional stage from informal to formal geometry (Senk, 1989). Van Hiele's level 3 appears to correlate with Piaget's stage II. While Piaget's work greatly influenced van Hiele, there are important differences (Van Hiele, 1986). Van Hiele's theory is one of learning, not one of psychological development. There are five levels not two; and the higher level is attained if the rules are made explicit and studied. The higher the van Hiele level of the student on entering geometry, the more successful that student will be in writing proofs.

Senk (1989) did research with the Cognitive Development and Achievement in Secondary School Geometry Project (CDASSG). The first part of the project investigated secondary students proof writing skills. The CDASSG found most students entering geometry were at the van Hiele level "0" or "1." The project found that the van Hiele levels address student readiness; the higher the student's level, the greater the student's success in writing proofs. There was a strong relationship between the two. In the second part of the CDASSG study, the cognitive factors necessary for doing proofs were investigated. Senk (1989) stated that recent research had upheld van Hiele's model as a description of students' geometric thinking. In this CDASSG study, the data showed that the higher the student's van Hiele level on entering geometry, the more successful the student was at writing proofs. There was a correlation with standard non-proof geometry topics as well. Other researchers (Senk, 1989) believed students do not think at the same van Hiele level in all geometric areas. Research needs to be conducted to sort out skill knowledge and the thinking processes that characterize the van Hiele levels.

Formal operational thinking plays a major role in the process of scientific investigation as well as mathematical processes as these studies have shown. Lawson, Karplus, and Adi (1978) investigated whether propositional logic and formal operational thinking develop together, whether they develop gradually and whether they develop because of Piagetian development principles. Does successful use of propositional logic and formal thinking come from direct teaching? The results of the study indicated that propositional logic and formal thinking were two separate psychological factors. They saw a definite increase in formal thinking abilities with age. R. Karplus, E. Karplus, Formisano, and Paulsen (1977) conducted a similar study that included variable control. In this study, a large number of thirteen to fifteen year old students could not articulate propositional reasoning and/or control of variables.

Much research has focused on the assumption that formal operational thought is a single structure and is a prerequisite to success in science courses (Lawson, 1985). The development of formal reasoning ability may be a gradual evolution because of consolidation and integration. The transition from concrete to formal thought is age related according to both theory and research (Pallrand, 1979). From a study to determine changes in this transition, Pallrand (1979) found that change during the transitional period is gradual. Only gradual increases in completing combinatorial and proportional tasks were found. Few of the test subjects displayed fully formal reasoning. Most demonstrated some aspects of formal reasoning; thus Pallrand's conclusion was that transition to fully formal reasoning is gradual. Combinatorial reasoning seemed to develop earlier than proportional reasoning. Proportional reasoning should develop by using qualitative relationships before quantitative relationships are stressed.

In a review of research done on formal reasoning and science teaching, Lawson (1985) made a number of conclusions:

1. Formal thought represents a general way of intellectual functioning which consists of identifiable reasoning patterns.

2. Deficiencies in formal reasoning probably cause deficiencies in achievement in math, science, and other subjects as well as everyday decisions.

3. Successful performance on formal tasks indicates acquisition of formal reasoning. The converse is not necessarily true.

4. Increased achievement in formal tasks with age is due to experiences, school learning and cognitive development.

5. Older students respond to instruction in formal reasoning. Increased experience may be an important factor.

<u>Conclusions</u>

From the research studies looking for the factors affecting achievement in high school chemistry and first year algebra, these points can be made:

1. Chemistry is a very abstract subject which requires students be capable of using formal reasoning skills to be successful.

2. Proportional reasoning is a formal reasoning skill and a major factor in student achievement in chemistry.

3. Proportional reasoning is a mathematical relationship. Ratios and fractions are components of proportional reasoning. Proportional reasoning is a prerequisite for many high school math concepts. This includes algebra and geometry.

4. Prior knowledge has a significant effect on achievement.

5. Students can be taught certain skills and algorithms to aid formal reasoning skills, but acquisition is gradual and requires additional experiences.

6. The more math a student has had, the greater the achievement in chemistry.

7. A major function of algebra is the abstract representation of arithmetic concepts. The abstractions require the use of formal reasoning abilities. Proportional reasoning is a major component of first year algebra.

8. Geometric skills of visual-spatial reasoning and drawing using proportions can aid the science student's understanding.

9. Concrete thinkers can be taught concrete skills successfully, but they do poorly on formal tasks in both chemistry and math classes.

In reviewing the research studies done on factors affecting achievement in high school chemistry and math classes, it becomes apparent that proportional reasoning is central to both math and science. Many algebra and chemistry concepts are considered abstract and require formal reasoning abilities to be successful in the subjects. Since acquisition of proportional reasoning is gradual and develops with age and experience, algebra should be retained as a prerequisite to chemistry. The research supports this.

The current first year algebra course takes the student from the concrete arithmetic concepts into the abstract symbolic notation of algebra. The course also reinforces manipulations with fractions and ratios and further exposes the students to working with exponents. These are concepts that are heavily used in chemistry. Concurrent enrollment in geometry is also supported by the research in that geometry requires formal reasoning abilities also. In addition, students deal with spatial visualizations and linear relationships that further aid their understanding of a number of chemistry concepts. Since the research indicates that students need continuing external experiences along with instruction to internalize and develop their formal reasoning abilities, the concurrent enrollment of geometry and chemistry help to provide the experiences and instruction.

Philosophy and Goals of *ChemCom*

ChemCom was developed because traditional high school programs did not address the relationships between science, technology and society. In addition, many traditional chemistry programs were encyclopedic in content and used laboratory experiences out of context or as verification of prior knowledge. There was also a need for a chemistry course that would motivate students to learn more chemistry and recognize chemistry's value to their lives and societal issues (Sutman and Bruce, 1992). Traditional chemistry courses did not attract students marginally interested in science, nor have they prepared future citizens to handle decision-making responsibilities (Nelson, 1988).

ChemCom was designed for all high school students interested in relevant and useful chemical phenomena (Nelson, 1988). These students may or may not be college bound, but read at slightly below grade level (Sutman and Bruce, 1992). *ChemCom* was not developed to be a watered-down course. *ChemCom* presents an intellectually challenging alternative to high school chemistry courses. In this year long course, students are introduced to eight societal issues related to chemistry. These issues are water quality and supply, natural resource use and conservation, petroleum usage, food and nutritional chemistry, nuclear chemistry, air and climate, chemistry and health and the role of the chemical industry in society. Chemistry is introduced on a "need to know" basis to understand chemical facts and concepts that will help students clarify and analyze these issues to come up with feasible solutions (Nelson, 1988).

While *ChemCom* includes less math, it still covers basic vocabulary, major concepts and laboratory skills found in traditional high school programs (Nelson, 1988). Basic math skills are used, but not presented by algorithms. If algorithms are needed, a rationale is provided (Sutman and Bruce, 1992). *ChemCom* includes more organic and nuclear chemistry than the traditional programs but covers less physical chemistry. Chemical principles are taught at a reasonable conceptual level (Sutman and Bruce, 1992). The "laboratory" is imbedded into the program so that completion and understanding of the activities lead to the development and understanding of the next instructional step (Sutman and Bruce, 1992). Another feature of *ChemCom* is the decision-making activities that lead students to solve problems and use higher order thinking skills such as interpretation of data and evaluation of risks and benefits or the worth and objectivity of sources (Nelson, 1988). *ChemCom* slides used for teacher training are presented in Appendix B.

Sutman and Bruce (1992) reported in their five year evaluation of the *ChemCom* program that the *ChemCom* objectives were developed to contain objectives that were traditional and related to societal issues. These objectives were also validated by accepted methods. The *ChemCom* unit tests, in a multiple choice format, were developed to contain questions that tested chemical knowledge and applications of that knowledge to societal issues. The ratio of knowledge to applications questions was set at 2:1. These questions were also validated by accepted methods.

The diverse groups of students who were involved in the pilot testing were administered the shortened form of the Longeot Test for Cognitive Development. A modest significantly positive correlation was seen between cognitive level and the ability to answer the application questions. The conclusion was made that the test contained a reasonable number of valid items that would measure students' abilities to apply content and tasks. However, teachers were cautioned that students with low levels of cognitive development would show poor performance on the application questions (Sutman and Bruce, 1992).

Sutman and Bruce concluded that *ChemCom* was a valid and highly functional chemistry program when used for those students that it was designed for. These students would be in grades ten and eleven and who read slightly below grade level. There was also some evidence that *ChemCom* motivated more students to pursue more chemistry or other sciences. However, no claim was made to meet the mathematical needs of college bound science majors. Mathematics skills should not be overlooked as they would be needed in analytically oriented science subjects.

Results of Recent Research of *ChemCom* Effectiveness

Minority students will comprise nearly 50% of all students by the year 2020. African-American and Hispanic students have a low proficiency in science (Winther and Volk, 1994). If the United States is going to increase science proficiency overall then these students' needs must be addressed. Cooperative learning has been found to be effective in raising achievement and in producing changes in behavior and attitudes of these minority populations (Winther and Volk, 1994). Because *ChemCom* uses an approach that incorporates cooperative learning, Winther and Volk (1994) conducted a study comparing the achievement of inner-city minority students taking traditional chemistry versus the *ChemCom* program. The subjects were average ability African-American students, from sophomore to senior level, in an inner-city school where every student was expected to take four years of science. Many had not yet completed algebra and would never have taken chemistry if they attended another school. Local standardized chemistry tests were used. This presented a problem because the chemistry test had a major emphasis on quantitative concepts and the students in both the traditional and the *ChemCom* groups had learned chemistry with a major emphasis on the qualitative concepts.

In assessing their pretest results, Winther and Volk (1994) found a significant difference between the two groups in mathematics achievement but not in reading or science. Their data showed the *ChemCom* group had the higher mean score in math, reading, and science, but overall the students' scores were near the city's median scores. In analyzing the chemistry post-test, a significant difference was found. The students who had used the *ChemCom* program had significantly higher scores on the local standardized chemistry exam. They concluded that while there were some problems with the study, the *ChemCom* program was effective in raising student achievement in chemistry and was a viable alternative to traditional chemistry classes.

Another comparison of *ChemCom* versus traditional chemistry was done by Smith and Bitner (1993). In their study they investigated the effect the two approaches had on the acquisition of logical thinking skills and any possible difference in reasoning levels the students in the two courses might have. Their subjects were randomly distributed throughout a Midwestern city. The students in the traditional courses used the same text book and were enrolled in a course taught as a pre-requisite for students pursuing a science related career. As a pre-requisite to general chemistry, the students had to have passed Algebra 1 with a grade of 75% or better. The students enrolled in *ChemCom* were pursuing nonscience related careers and had no math pre-requisite.

In analyzing the different components of the Group Assessment of Logical Thinking (GALT) test used to test reasoning level, Smith and Bitner (1993) found that the *ChemCom* students showed a larger gain in the six reasoning skills tested in the GALT test than the general chemistry students did. However, Smith and Bitner's analysis of covariance showed no significant difference. When the gain in formal thinking was compared, the results indicated that the *ChemCom* students showed a significant gain in reasoning even though the general chemistry students had a larger number of students at the formal level of reasoning. In the results, they stated that there was a significant difference in student gain in reasoning level between groups. However, in their conclusions, they stated that there was no significant difference in student reasoning gain which was a contradiction.

Smith and Bitner (1993) concluded that while their results showed no significant differences in reasoning gain, there was strong evidence that the *ChemCom* STS format offered a technique to encourage reasoning gain for concrete and transitional thinkers. They recommended that a comparison of previous science classes taken and student reasoning level be investigated as well as a comparison of number and achievement in math classes prior to taking the chemistry class.

In summary, the literature reviewed provided the knowledge of the results of other studies which led to the formulation and testing of relevant hypotheses in this study.

CHAPTER 3

RESEARCH DESIGN AND PROCEDURES

The primary purposes of this study were to investigate the levels of success students were achieving in the *ChemCom* program and to determine if any relationship existed between that success and the students' level of formal reasoning, proportional reasoning abilities, and the level of math course a student had completed. Another purpose was to determine the degree of abstract and concrete thinking needed for success on the *ChemCom* exam by analyzing reasoning patterns needed on individual exam questions.

In this chapter, the methods and procedures followed will be presented.

Research Design

Description of the Subjects

The subjects in this study were students at an urban, ethnically diverse public high school. During the year that this study was conducted, the ethnic make-up of the student body, as determined by the administrators based on parent response, was 22% Hispanic, 8.6% African-American, 7.7% Filipino, 29.7% Asian, 1.7% Native American, and 30.3% White (See Appendix A). Many of the students were of mixed ethnicity and often classified themselves differently than their parents had. The ethnic make-up of the *ChemCom* classes was approximately 21% Hispanic and Filipino (combined), 6% African-American, 22% Asian, and 51% White. There was one foreign exchange student from Croatia in the classes. This student was of interest because his prior science experience had been a "spiraling" of science topics. Each year during his last three years of schooling, equivalent to freshman through junior year in the United States, he had had biology, chemistry and physics.

Most of the students had either chosen *ChemCom* or had been placed in the classes due to science teacher recommendation and math placement. Prior to student scheduling, science students were advised by the science teachers as to what science classes were available to them the following school year. Students planning on being science, engineering, or math majors in college were advised to take Honors Chemistry if they had met the math pre-requisites. These pre-requisites were having passed geometry with a C or better and concurrent enrollment in Algebra 2 or a higher level math class while in the Honors Chemistry class. Those students planning on non-science majors in college or those just interested in taking chemistry were advised to request *ChemCom* as long as they had completed Algebra 1 successfully by the beginning of their enrollment in *ChemCom.* Students transferring to the school usually were placed in *ChemCom* because the Honors classes were full.

Four intact *ChemCom* classes were used for this study. Complete data were obtained for 105 students out of the 126 students registered in the classes. The sample contained one freshman, 11 sophomores, 81 juniors, and 12 seniors. Fifty-two out of the 105 students were female.

Instruments

Test of Formal Reasoning

The test used to determine the students' level of reasoning (cognitive levels of development) was Anton Lawson's Classroom Test of Scientific Reasoning, the Lawson test (Revised pencil-paper edition, 11/87). This was the pencil and paper version of Lawson's Classroom Test of Formal Reasoning (Lawson, 1978). The Classroom Test of Scientific Reasoning was used because the necessary apparatus could not be obtained for the demonstration of test items needed to administer the Classroom Test of Formal Reasoning.

The Classroom Test of Scientific Reasoning, consisting of twelve questions, measured the following thinking operations: conservation, proportional thinking, identification and control of variables, isolation and control of variables, probabilistic thinking, combinatorial thinking, and correlational thinking. Real objects were represented by pictures as can be seen in Appendix C. The test could be administered to a large class during one class period by a single proctor.

The test used several different formats for answering the questions. Five of the questions used both a multiple choice component as well as asking for a written explanation for the choices used. Both parts of each answer needed to be correct for the answers as a whole to be considered correct. The remaining questions were answered by written explanations alone. The test had sufficient validity and reliability to determine what stage of cognitive development the students had attained.

Research investigating the reliability of the Classroom Test of Formal Reasoning when compared to Piagetian interview tasks showed that the test had factorial validity, face validity and convergent validity. The Kuder-Richardson 20 estimate of reliability was .78 (Lawson, 1978). However, the paper and pencil version had some deficiencies. According to Lawson (1978), these included the loss of motivating aspects and meaningfulness evident when physical equipment is present, an increase in demand on reading and writing skills which are not the same as the Piagetian tasks themselves, and poor performance by some students because of the climate of a test. Another drawback was that a classroom test can slightly underestimate the capabilities of a class as a whole compared to interview tasks (Lawson, 1978).

Student Achievement

Student achievement was measured by use of student scores obtained from the 1991 version of the American Chemical Society-National Science Teacher Association *ChemCom* Chemistry Achievement exam (the *ChemCom* exam). The *ChemCom* exam was developed by the Examinations Institute of the American Chemical Society's Division of Chemical Education specifically for the *ChemCom* program.

The *ChemCom* exam contained two parts. Part I had forty questions, five questions per unit. Part II had twenty questions, most of which had multiple answers. Students were penalized for wrong answers in Part II.

The Examinations Institute provided test statistics for the *ChemCom* exam. These norms were based on the scores of 1391 students for the test as a whole, while item statistics were based on the responses of 1268 students from 23 high schools that supplied data considered to be usable (See Appendix D).

Overall test statistics from the Exam Institute include:

mean	35.75
standard deviation	7.35
median	35.9
KR-21 reliability	.74
standard error of measurement	3.71

There were three types of item statistics. The difficulty index was simply the percentage of students responding correctly to a question. The discrimination index measured the performance on a question for students doing well on the test overall compared to those who did not do well. The distribution of incorrect responses showed the relative frequency with which the alternative answers where chosen.

Curriculum Design

The *ChemCom* program covers eight societal issues related to chemistry. These issues are water quality and supply, use and conservation of resources, the use of petroleum as a fuel and chemical feedstock, the chemistry of food and nutrition, nuclear chemistry, air and climate, chemistry and health, and the role of the chemical industry in our society. The students are presented with a problem facing society such as a sudden, unexplainable fish kill or the significant role petroleum plays in our society and the dwindling supplies of this valuable resource. Then they are taught the chemistry needed to understand the problems so that they can either solve the problem or come to terms with the impact that society faces because of the problem. The course is more qualitative than quantitative. *ChemCom* still covers the major concepts such as nomenclature, atomic structure, gas laws, chemical bonding, basic vocabulary and laboratory skills found in a traditional high school chemistry course. Added features are the decision-making activities that require critical thinking and problem solving strategies and the interpretation of quantitative data such as graphs, tables and charts to formulate and make decisions logically. The approach also gives students ownership of the course content by making it relevant to their lives by showing the connections to the issue or problem.

ChemCom was designed for non-technical college-bound students, good students not planning on going to college and for college-bound science majors having difficulty with quantitative skills. It was not intended for students with weak math skills or serious college-bound science majors (ACS and Kendall/Hunt Publishing Company).

Procedures

The four *ChemCom* classes were taught by two teachers, each with two classes. Both teachers had gone through the ACS training to teach the program and had taught the program for two years. The two teachers worked together in planning and presenting the course. Some supplementation was done where experience had shown that students needed more practice or exposure to concepts for better understanding. These areas included metric measurements, compound naming, formula writing, determining molar mass and molarity, and balancing chemical equations. Both teachers collaborated in making up all quizzes and tests with the result that all *ChemCom* students took the same quizzes and tests during the school year. They tried to keep all components of the course the same in the four classes.

Instruction

All four classes were taught using cooperative learning, a *ChemCom* standard. Many of the activities encouraged divergent thinking that incorporated empirical data as well as value judgements. Both inductive and deductive teaching strategies were used. Student evaluation was based on individual achievement as well as group performance.

The instruction for the school year covered the first four units of *ChemCom*: Supplying our Water Needs; Conserving Chemical Resources; Petroleum: To Build or to Burn; and Understanding Foods. These units covered such topics as physical and chemical properties, metric measurements, elements and compounds, formula and equation writing, nomenclature, the mole concept, energy relationships, atomic structure and chemical bonding, solutions and solubility, organic chemistry, biochemistry, and periodicity to name a few.

Data Collection and Analysis

Lawson's Classroom Test of Scientific Reasoning was administered in March 1994. By this time, few or no students would be entering or leaving the course. All the students present in the four classes were tested on the same day. Fifteen of the 126 students enrolled in the course were absent when the test was given. The test was scored according to the directions included with the copy of the test that Dr. Lawson graciously provided.

The *ChemCom* exam was inspected and only those questions that pertained to the four units covered were given to the students. The first twenty questions of the forty questions in Part I of the exam were used. Of the twenty questions in Part II of the exam, all but four were applicable to the topics covered. The *ChemCom* exam was given to the four *ChemCom* classes during their regularly scheduled final. The students had been told that this exam would be their final exam for the chemistry course. All but eight of the enrolled students took the final exam; two of these students had missed both of the testing instruments.

The *ChemCom* exam was graded according to the instructions on the front of the examination itself (Examination Committee, 1991). The score for the exam was the sum of the scores from the two parts.

Part I: Score = Σ (R) Part II: Score = Σ (R/N - W/M)

R = number of correct answers

W = one incorrect answer from M incorrect ones, in other words:

$$\frac{\text{number of correct choices}}{\text{total correct answers possible}} - \frac{\text{number of incorrect choices}}{\text{total of incorrect answers possible.}}$$

Microsoft Excel Statistical Tool Pack was used to calculate descriptive statistics, the frequency distributions. and the analysis of variances (ANOVA). Descriptive statistics provided the mean, median, and mode values, standard deviation and the minimum and maximum values for all statistics. The null hypotheses were tested at the .05 level of significance (α = .05) using ANOVA to determine any significant differences present between the different groups. After the ANOVAs were obtained, the Tukey-Kramer method (see Appendix E) was used for unplanned comparisons among the means for those

ANOVAs that showed a significant difference (Sokal and Rohlf, 1981). Only data from students who completed both tests were used for the statistical analysis.

CHAPTER 4

RESULTS

Student cognitive levels were identified and proportional reasoning abilities were determined. The number of students in each math class at each cognitive level and at each proportional reasoning level was established. Included in this section are the frequency and percentage of students at each Piagetian level. The descriptive statistics for the *ChemCom* exam are presented. The correlations of students at each level of math with cognitive level and with proportional reasoning levels are reported.

Lawson Test Results

The scores on the Lawson test ranged from 0 to 15 with a mean of 5.7 and a standard deviation of 2.77. From the directions provided with the test, 39 students were classified as concrete operational (empirico-inductive level thinking), 46 as transitional, and 20 as formal operational (hypothetico-deductive level thinking). The Lawson test scores for the entire group are presented in Table 3.

Table 3

Frequency and Percentage of Students with a Given Score on the Lawson test and the Piagetian Classification

Score on the Lawson Test	Frequency (N = 105)	Percentage	Classification Based on the Lawson Test
12	1	0.9	Formal
11	4	3.8	Formal
10	4	3.8	Formal
9	11	10.5	Formal
8	7	6.7	Transitional
7	11	10.5	Transitional
6	15	14.3	Transitional
5	13	12.4	Transitional
4	15	14.3	Concrete
3	12	11.4	Concrete
2	7	6.7	Concrete
1	2	1.9	Concrete
0	3	2.9	Concrete

ACS *ChemCom* Exam Statistics

The mean score for the subjects on the *ChemCom* exam was 21.76 with a standard deviation of 4.98 and a standard error of 0.49. The median was 22.95 with the mode at 23.00. The low score was a 8.0 and the highest score was 32.7 based on twenty questions from Part I of the exam and 16 questions from Part II of the exam. The frequency distribution for the grades on the exam is shown in Figure 1 (See Appendix F for the test data).

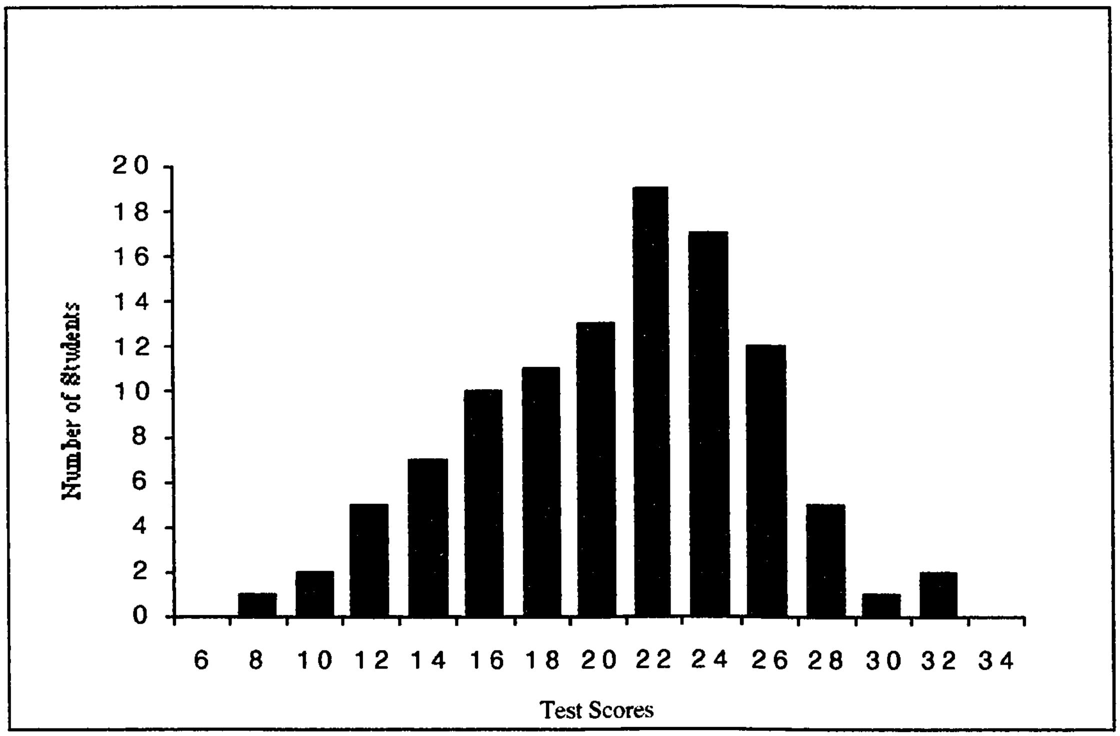

Figure 1. Distribution of Test Scores on the ACS *ChemCom* Exam.

Because the questions used only pertained to the units of the *ChemCom* text covered, a thorough comparison with the overall test norms provided with the *ChemCom* exam was not possible. Only a question by question comparison was completed.

Proportional Reasoning Levels

Four of the questions on the Lawson test (one-third of the test) measured proportional reasoning. Proportional reasoning scores were determined for each of the subjects by calculating the number of proportional reasoning questions correct out of the total of four questions. The proportional reasoning scores for the subjects at the different reasoning levels are summarized in Table 4. A correspondence clearly can be seen between the subjects' levels of cognitive development and their proportional reasoning abilities. In general, the better the student was in using proportional reasoning, the higher the reasoning level.

Table 4

Frequency of Students Receiving a Given Proportional Reasoning Score and Level of Cognitive Development

	Proportional Reasoning Questions Correct				
	4 out of 4	3 out of 4	2 out of 4	1 out of 4	None
Reasoning Level					
Formal	13	3	4		
Transitional	3	10	17	16	
Concrete		1	10	19	9

The highest level of math achieved by the subjects at the time of the *ChemCom* exam is summarized in Table 5. The math level attained has been compared to the cognitive developmental level. At the beginning of the school year, none of the students were enrolled in Algebra 1. The *ChemCom* teachers checked for this. Students not doing sufficiently well in Geometry and occasionally Algebra 2 were placed back into Algebra 1. Six of the students were in Algebra 1 at the end of the school year. No apparent correspondence can be seen in the level of cognitive development and the level of math achieved.

Table 5

Frequency of Students Enrolled in Math Classes and Level of Cognitive Development

	Level of Math Class at Time of *ChemCom* exam				
	Algebra 1	Geometry	Algebra 2	Math Analysis	Calculus
Reasoning Level					
Formal	0	4	11	2	0
Transitional	2	15	20	5	1
Concrete	4	8	23	2	1

The level of math achieved in relation to the proportional reasoning scores is presented in Table 6. Again, no correspondence is apparent between the math level and the proportional reasoning scores. The majority of the *ChemCom* students were still enrolled in Algebra 2 at the time of the *ChemCom* exam.

Table 6

Frequency of Students Enrolled in Math Classes and Proportional Reasoning Score

	Level of Math Class at Time of *ChemCom* exam				
	Algebra 1	Geometry	Algebra 2	Math Analysis	Calculus
Proportional Reasoning Level					
4 out of 4	0	2	9	3	0
3 out of 4	0	5	4	2	1
2 out of 4	2	11	15	0	1
1 out of 4	2	8	20	4	0
0 out of 4	2	1	6	0	0

The data for Tables 4, 5, and 6 can be found in Appendix F.

CHAPTER 5

ANALYSIS OF DATA

The results of the *ChemCom* exam were analyzed by cognitive developmental level, by proportional reasoning levels, by level of math class completed and by year in high school. Included in the analysis section is the analysis of variance (ANOVA) for each of the null hypotheses. Unplanned comparisons of means are reported for the analysis of variances that indicated significant difference among means. Also reported are the results of analyzing the *ChemCom* exam questions used with the ACS Test Statistics for those questions.

Hypothesis One and the Results

The first hypothesis proposed that no significant difference would be found in student success on the *ChemCom* exam dependent on the level of cognitive development. A comparison of the descriptive statistics is presented in Table 7. The mean, median, and minimum statistics all show a decrease from the formal level to the concrete level. The range is greater for the transitional students than for the others. The maximum score was attained by a transitional level student.

Table 7

Descriptive Statistics for the Test Scores by Level of Cognitive Development

Statistic	N	Mean	SD	Median	SE	Minimum	Maximum
Level of Cognitive Development							
Formal	20	25.72	4.14	26.06	0.92	16.22	32.27
Transitional	46	21.32	4.57	21.07	0.67	10.68	32.67
Concrete	39	20.26	4.87	20.92	0.78	8.03	27.92

SD = standard deviation
SE = standard error

The distribution of student scores by the level of cognitive development is presented in Figure 2 (see Appendix F). While overlap exists between the three different cognitive levels, more of the formal thinkers' scores are observed among the higher scores. A comparison of the descriptive statistics in Table 7 supports this observation.

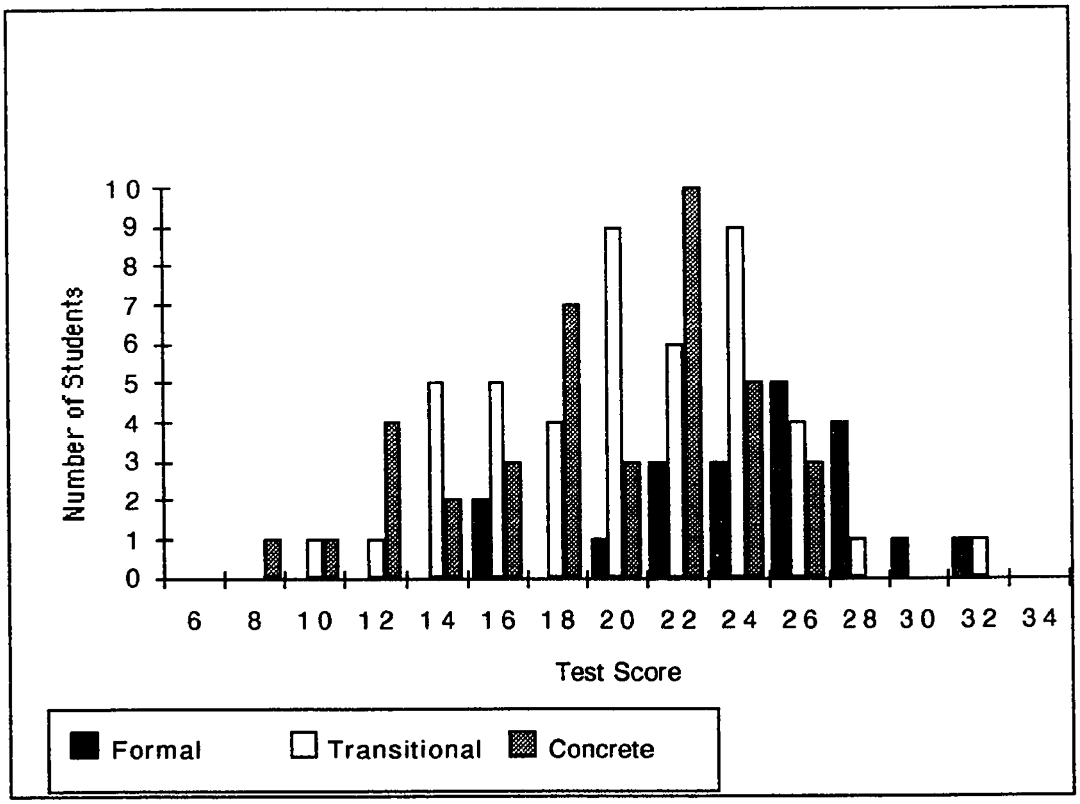

Figure 2. Distribution of Test Scores on the *ChemCom* Exam by Cognitive Level.

The results of the analysis of variance (ANOVA) are presented in Table 8. The F-statistic value (F-crit) required for significance is 3.085. Since the calculated value is $F = 9.65$, there was a significant difference in student success dependent upon cognitive development. These results supported the rejection of the first null hypothesis, that there was no significant difference in student success due to the level of cognitive development at a confidence level beyond 95% ($p < .05$).

Table 8

ANOVA for Student Scores by Level of Cognitive Development

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	410.20	2	205.10	9.65	.0001	3.085
Within Groups	2167.54	102	21.25			
Total	2577.74	104				

$\alpha = 0.05$

After determining that there was a significant difference comparing student achievement with the level of cognitive development as shown in Table 8, an unplanned comparison of means was done to establish which means were significantly different from each other. The Tukey-Kramer method was used at a significance level of $\alpha = .05$ (Sokal and Rohlf, 1981). The results are shown in Table 9. The absolute difference of the two means being compared is given below the diagonal, and the minimum significant difference (MSD) values are given above the diagonal. Absolute differences greater than their MSD value are significant at the $\alpha = .05$ level.

Table 9

Tukey-Kramer Comparison of Means for Level of Cognitive Development [a,b]

	Formal	Transitional	Concrete
Formal	—	2.915	2.993
Transitional	4.404*	—	2.369
Concrete	5.458*	1.053	—

* significant at $\alpha = .05$

[a] See Appendix E for method

b The $|y_1 - y_2|$ values are below the diagonal, and the MSD values are above the diagonal.

The comparison of means showed that those students at the formal level of cognitive development scored significantly higher on the ACS *ChemCom* exam than either the transitional or concrete operational groups. This supports the statement by Sutman and Bruce (1992) that teachers should not expect students who have a lower level of cognitive development to do as well on higher level thinking in the *ChemCom* program.

Hypothesis Two and the Results

The second hypothesis proposed that no significant difference would be found in student success on the *ChemCom* exam dependent on proportional reasoning ability. A comparison of the descriptive statistics is presented in Table 10. Students with all four out of the four questions correct are represented by 1; three out of the four questions correct are represented by 0.75; two out of four by 0.50, one out of four by 0.25 and those with none correct are represented by 0. Those students at the proportional reasoning level of 0.75 show a higher mean and median score than the other levels.

Table 10

Descriptive Statistics for the Test Scores by Proportional Reasoning Level

Statistic	N	Mean	SD	Median	SE	Minimum	Maximum
Proportional Reasoning Level							
1.0	16	24.62	4.80	25.28	1.20	16.22	32.27
0.75	13	25.13	4.32	26.11	1.20	15.87	32.67
0.50	31	21.13	4.85	21.22	0.87	10.16	31.43
0.25	36	20.12	4.17	20.61	0.70	10.68	27.55
0	9	20.55	6.08	23.00	2.03	8.031	26.25

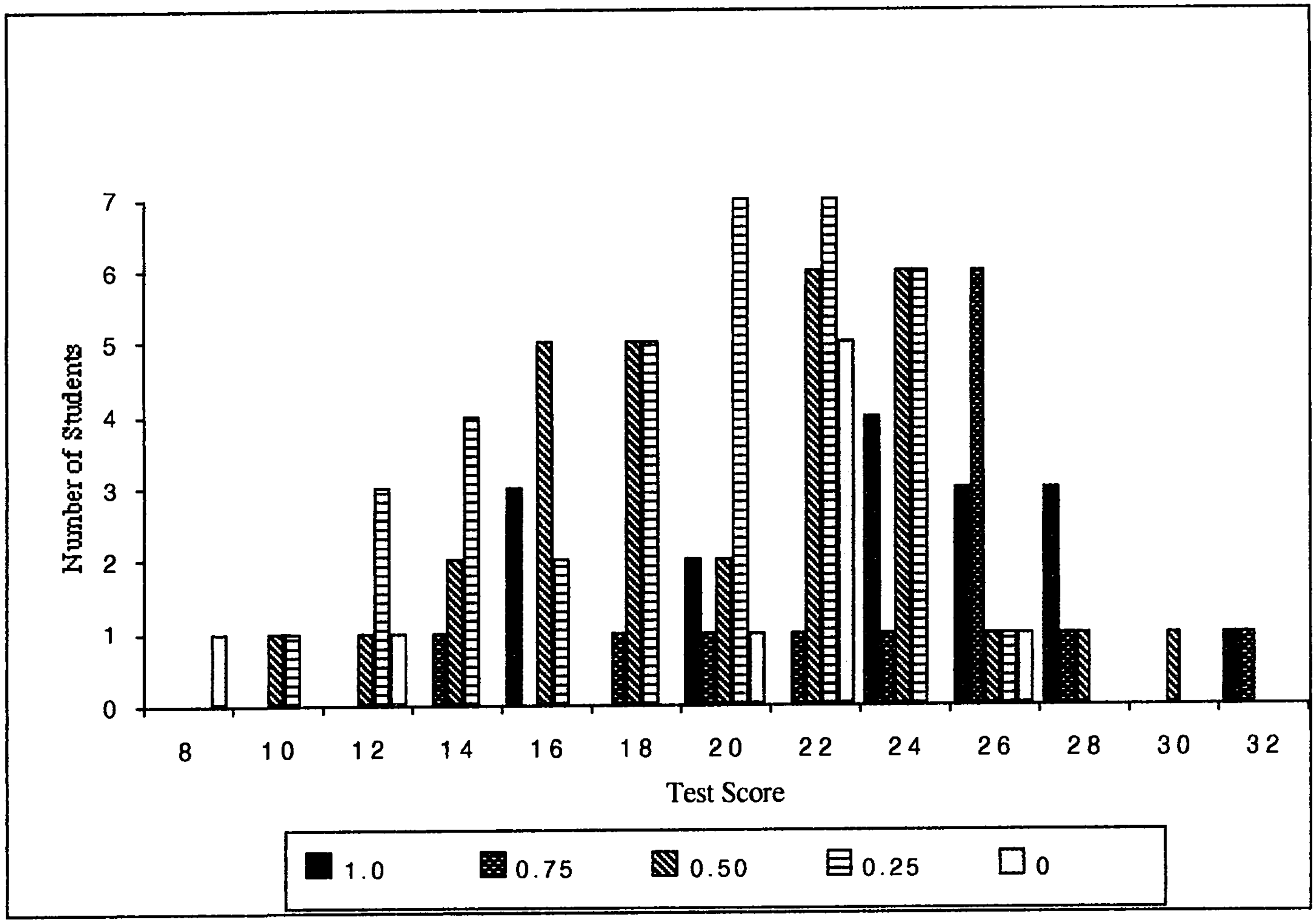

Figure 3. Distribution of Test Scores on the *ChemCom* Exam by Proportional Reasoning Ability. Four out of the four proportional reasoning questions correct on the Lawson test are represented by 1.0; three out of the four questions correct are represented by 0.75; two out of four by 0.50, one out of four by 0.25, and those with none correct are represented by 0.

The distribution of student scores on the *ChemCom* exam by proportional reasoning ability is presented in Figure 3. It can be seen that student scores for the different levels of proportional reasoning are spread throughout the graph and are not clustered as would be expected. A possible explanation for this is that proportional reasoning was not as important to success in the *ChemCom* program as it is to chemistry taught in the traditional manner.

The results of the analysis of variance presented in Table 11 show that there was a significant difference in student success dependent upon proportional reasoning abilities. The F = 4.58 value was greater than the value (F-crit = 2.463) required for significance. These results supported the rejection of the second null hypothesis, which stated that there was no significant difference in student success due to proportional reasoning abilities at a confidence level beyond 95% (p <.05).

Table 11

ANOVA for Student Scores by Proportional Reasoning Levels

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	399.92	4	99.98	4.58	.002	2.463
Within Groups	2181.45	100	21.81			
Total	2581.37	104				

$\alpha = .05$

After determining that there was a significant difference comparing student achievement with proportional reasoning abilities, an unplanned comparison of means of proportional reasoning levels was done to establish which means were significantly different from each other. The results are shown in Table 12.

Table 12

Tukey-Kramer Comparison of Means for Proportional Reasoning Levels [b]

	4 out of 4	3 out of 4	2 out of 4	1 out of 4	0 out of 4
4 out of 4	-	4.800	3.958	3.863	5.357
3 out of 4	-0.509	-	4.248	4.160	5.575
2 out of 4	3.484	3.996	-	3.150	4.868
1 out of 4	4.495*	5.007*	1.007	-	4.791
0 out of 4	4.067	4.579	0.579	-0.428	-

* significant at $\alpha = .05$
b The $|y_1 - y_2|$ values are below the diagonal, and the MSD values are above the diagonal.

The comparison of proportional reasoning means showed that those students with the highest proportional reasoning levels (1.0 and 0.75) only scored significantly higher on the ACS *ChemCom* exam than those who scored one out of four questions correct. It would be expected that a significant difference would also be seen between the highest proportional reasoning levels and the lowest level possible. The mean and median for the lowest proportional reasoning level are actually higher than those for the group scoring 0.25 on the proportional reasoning questions (see Table 10).

There were nine students who scored zero on the proportional reasoning questions. They had all been classified as concrete operational thinkers. Data on these nine students are presented in Table 13. Of these nine students, five were English second language (ESL) students. Four of these five were also in Algebra 2 as were two of the native English speakers. Three of the ESL students actually scored higher than the mean and mode on the *ChemCom* exam. It is quite possible that the ESL students did not understand what the proportional reasoning questions on the Lawson test were asking and due to language problems, scored lower on the proportional reasoning questions as well as the Lawson test as a whole. Lawson (1978) did state that paper-and-pencil measures of cognitive level increased the demand on reading and writing skills which were not the same as Piagetian operations.

Table 13

Data for Students Scoring Zero on The Proportional Reasoning Questions

Student	Year in School	*ChemCom* Exam Score	Lawson Test Score	Proportional Reasoning Score	Math Alg 1	Class Geom	Alg 2
C20	Jr	26.3	1	0	A1		
C27*	Jr	23.8	3	0			A2
C19*	Jr	23.7	0	0			A2
C17	Jr	23.7	4	0			A2
C16*	Sr	23.0	4	0		G	
C28	Jr	23.0	3	0			A2
C9*	Sr	20.9	0	0			A2
C35	Jr	12.5	4	0	A1		
C10*	Sr	8.0	0	0			A2
Totals		185.0			2	1	6
Mean		20.6	2.1				

* ESL students

Hypothesis Three and the Results

The third hypothesis proposed that no significant difference would be found in student achievement on the *ChemCom* exam dependent on the level of math completed. A comparison of the descriptive statistics is presented in Table 14. The Math Analysis and Calculus students show a higher mean score than the other levels. The two Calculus students were included for comparison. Since there were only two, their statistics did not contribute to the overall correspondence and they were not included in further analysis.

Table 14

Descriptive Statistics for the Test Scores by Math Class Completed

Statistic	N	Mean	SD	Median	SE	Minimum	Maximum
Math Class							
Algebra 1	8	17.64	6.60	15.48	2.69	10.68	26.25
Geometry	27	21.72	4.73	21.38	0.91	12.45	32.27
Algebra 2	54	21.48	4.76	22.93	0.65	8.03	29.80
Math Analysis	9	25.41	2.58	24.98	0.86	21.08	28.80
Calculus	2	26.33	8.96	26.33	6.34	19.99	32.67

The distribution of student scores on the *ChemCom* exam by level of math class is presented in Figure 4. It can be seen that the Math Analysis students' scores are in the upper portion of the distribution. The Geometry and Algebra 2 student's scores are spread out. The lowest score shown was earned by an Algebra 2 student while the highest score shown was earned by a Geometry student (See Appendix F for test scores).

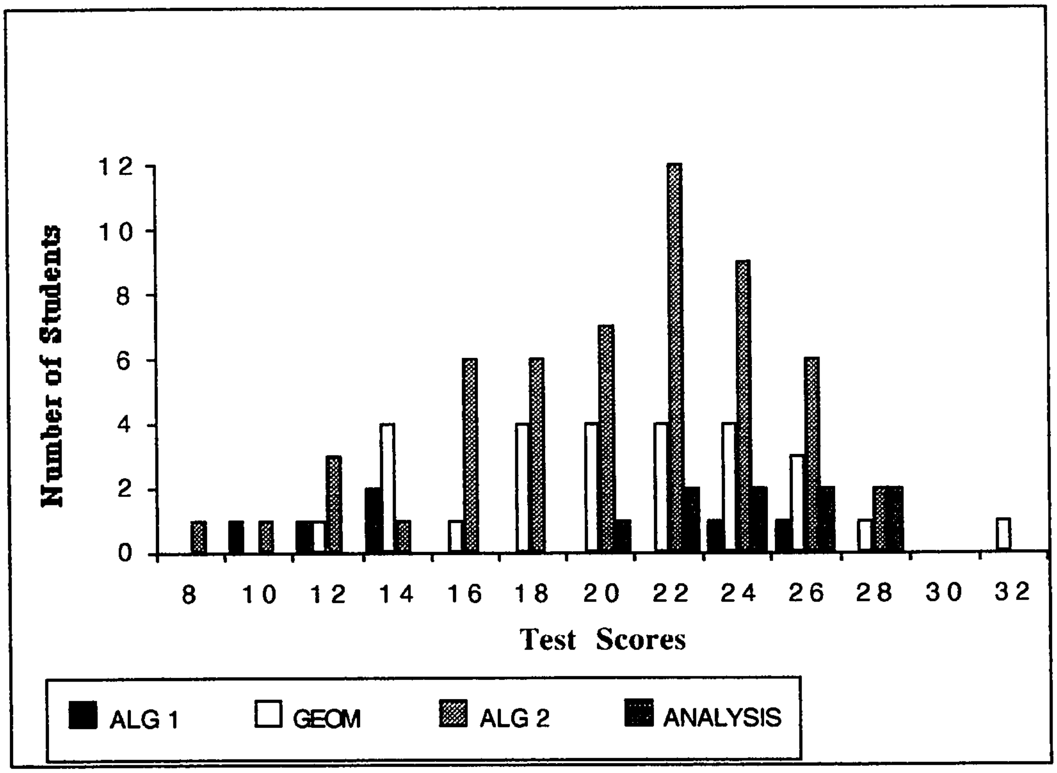

Figure 4. Distribution of Test Scores on the *ChemCom* Exam by Math Class Completed.

The results of the analysis of variance for the *ChemCom* exam scores by level of math class are presented in Table 15. The results show that there was a significant difference in student success dependent upon the level of math attained. The calculated $F = 2.91$ was larger than the F-crit $= 2.47$ required for significance. These results supported the rejection of the third null hypothesis, that there was no significant difference in student success due to the level of math class completed at a confidence level beyond 95% ($p < .05$).

Table 15

ANOVA for Student Scores by Level of Math Class Completed

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	267.62	4	66.91	2.91	.0255	2.470
Within Groups	2135.24	93	22.96			
Total	2402.87	97				

$\alpha = .05$

After determining that there was a significant difference comparing student achievement with level of math class attained, an unplanned comparison of means was done to establish which means were significantly different from each other. The results are shown in Table 16. The only means significantly different were the means of the Algebra 1 students and the Math Analysis students.

Table 16

Tukey-Kramer Comparison of Means for Level of Math Class Completed [a]

	Algebra 1	Geometry	Algebra 2	Math Analysis
Algebra 1	—	5.958	5.681	6.957
Geometry	4.09	—	3.111	5.081
Algebra 2	3.85	0.24	—	4.753
Math Analysis	7.77*	3.68	3.92	—

* significant at $\alpha = .05$

a The $|y_1 - y_2|$ values are below the diagonal, and the MSD values are above the diagonal.

A comparison of data on the two math levels is presented in Table 17. As can be observed from this table, more of the Math Analysis students are transitional and formal thinkers. The overall average on the different measuring instruments is higher for the Math Analysis students than for the Algebra 1 students. It must be restated; the Algebra 1 students had not been in Algebra 1 at the beginning of the school year. These students had been placed back into Algebra 1 at some point during the school year because they were having difficulties in the math class they were originally assigned to which was either Geometry or Algebra 2.

Table 17

Comparison of Data Between Algebra 1, Math Analysis, and Calculus Students

Math Level	Number of students			Lawson Test Mean	Proportional Reasoning Mean	*ChemCom* Exam Mean	Number of ESL Students
	Formal	Transitional	Concrete				
Algebra 1		2	4	6.56	0.25	17.64	1
Math Analysis	2	5	2	3.83	0.61	25.41	3
Calculus		1	1	5.50	0.63	26.33	2

A significant difference would be expected between the Algebra 1 students and the Calculus students as well. Only two of the *ChemCom* students were enrolled in Calculus. One was the foreign exchange student who had been through a "spiraling" of sciences. This student had had biology, chemistry, and physics through prior high school years. While this student's cognitive level was classified as transitional with a proportional reasoning score of three out of four, he earned the highest grade on the *ChemCom* exam. The other calculus student was an ESL student who was having difficulties with English and "senior slump."

It is interesting that the overall mean on the Lawson test was higher for the Algebra 1 students than it was for either the Math Analysis or the Calculus students. Yet, their proportional reasoning scores and *ChemCom* exam scores were the lowest of the three math groups. There is a strong possibility that the two calculus students and three of the math analysis students tested out lower on the Lawson test due to language problems rather than cognitive level.

Hypothesis Four and the Results

The fourth hypothesis proposed that no significant difference would be found in student achievement on the *ChemCom* exam dependent on the year in high school. A comparison of the descriptive statistics is presented in Table 18. A pattern is seen in the mean scores with the younger students having a higher mean score than the older students.

The distribution of student scores by the year in school is presented in Figure 5 (see Appendix F). And the distribution pattern for the juniors is similar to the distribution pattern for the subjects as a whole (see Figure 1, p.44). Much overlap exists between the three different grade levels (there was only one freshman in the whole group).

Table 18

Descriptive Statistics for the Test Scores by Year in High School

Statistic	Count	Mean	Median	Std Dev	Range	Minimum	Maximum
Year in School							
Freshman	1	29.30	29.3				
Sophomore	12	23.98	23.91	5.06	16.73	15.55	32.27
Junior	81	21.44	22.77	4.66	21.28	10.16	31.43
Senior	11	20.98	20.92	6.52	24.64	8.03	32.67

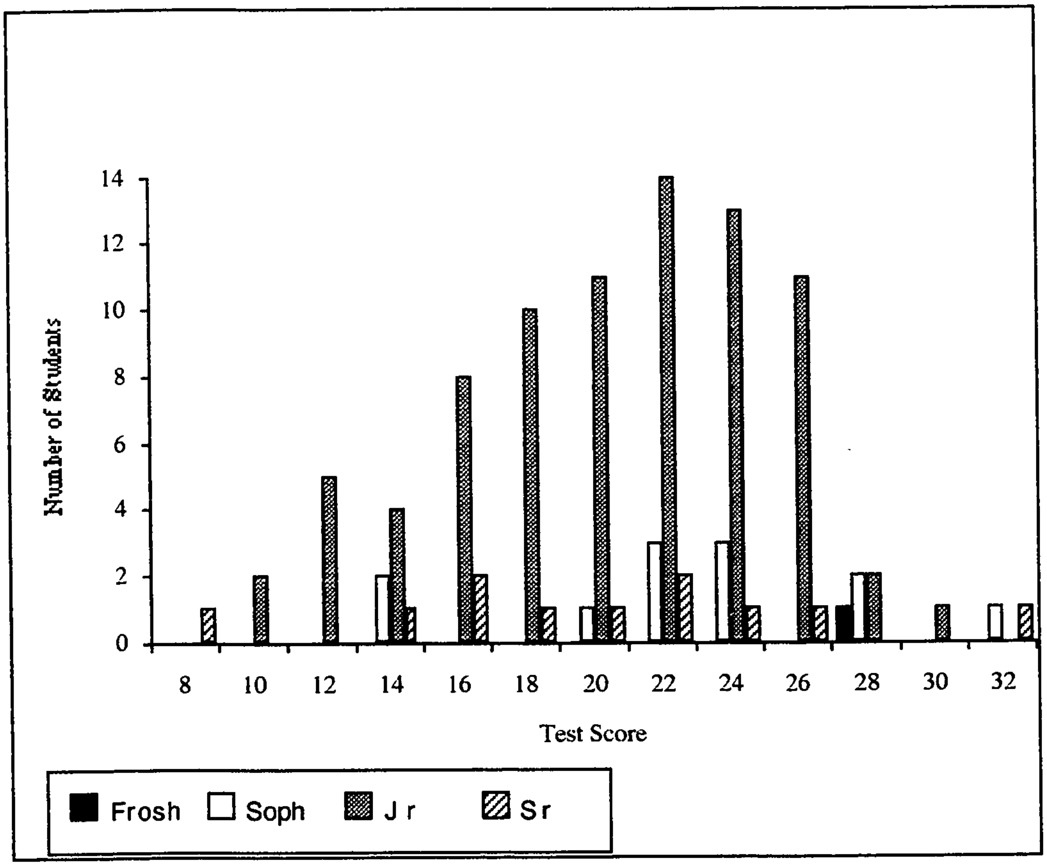

Figure 5. Distribution of Test Scores on the *ChemCom* Exam by Year in High School.

It should be pointed out that the mean and the median of the scores decreased from the freshman level to the senior level, while the overall range of scores increased. This overall pattern could also be seen when comparing the scores on the Lawson test and the proportional reasoning scores as shown in Table 19.

Table 19

Comparison of Data By Year in School

Year in School	Piagetian Number	Levels of students		Count	*Chem-Com* Exam Mean	Lawson Test Mean	Proportional Reasoning Mean
	Formal	Transitional	Concrete				
Freshman	1			1	29.30	10	1.0
Sophomore	3	7	2	12	23.98	6.33	0.71
Junior	15	34	32	81	21.44	5.62	0.44
Senior	1	5	5	11	20.98	4.95	0.48

Bloland and Michael (1984) found similar patterns in their investigation into student achievement in algebra and predictors that included age and Piagetian levels. While their findings showed significant differences, the analysis of variance on scores by year in high school in this study showed no significant difference at the 95% confidence level ($p < .05$) as presented in Table 20. With the F = 1.80 less than the F-crit = 2.695, the fourth null hypothesis that there was no significant difference in student success dependent on year in school was accepted.

Table 20

ANOVA for Student Scores by Year in School

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	130.80	3	43.60	1.80	.152	2.695
Within Groups	2445.68	101	24.21			
Total	2576.47	104				

$\alpha = .05$

Analysis of the *ChemCom* Exam Questions

One of the goals of this study was to determine the degree of abstract and concrete thinking and the degree of proportional reasoning ability needed for success on the *ChemCom* exam by analyzing reasoning patterns needed on individual exam questions. For the purpose of analyzing the degree of abstract thinking required, two groups of students were identified: a high or formal reasoning group whose scores ranged from 7-12 on the Lawson test and a low or concrete reasoning group whose scores ranged from 0-4. Those whose scores ranged from 5-6 were eliminated to minimize the possibility of overlap between the two groups.

For the purpose of analyzing the amount of proportional reasoning required, two groups of students were identified: a high group whose proportional reasoning scores were 1.0 and 0.75 and a low group whose proportional reasoning scores were 0.25. These groups were chosen on the basis of the results of the Tukey-Kramer Unplanned Comparisons of Means (Table 10). These were the three groups that showed a significant difference between the means.

There were two parts to the *ChemCom* exam: Part 1 had questions that had only one correct answer while Part 2 contained questions having multiple correct answers. Some of these questions the ACS Examinations Institute called grid questions. The grid was either a two by three matrix or a three by three matrix. Any combination of the answers in the grid could be possible answers to a number of questions following presentation of the grid. The format of Part 2 made it quite difficult to analyze the questions by usual statistical means. Thus, the decision was made to analyze the exam using the ACS Test Statistics of Difficulty Index and Discrimination Index (see Appendix D).

Prior to comparing student results with the ACS Item Statistics, the individual exam questions were analyzed for the type of reasoning patterns required. The criteria for determining the reasoning patterns are presented in Tables 21 and 22 respectively (Krajcik and Haney, 1987). Nine of the questions were determined to require formal reasoning patterns. One of these nine questions was also identified as an application of knowledge questions. Eight of the questions used proportional reasoning patterns with two of these questions using concrete proportional reasoning. Eight of the questions were determined to emphasize application of knowledge to the societal issues presented in the *ChemCom* text. The remainder of the questions emphasized chemical knowledge such as determining an acid or base, defining terms, and identifying laboratory equipment.

Table 21

Reasoning Patterns Applied at the Concrete Level

Classification -- separating a group of objects into several groups according to an observable property.

Conservation -- realizing that an observable quantity remains the same if nothing is added or taken away, even though it may appear to be different.

Proportional Reasoning -- making inferences from data under conditions of a constant ratio equal to a small whole number.

Interactional Reasoning -- attributing an easily observable change to interaction among a set of objects.

Additive Reasoning -- making inferences from data under condition of constant difference or sum.

Table 22.

Reasoning Patterns Applied at the Formal Level.

Classification -- arranging a group of items (objects or abstractions) into a multi-level hierarchy according to observable or intangible properties.

Conservation -- realizing that certain properties of a system remain the same if nothing is added or taken away, but that this reasoning cannot be applied to all properties.

Proportional Reasoning -- making inferences from the data under conditions of a constant ratio not equal to a whole number ratio.

Correlational Reasoning -- recognizing relationships among variable in spite of unpredictable fluctuations that mask them.

Propositional Reasoning -- using postulates or axioms of a theory to derive consequences without regard to the factual basis of the postulates.

The difficulty index is the percentage of students who responded to the item correctly (ACS DivCHED Examinations Institute). The larger the value of the difficulty index, the easier the question. The comparisons of the ACS item statistics for the difficulty index with those for the students as a whole, by cognitive developmental level, and by proportional reasoning scores are presented in Tables 21, 22, and 23. The questions have been classified as application, formal reasoning and chemical knowledge. The question numbers do not correspond to the actual test question numbers to preserve confidentiality of the test.

As can be seen in Table 23, the subjects' percentage on the application questions compared favorably with the ACS difficulty statistics except for question 3. The higher level thinkers scored as well or better except for questions 1, 3, and 8. For two questions (1 and 4) the lower level thinkers outperformed the higher level thinkers as well as the ACS difficulty statistic. This observation did not exactly agree with Sutman and Bruce's (1992) finding that students with low levels of cognitive thinking did not perform well on application questions.

Table 23

Difficulty Index Item Statistics for Application Questions

Question	1	2	3*	4	5	6	7	8
ACS Item Statistics								
Difficulty	0.72	0.72	0.85	0.68	0.62	0.45	0.43	0.63
Subjects Exam	0.73	0.66	0.72	0.70	0.56	0.46	0.43	0.56
Lawson Scores								
7-12	0.68	0.81	0.76	0.76	0.76	0.68	0.46	0.61
0-4	0.77	0.56	0.64	0.77	0.41	0.23	0.45	0.54
Proportional reasoning level								
1.0-0.75	0.69	0.79	0.76	0.66	0.78	0.68	0.41	0.60
0.25	0.78	0.61	0.86	0.67	0.41	0.40	0.36	0.60

* require proportional reasoning

When the results of the proportional reasoning groups were compared, the high proportional reasoning group showed mixed results. The low proportional reasoning students outperformed the higher group as well as the ACS difficulty statistic on questions 1 and 3. Question 3 was the one application question identified as requiring use of proportional reasoning. A possible explanation for low proportional reasoning students outperfoming higher proportional reasoning students was that the question did not really need proportional reasoning to correctly answer it.

As can be seen in Table 24, the subjects as a whole compared less favorably on four (1, 4, 10, and 11) of the formal questions when compared with the ACS difficulty statistics. The higher level thinkers did as well or better except for questions 1 and 4, both of which required proportional reasoning skill. The lower level thinkers had lower scores than the higher level thinkers except for question 1. Similar results were seen for the proportional reasoning groups.

Table 24

Difficulty Index Item Statistics for Formal Questions

Question	1*	2*	3	4*	5	6	7*	8*	9*	10	11
ACS Item Statistics											
Difficulty	0.62	0.53	0.60	0.85	0.46	0.66	0.62	0.86	0.92	0.80	0.62
Subjects Exam	0.51	0.52	0.65	0.72	0.54	0.62	0.54	0.88	0.90	0.69	0.46
Lawson Score											
7-12	0.54	0.62	0.65	0.76	0.62	0.70	0.70	1.00	0.97	0.83	0.61
0-4	0.54	0.51	0.59	0.64	0.49	0.59	0.41	0.77	0.85	0.62	0.34
Proportional Reasoning Level											
1.0-0.75	0.55	0.72	0.72	0.76	0.52	0.62	0.76	0.97	0.97	0.88	0.62
0.25	0.53	0.39	0.53	0.86	0.50	0.53	0.47	0.89	0.86	0.11	0.37

* require proportional reasoning

The higher proportional reasoning groups did as well or better except for questions 1, 4, and 6. It would have been expected that the higher proportional reasoning students would do better on these questions than they did since two of the questions required proportional reasoning skill. The lower proportional reasoning group had lower scores than the higher proportional reasoning group except for question 4. Again, this result was unexpected because the question had been identified as requiring proportional reasoning.

As can be seen in Table 25, the subjects as a whole compared less favorably with the ACS difficulty statistics on knowledge questions. On fifty percent of the questions they did better. The higher level thinkers (Lawson scores 7-12) performed as well as or better than the ACS statistics for difficulty except for five questions. The low level thinkers (Lawson scores 0-4) performed better than the higher level thinkers on questions 4 and 15 and performed as well as the higher level thinkers on questions 1, 5, 7, and 10. These results would not be unexpected since these questions were chemical knowledge questions.

However, since questions 1 and 4 had been identified as questions requiring proportional reasoning skills, it might be expected that the lower level thinkers would not perform as well as the higher level thinkers. This was not the case, they perfomed better.

The results for the proportional reasoning levels on the knowledge questions are much more consistent than the results seen for the application and formal level questions as seen in Tables 23 and 24. The higher proportional reasoning group outperformed the lower proportional reasoning group on all of the knowledge questions but one, question 4. This was unexpected since the results for the Piagetian levels were mixed.

It is interesting that the ACS pamphlet "How to Interpret Test Statistics" (See Appendix D) stated that items with a difficulty index less than 0.30 and greater than 0.70 were usually eliminated, and yet there were thirteen questions on the *ChemCom* exam that had a difficulty index greater than 0.70. Since the pamphlet also stated that items that were too hard or too easy provided limited information because they lacked discrimination, there is a concern that their discrimination index might be invalid for those questions.

Table 25

Difficulty Index Item Statistics for Knowledge Questions

Question	1*	2	3	4*	5	6	7	8	9
ACS Item Statistics									
Difficulty	0.74	0.51	0.53	0.79	0.58	0.49	0.39	0.61	0.76
Subjects exam	0.80	0.46	0.39	0.81	0.59	0.68	0.48	0.67	0.89
Lawson Scores									
7-12	0.85	0.70	0.50	0.70	0.65	0.80	0.50	0.80	0.95
0-4	0.85	0.35	0.35	0.87	0.65	0.59	0.50	0.61	0.87
Proportional Reasoning Level									
1.0-0.75	0.93	0.52	0.48	0.86	0.72	0.76	0.59	0.76	0.94
0.25	0.67	0.39	0.39	0.89	0.44	0.61	0.42	0.56	0.87
Question	10	11	12	13	14	15	16	17	18
ACS Item Statistics									
Difficulty	0.76	0.45	0.51	0.34	0.72	0.71	0.51	0.80	0.47
Subjects exam	0.84	0.38	0.46	0.22	0.62	0.64	0.62	0.80	0.44
Lawson Scores									
7-12	0.86	0.46	0.57	0.33	0.69	0.67	0.61	0.90	0.62
0-4	0.86	0.39	0.41	0.14	0.58	0.68	0.71	0.80	0.44
Proportional Reasoning Level									
1.0-0.75	0.87	0.42	0.53	0.32	0.64	0.66	0.90	0.53	0.72
0.25	0.82	0.30	0.37	0.20	0.61	0.60	0.69	0.35	0.59

* require proportional reasoning

The discrimination index measures the effectiveness of the question in differentiating "good" from "poor" students (ACS DivCHED Examinations Institute). The higher the discrimination index is, the greater the usefulness of the question. Values in the range of 0.30-0.50 are typical for most of the Examination Institutes' standardized tests. Questions with discrimination values below 0.20 are usually discarded after the trial test (ACS DivCHED Examinations Institute).

Presented in Tables 26, 27, and 28 are the comparisons of the ACS item statistics for the discrimination index with those for the students as a whole, by Piagetian level, and by proportional reasoning scores. The questions have been classified as application, formal reasoning and chemical knowledge. In the ACS Item Statistics for the application questions, three of the questions have a difficulty index over 0.70 and two of the questions have discrimination indices less than 0.20. This does not agree with the Examinations Institute's statements.

In Table 26, the subjects' statistics for the application questions compare quite favorably with the ACS statistics for discrimination except for the first question. The comparisons by cognitive ability show completely different results except for three questions: 2, 5, and 6. The negative values correspond to the lower levels having more students answering the question correctly than the higher levels did. The comparisons by proportional reasoning ability show results similar to those of cognitive level. Questions 1, 3, and 5 have discrimination indices that meet the Examinations Institute's conditions. However, two of the questions, 1 and 3, show that the lower level proportional reasoning students performed better.

Table 26

Discrimination Index Item Statistics for Application Questions

Question	1	2	3*	4	5	6	7	8
ACS Item Statistics								
Difficulty	0.72	0.72	0.85	0.68	0.62	0.45	0.43	0.63
Discrimination	0.18	0.38	0.25	0.46	0.34	0.40	0.24	0.13
Subjects Exam	0.07	0.46	0.29	0.46	0.48	0.57	0.13	0.29
Cognitive Comparison	-0.13	0.21	0.079	-0.05	0.32	0.43	-0.01	0.05
Proportional Reasoning								
Comparison	-0.25	0.03	-0.28	-0.16	0.24	0.17	-0.03	-0.13

* require proportional reasoning

In Table 27, four of the questions have difficulty indices above 0.70. The subjects' statistics for the formal questions compare quite favorably with the ACS statistics for discrimination. The comparisons by cognitive ability show completely different results except for two questions: 7 and 11. However, the discrimination indices for these two questions are much lower than the scores as a whole. The comparisons by proportional reasoning ability show results less discriminating than by cognitive level. Questions 2 and 4 have discrimination indices that meet the Examinations Institute's conditions. The lower level proportional reasoning students performed better on question 4.

Table 27

Discrimination Index Item Statistics for Formal Questions

Question	1*	2*	3	4*	5	6	7*	8*	9*	10	11
ACS Item Statistics											
Difficulty	0.62	0.53	0.60	0.85	0.46	0.66	0.62	0.86	0.92	0.80	0.62
Discrimination	0.43	0.34	0.11	0.25	0.44	0.42	0.45	0.30	0.16	0.34	0.38
Subjects Exam	0.46	0.32	0.25	0.29	0.36	0.54	0.50	0.32	0.25	0.51	0.33
Cognitive Comparison	-0.03	0.079	0.026	0.079	0.105	0.079	0.263	0.184	0.079	0.180	0.250
Proportional Reasoning											
Comparison	-0.09	0.22	0.06	-0.28	-0.09	-0.03	0.16	-0.13	-0.09	0.11	0.15

* require proportional reasoning

In Table 28, seven of the knowledge questions have difficulty indices above 0.70. The subjects' statistics for the knowledge questions show mixed results when compared with the ACS statistics for discrimination. The comparisons by cognitive ability show even less discrimination. And the comparisons by proportional reasoning ability show even less discriminating results than by cognitive level.

Table 28

Discrimination Index Item Statistics for Knowledge Questions

Question	1*	2	3	4*	5	6	7	8	9
ACS Item Statistics									
Difficulty	0.74	0.51	0.53	0.79	0.58	0.49	0.39	0.61	0.76
Discrimination	0.03	0.36	0.45	0.34	0.42	0.36	0.39	0.36	0.19
Subjects exam	0.18	0.20	0.18	0.32	0.36	0.43	0.18	0.43	0.22
Cognitive Comparison	0.016	0.026	-0.13	-0.08	0.211	-0.03	0.053	0.053	0.00
Proportional Reasoning									
Comparison	0.09	0.03	0.00	-0.22	0.16	0.00	0.06	0.06	-0.13

Question	10	11	12	13	14	15	16	17	18
ACS Item Statistics									
Difficulty	0.76	0.45	0.51	0.34	0.72	0.71	0.51	0.80	0.47
Discrimination	0.14	0.33	-0.01	0.28	0.28	0.33	0.20	0.24	0.25
Subjects exam	0.09	0.25	0.32	0.32	0.32	0.32	0.23	0.31	0.32
Cognitive Comparison	0.01	0.06	0.06	0.03	0.03	0.11	0.11	0.21	0.09
Proportional Reasoning									
Comparison	-0.13	0.04	0.07	0.06	-0.10	-0.08	0.04	0.08	-0.01

* require proportional reasoning

While the subjects' item statistics for discrimination as a whole compared favorably with the ACS item statistics for discrimination, the discrimination statistics by cognitive and proportional reasoning levels showed that achievement on the *ChemCom* exam was not that dependent on cognitive level and proportional reasoning skills. On a number of questions as shown in Table 29, those questions that were identified as requiring higher levels of thinking skills, the lower levels actually performed as well as or better than the higher cognitive and proportional reasoning thinkers.

Table 29.

Item Statistics for Proportional Reasoning Questions.

Question	1	2	3	4	5	6	7	8
ACS Standards								
Difficulty	0.74	0.62	0.79	0.53	0.85	0.62	0.86	0.92
Subjects exam	0.80	0.51	0.81	0.52	0.72	0.54	0.88	0.90
Lawson 7-12	0.92	0.54	0.76	0.62	0.76	0.70	1.00	0.97
Lawson 0-4	0.72	0.54	0.79	0.51	0.64	0.41	0.77	0.85
Proportional Reasoning Level								
1.0-0.75	0.93	0.55	0.86	0.72	0.76	0.76	0.97	0.97
0.25	0.67	0.53	0.89	0.39	0.86	0.47	0.89	0.86
ACS Standards								
Discrimination	0.03	0.43	0.34	0.34	0.25	0.45	0.3	0.16
Subjects exam	0.18	0.46	0.32	0.32	0.29	0.50	0.32	0.25
Cognitive Comparison	0.016	-0.03	-0.08	0.079	0.079	0.263	0.184	0.079
Proportional Reasoning	0.09	-0.09	-0.22	0.22	-0.28	0.16	-0.13	-0.09

CHAPTER 6

DISCUSSION

The analysis of the data in this study supported previous research done on student achievement, cognitive level, proportional reasoning skills, and mathematical background (Bednarek, 1991; Bruce and Lawrenz, 1991; Krajcik and Haney, 1987; Lawson, 1985; Wheeler and Kass, 1977). While other studies found a relationship between year in school and success in chemistry, this study did not (Khouj, 1982).

The analysis of the *ChemCom* exam questions yielded some surprising results. Since the analysis of variance showed the formal level was significantly different from the others, it was expected that the discrimination index would also show a value close to or above the ACS Item Statistics. It did not. In calculating the discrimination index, an equal number of students was used. Five of the concrete level students scored in the top 27% of the *ChemCom* exam scores while five of the students with Lawson scores of 7-12 scored in the lowest 27% of the *ChemCom* exam. This was sure to have affected the discrimination index of the subjects.

There were some unexpected results. Those students determined to have the best proportional reasoning skills did not achieve as high on the *ChemCom* exam as those with slightly poorer proportional reasoning skills. The reason for this could be that the *ChemCom* exam did not require as much proportional reasoning as evidenced by the analysis of the test questions. The students with the poorest level of proportional reasoning skills had a higher achievement than those at the next higher level. A possible explanation for this could be that the majority (5 out of 9) of the students at this lowest level were English Second language students and more of their English skills were being tested than their proportional reasoning skills on the Lawson test.

The small number of calculus students did not allow for a good comparison with the other levels of mathematics. The mean on the Lawson test was higher for the Algebra 1 students than it was for either the Math Analysis or the Calculus students. Yet, the Algebra 1 students' proportional reasoning scores and *ChemCom* exam scores were the lowest of the three math groups. There is a strong possibility that the two calculus students and three of the math analysis students tested out lower on the Lawson Test due to language problems rather than cognitive level. A number of teachers have complained that the *ChemCom* exam is more of a reading exam than a chemistry exam.

Similar results were seen for the analysis by proportional reasoning skills. Three of the students at the 0.25 level of proportional reasoning scored in the top 27% of the *ChemCom* exam while four of the students at the 1.0 and 0.75 levels scored in the lowest 27% of the *ChemCom* exam. This must have had some effect on the discrimination index of the subjects even though there was a significant difference between these two groups in the analysis of variance.

There are two other reasons that could account for the differences seen in comparing the discrimination indices. The *ChemCom* program was designed for college bound nonscience majors. The course was purposely made less quantitative and more science, technology and society based. These results could support the premise that the goals of the *ChemCom* program are being achieved. Only eight of the questions were determined to use proportional reasoning skills and eight were application to society questions. The rest required knowledge of chemical concepts. The other possibility is that the teachers of these students have done a good job teaching abstract concepts to their students and helped them to become better abstract thinkers and problem solvers.

The following conclusions were drawn from this study:

1. There was a significant difference in student achievement on the *ChemCom* exam based on Piagetian developmental level. The formal level students were more successful than transitional and concrete level students.

2. There was a significant difference in student achievement on the *ChemCom* exam based on proportional reasoning skill. Students with greater proportional reasoning skills were more successful on the *ChemCom* exam than those operating at a lower level of proportional reasoning skill.

3. There was a significant difference in student achievement on the *ChemCom* exam between students taking Math Analysis and those taking Algebra 1.

4. There was no significant difference in student achievement on the *ChemCom* exam based on level of year in school.

5. Achievement on the *ChemCom* exam is not dependent on abstract and proportional reasoning skills.

This study should be regarded as preliminary. There was a weakness in analyzing the questions of the *ChemCom* exam. This was due to the nature of questions in Part 2 with multiple answers. A more rigorous experimental design would be desirable with knowledge of a statistical instrument that could be used for the analysis. This study should also be done with students who have managed to study the whole program so that the remaining questions not used in this study could be analyzed.

A prior study (Smith and Bitner, 1993) looked at reasoning gains using the *ChemCom* program. This study could have been strengthened by having tested the students at the very beginning of the school year. A similar study should be done to verify Smith and Bitner's findings.

Both of the prior studies conducted on the use of the *ChemCom* program noted that there was no math prerequisite for taking the course. The students in this study had a math prerequisite. The students had to have completed Algebra 1 prior to enrollment in the *ChemCom* class. A study should be done to compare reasoning gains of students at various math levels using the *ChemCom* program.

Throughout the preparation and research set forth in this paper a recurrent theme for the need of proportional reasoning and abstract thinking skills in learning chemistry has been heard from most of the quoted authorities. Efforts to produce gains in intellectual development are small and require substantial effort by both student and teacher. While Piaget's theory provided a framework for understanding the difficulties students have, an STS approach may be providing an answer for helping students gain in intellectual development. Students need to be scientifically literate in an increasingly technological society. Since science and technology are formal by their nature, students need to be helped to acquire formal reasoning skills. The *ChemCom* program may be an instrument for helping students achieve these skills.

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APPENDIX A

PIEDMONT HILLS HIGH SCHOOL

STUDENT ETHNIC SURVEY

1994-1995

	1990	1991	1992	1993
HISPANICS	19.0	20.4	21.4	22.0
AFRICAN-AM	7.8	7.7	7.9	8.6
FILIPINO	8.2	6.9	6.4	7.7
ASIAN	24.1	27.8	29.1	29.7
NATIVE AM.	3.4	2.4	2.2	1.7
WHITE	37.4	34.8	33.0	30.3
PACIFIC IS.	0.1	0	0	0

Piedmont Hills High School

APPENDIX B

ChemCom's Uniqueness

- Written by high school teachers
- Developed concurrently at several sites
- Focus on technological/societal relevance
- Focus on use and application of knowledge, not just its development
- Decision-making skills cultivated
- Aimed at the general student
- External project evaluation

ChemCom
Chemistry In the Community

developed by
The American Chemical Society

Kendall/Hunt Publishing Company

Who Does it Serve?

1. Non-technical college-bound students.
2. Good students who are not going to college.
3. College-bound science majors who have difficulty with quantitative skills.
4. Not a parking place for problem students.
5. Not for senior students seeking a no-work course.
6. Not for those with weak math skills.
7. Not for college-bound science major.

Chemistry Style 1960's - 1980's	ChemCom Style
preparation	popularization
generating knowledge	applying knowledge
discipline focus	societal issue focus
science on lab bench	science in community
model building	decision making
mastery of content	ownership of content
class as "unit"	small-group work
individual problem solving	

ChemCom

Chemistry In the Community

developed by
The American Chemical Society

Kendall/Hunt Publishing Company

ChemCom: Teaching chemistry to students on a "need-to-know" basis

- Introduce students to a community or social issue involving a chemical component

- Lead students to realize they need additional chemical background to deal with the issue intelligently

- Develop the relevant chemistry; show its connection to the issue or problem

- Apply the chemical knowledge in decision-making activities related to scientific/technological aspects of the problem

ChemCom Objectives

- Place chemistry in societal context
- Use chemistry to understand socio-technological problems
- Introduce data analysis and scientific inquiry
- Practice decision making skills

Decision-Making Stages

- Analyze the issue
- Identify/define questions of concern
- Generate list of alternatives
- Weigh burdens and benefits
- Seek/process needed information
- Reweigh burdens and benefits
- Commit to a decision
- Implement decision (with contingency plan)

Academic Problem Solving vs Real Life Decision Making

Academic Problem Solving	Real Life Decision Making
• One result expected	• Multiple alternatives
• Fully defined system	• Imperfectly defined
• Single-discipline focus	• Multi-disciplinary
• Right/wrong	• Burdens/benefits
• Judged immediately	• Judged later
• Algorithmic	• Heuristic
• Driven by knowledge	• Constrained by missing knowledge
• Objective orientation	• Value-laden
• Lack of a solution is no solution	• Lack of a decision is itself a decision
• Dull (at worst)	• Agonizing (at worst)
• Tendency to avoid	• Tendency to avoid

C Overview of Types of ChemCom Decision Making Activities

YOUR TURN

CHEM QUANDARY

YOU DECIDE

PUTTING IT ALL TOGETHER

---> Instructional Time -------------------------------------->
10 min. 2 days

--> Open Endedness -->
A "Right" Answer Alternatives

--------------------------------------> Cooperative Learning ------------------------------------>
Low High

--------------------------------------> Student Autonomy --------------------------------------->
Teacher Directed Student Run

--------------------------------> Problem Solving/Decision Making -------------------------->
Academic Real Life

Chemical Concepts Utilized in CHEMCOM

Chemical Concepts Introduced or Utilized	Water	Res.	Petrol.	Food	Nuclear	Air	Health	Industry
Physical & Chemical Properties	I	E	U	U	U	U	U	U
Formula and Equation Writing	I	E	E	U	U	U	U	U
Elements and Compounds	I	E	E	E	E	U	U	U
Nomenclature	I	E	E	U	U	U	U	U
Stoichiometry	I	E	E	U	U	U		U
Mole Concept		I	U	U	U	U	U	U
Energy Relationships	I	U	E	E	E	U	E	U
Atomic Structure	I				I	U		
Chemical Bonding	I		E	U		U	U	U
Shape of Molecules			I	E		U	U	U
Solids, Liquids, Gases			I	U		U	U	U
Reaction Rate/Kinetics					I	U	U	U
Acids, Bases & pH	I					E	U	U
Oxidation/Reduction		I	E	U		U	U	U
Dissociation	I	U		U	U	U		U
Solutions & Solubility	I	U	U	U		U		U
Periodicity		I			U			
Gas Laws						I		
Scale and Order of Magnitude	I	U	U	U	U	U	U	U
Metric Measurement(SI)I	E	E	U	U	U	U	U	U
Equilibrium	I					E		E
Synthesis			I			U	U	E
Analysis	I	E	E	U		U	U	U

I = Introduced E = Elaborated U = Used

Evaluator's Summary Relative to **ChemCom**

1. Only a small proportion of college bound students plan to study chemistry.

2. College preparation for chemistry, as conventionally defined, is not as important as commonly thought.

3. There is little correlation between studying conventional chemistry in high school and receiving good grades in college.

4. ChemCom may enhance, rather than limit, students' preparation for college as well as most other future activities.

5. Teachers can use this innovative course with confidence and without excessive concern about shortchanging students who may major in chemistry.

Dr. Ronald Anderson
University of Colorado

An excellent chemistry program provides opportunities for students to:

- Become aware of chemistry-related societal issues and to seek solutions through consideration of real-world situations amenable to chemistry based solutions,
- Focus on current chemistry-related issues,
- Emphasize the complexity of chemistry-related issues,
- Illustrate the use of scientific and technological information in the decision-making process,
- Demonstrate the pragmatism of a multidisciplinary attack on chemistry-related societal issues.

excerpt from *NSTA Search* for *Excellence* in Science Education Criteria for *Chemistry; 1984*

The teaching of science in high school should provide graduates with an introduction to:

A. The concepts, laws, and processes of the physical and biological sciences;

B. The methods of scientific inquiry and reasoning;

C. The application of scientific knowledge to everyday life; and

D. The social and environmental implications of scientific and technological development.

Science courses must be revised and updated for both the college-bound and those not intending to go to college. An example of such work is the American Chemical Society's "Chemistry in the Community" program.

---excerpt from A Nation at Risk

ChemCom

Chemistry In the Community

developed by
The American Chemical Society

Kendall/Hunt Publishing Company

Basis for the Curriculum Project

"Curriculum should be organized around problem-solving skills, real-life issues and community decision-making opportunities."

-- National Science Board's
Commision on Pre-College
Education in Mathematics,
Science, and Technology (1983)

-- Quoted by Henry Heikkinen,
ChemUnity '87
8 (2), 7 (Summer 1987).

Questions Most Frequently Asked About *ChemCom*

1. **What does *ChemCom* mean?**
ChemCom is short for *Chemistry in the Community a* high school chemistry course developed by the American Chemical Society (ACS).

2. **Who wrote *ChemCom?***
Groups of high school and college chemistry educators working concurrently at several sites across the country drafted the original eight units during the summers of 1982 and 1983. These were revised twice more in light of pilot testing experience, leading to the currently-available first commercial edition.

3. **Who funded the development of *ChemCom?***
The National Science Foundation (NSF) has awarded grants totaling over $1.2 million toward the development of the curriculum and to support teacher-training efforts. The ACS has contributed $2.7 million to match the NSF support and to continue teacher-training efforts. Kendall/Hunt Publishing Company has contributed an additional $150,000.

4. ***Is ChemCom* appropriate for college bound students?**
Yes, *ChemCom* is a year long discipline-based chemistry course designed primarily for college-bound high school students who plan to pursue careers in fields other than science.

5. **Are colleges accepting *ChemCom* as a laboratory-based science credit?**
Yes, with few exceptions, once a college realizes that *ChemCom is a* "real" chemistry course. Despite its societal issue focus, *ChemCom* contains the core concepts and skills of conventional chemistry courses.

6. **Does *ChemCom* prepare students for college chemistry?**
It is the viewpoint of the ACS Society Committee on Education that *ChemCom* is an extremely effective first course in chemistry even for students planning to take college chemistry.

7. **What is the reading level of *ChemCom?***
Field tests indicate the average reading level is grade 10.

8. ***Is ChemCom* appropriate for the slower learner?**
ChemCom is not appropriate for the slow learner although it has been adapted successfully by some teachers who have made adjustments for the reading level and computations in the text.

9. **Are the standard high school chemical concepts covered in *ChemCom?***
Most of the key concepts of conventional chemistry courses are covered throughout the eight units. Some exceptions are quantum mechanics, and calculations dealing with equilibrium constants and kinetics. However, *ChemCom* introduces considerably more ideas from nuclear, organic, and biochemistry than do most conventional chemistry courses.

10. What societal issues are covered in *ChemCom?*
The issues include: supplying clean water; conserving chemical resources; utilizing petroleum as both a fuel and a chemical feedstock; feeding the world; nuclear energy production; isotope utilization and waste disposal; air quality; personal health; and the contemporary role of chemical industries in our society.

11. Will a student be prepared to take an Advanced Placement chemistry course after taking *ChemCom?*
Some *ChemCom* students have taken Advanced Placement chemistry and have been successful.

12. Does *ChemCom* require laboratory equipment and supplies that are different from those in standard high school chemistry?
Almost all materials and equipment used in *ChemCom* will be found in a standard high school chemistry laboratory. A complete list of expendable and nonexpendable materials can be found in the Teacher's Guide. Several vendors have produced purchase guides listing chemicals, apparatus, and equipment needed to perform *ChemCom* experiments. These are available from Flinn Scientific Inc. (708-879-6900), Sargent-Welch Scientific Company (1-800-SARGENT), and Science Kit & Boreal Laboratories (1-800-828-7777.) Items which are unique to *ChemCom* can usually be purchased in hardware, drug, and/or grocery stores.

13. Is there a laboratory manual?
No, all student laboratory activities are incorporated in the text. Laboratory Activities are used to introduce and develop important concepts in context within each unit. Some teachers decide to photocopy the procedures for use in the laboratory setting or ask students to summarize the procedures on their own paper to minimize risks to the textbook.

***14. Has a ChemCom* standardized final examination been prepared?**
Yes, the ACS DivCHED Examinations Institute has prepared an examination for the *ChemCom* curriculum. It is available for purchase from the ACS DivCHED Examinations Institute, Oklahoma State University, 107 Physical Sciences, Stillwater, OK 74078. Voice phone: (405) 744-5947, FAX (405) 744-5135.

15. How much of the *ChemCom* text is normally covered in a year? Teachers report that they cover anywhere from five to all eight units, depending on how thoroughly they do the activities, how many class periods and weeks they have available, etc. It is essential to cover units one through four in sequence; the selection and order of the remaining four units may be varied, based on teacher needs and student interest.

16. Is it appropriate to augment the content with additional exercises?
It can be done but it may not be appropriate. It is not the intent of *ChemCom* to expect mastery of any given concept/calculation on the first exposure (see page xxviii of the Teacher's Guide). Instead, key ideas are reinforced and extended throughout the course. Hence, any attempt by a teacher to augment a particular set of calculations, for example, might be unnecessary if the same skills are revisited later in the course.

17. What are some ways in which *ChemCom* differs from conventional chemistry courses?
The course is structured around motivating issues in the community involving chemistry rather than around specific chemical concepts. Chemical concepts are presented on a "need-to-know" basis. *ChemCom* students experience the use and application of their chemistry learning, leading to a greater sense of motivation and a feeling of "ownership" of their knowledge. The usefulness of relevant chemistry is stressed instead of requiring memorization of facts.
ChemCom emphasizes decision-making processes and cultivates critical thinking.

18. How expensive is the book and where is it available?
The student text sells for $24.90; the Teacher's Guide costs $37.90. Both are available from Kendall/Hunt Publishing Company, 2460 Kerper Boulevard, P.O. Box 539, Dubuque, IA 52004-0539, (800) 258-5622.

19. Who can receive articles about *ChemCom?*
Chemunity News is written for and by chemistry teachers; it has sections devoted to *ChemCom* issues. Any chemistry teacher may request to receive it, without cost, by writing to the ACS Education Division in Washington, DC.

Appendix C

3/4/94

Department of Zoology

Arizona State University

Box 871501
Tempe, AZ 85287-1501
602/965-3571

Dear Carolyn,

You have my permission to use the test in your research.

Sincerely,

Anton E. Lawson

CLASSROOM TEST OF SCIENTIFIC REASONING

(Revised Pencil-Paper Edition)

November 1987

by Anton E. Lawson

Arizona State University

Directions to Students:

!! DO NOT OPEN THIS BOOKLET UNTIL YOU ARE TOLD TO DO SO !!

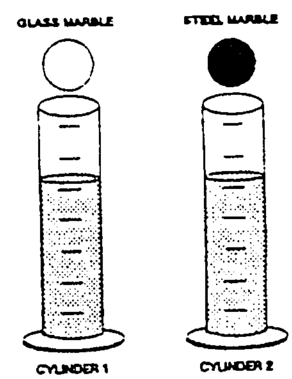
This is a test of you ability to apply aspects of scientific and mathematical reasoning to analyze a situation to make a prediction or solve a problem. In some test items you will be asked to show your work and/ or explain your answer. Try to answer as completely as you can in the spaces provided. On some items these explanations are more important than your actual answer. When the item lists answers, circle the best answer and explain your selection. **If you do not fully understand what is being asked in an item please ask the test administrator for clarification.**

CLASSROOM TEST OF SCIENTIFIC REASONING

Item 1.
Suppose you are given two balls of clay of equal size and shape. The two balls are also of equal weight. One of the balls is flattened into a pancake-shaped piece. Which of these statements is correct?
a. The ball weighs more than the pancake-shaped piece.
b. The two pieces weigh the same.
c. The pancake-shaped piece weighs more than the ball.

Please explain you selection.

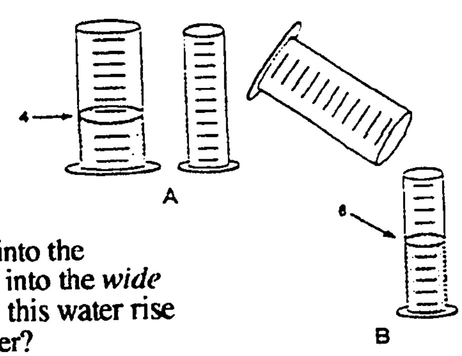
Item 2.
To the right are drawings of two cylinders that are filled to the same level with water. The cylinders are identical in size and shape. Also shown at the right are two marbles one made of glass and one made of steel. The marbles are the same size but the steel one is much heavier than the glass one.



When the glass marble is put into Cylinder 1 it sinks to the bottom and the water level rises to the 6th mark. If we put the steel marble into Cylinder 2, the water will rise
a. to a lower level than it did in Cylinder 1.
b. to a higher level than it did in Cylinder 1.
c. to the same level as it did in Cylinder 1.

Please explain your selection.

Item 3.
To the right are drawings of a wide and a narrow cylinder. The cylinders have equally spaced marks on them. Water is poured into the wide cylinder up to the 4th mark (see A).



This water rises to the 6th mark when poured into the narrow cylinder (see B). Water is now poured into the *wide* cylinder up to the 6th mark. How high would this water rise if it were poured into the empty narrow cylinder?

Please show (or explain) how you arrived at your answer:

Item 4.
Water is now poured into the narrow cylinder (described in Item 3 above) up to the 11th mark. How high would this water rise if it were poured into the empty wide cylinder?

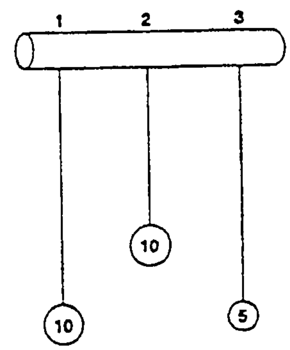
Answer: ______________________________

Please show (or explain) how you arrived at your answer.

____

____

Item 5.



At the right are drawings of three strings hanging from a bar. The three strings have metal weights attached to their ends. String 1 and String 3 are the same length. String 2 is shorter. A 10 unit weight is attached to the end of String 1. A 10 unit weight is also attached to the end of String 2. A 5 unit weight is attached to the end of String 3. The strings (and attached weights) can be swung back and forth and the time it takes to make a swing can be timed. Suppose you wanted to find out whether length of string has an effect on the time it takes to swing back and forth. Which strings would you use to find out?

Answer: ______________________________

Please explain why you choose those strings.

____

____

Item 6.
Suppose you wanted to find out whether the amount of weight attached to the end of a string has an effect on the time it takes for a string to swing back and forth. Which of the strings in item 5 above would you use to find out?

Answer:

____

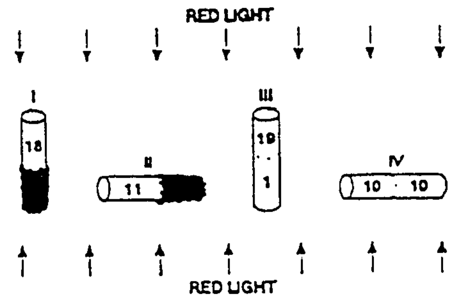
Please explain why you choose those strings.

____

____

Item 7

Twenty flies are placed in each of four glass tubes. The tubes are sealed. Tubes I and II are partially covered with black paper; Tubes III and IV are not covered. The tubes are suspended in midair by strings as shown. Then they are exposed to red light for five minutes. The number of flies in the uncovered part of each tube is shown in the drawing.



This experiment shows that flies respond to (respond means to go to or away from):

a. red light but not to gravity
b. gravity but not to red light
c. both red light and gravity
d. neither red light nor gravity.

Please explain your selection.

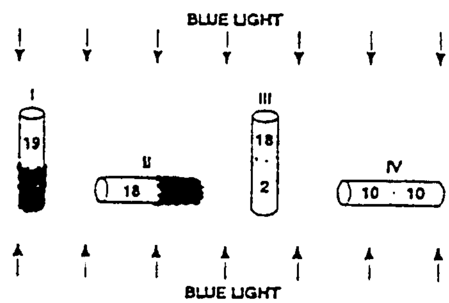
____

____

____

Item 8.

In a second experiment, blue light was used instead of red. The results are shown in the drawing.



These data show that flies respond to (respond means to go to or away from):

a. blue light but not to gravity
b. gravity but not to blue light
c. both blue light and gravity
d. neither blue light nor gravity.

Please explain your selection.

____

____

____

Item 9.
Six square pieces of wood are put into a cloth bag and mixed about. The six pieces are identical in size and shape, however, three pieces are red and three are yellow. Suppose someone reaches into the bag (without looking) and pulls out one piece. What are the chances that the piece is red?

Answer:

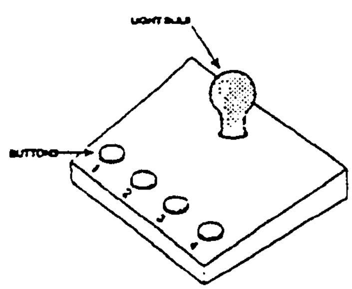
Please show (or explain) how you arrived at your answer.

Item 10.
Three red square pieces of wood, four yellow square pieces, and five blue square pieces are put into a cloth bag. Four red round pieces, two yellow round pieces, and three blue round pieces are also put into the bag. All the pieces are then mixed about. Suppose someone reaches into the bag (without looking and without feeling for a particular shape piece) and pulls out one piece. What are the chances that the piece is a red or blue circle?

Answer:

Please show (or explain) how you arrived at your answer.

Item 11.
The drawing below shows a box with four buttons numbered 1, 2, 3, and 4 and a light bulb. The bulb will light when the correct button, or combination of buttons, are pushed together. Your problem is to figure out which button, or which buttons, must be pushed all at the same time to make the bulb light. Make a list of all the buttons, and all the combinations of buttons you would push to figure out how to make the bulb light.



Item 12.
Look at the fish below that were caught by a fisherman. The fisherman noticed that some of the fish were big and some were small. Also some had wide stripes and others had narrow stripes. This made the fisherman wonder if there was a relation between the size of the fish and the width of their stripes.

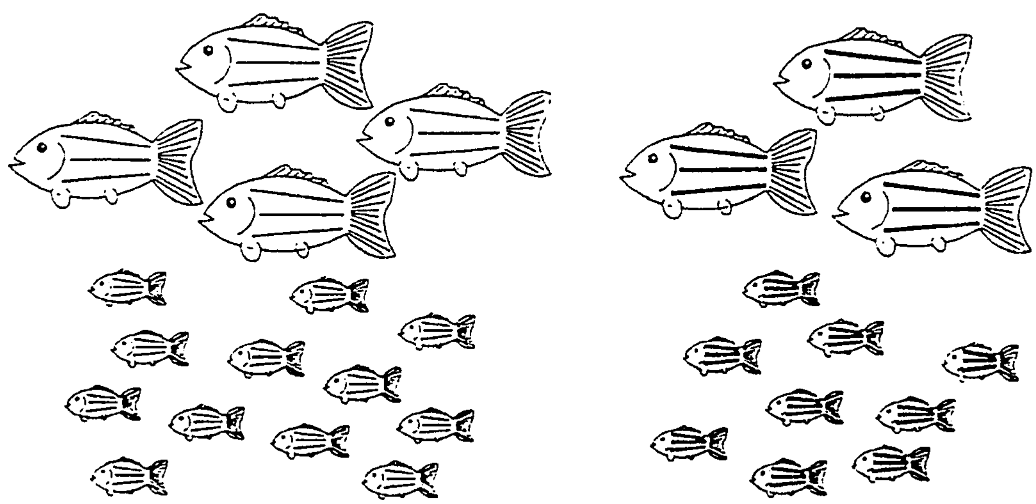
Do you think there is a relation between the size of the fish and the width of their stripes?

a. Yes
b. No

Please explain your choice:

____

____



APPENDIX D

ITEM STATISTICS-CHEMISTRY IN THE COMMUNITY(ChemCom) FORM 1991

ITEM	DIFFICULTY INDEX	DISCRIMINATION INDEX	DISTRIBUTION OF INCORRECT RESPONSES (%)		
1	0.74	0.25	11.51	11.75	2.05
2	0.62	0.43	17.43	10.17	9.46
3	0.51	0.36	28.79	13.64	6.07
4	0.53	0.45	21.21	10.49	13.96
5	0.72	0.18	8.36	4.26	14.75
6	0.79	0.34	10.65	3.23	5.99
7	0.53	0.34	20.90	13.09	11.83
8	0.60	0.11	32.33	5.84	1.34
9	0.72	0.38	14.83	4.65	7.73
10	0.85	0.25	8.04	0.79	5.84
11	0.46	0.44	20.50	19.79	13.09
12	0.58	0.42	16.40	10.41	15.06
13	0.49	0.36	8.91	22.40	19.32
14	0.68	0.46	7.26	4.34	19.32
15	0.39	0.39	11.20	27.84	19.64
16	0.61	0.36	4.42	12.46	21.21
17	0.66	0.42	4.50	24.53	4.10
18	0.62	0.45	1.34	30.21	6.07
19	0.86	0.30	2.29	8.44	3.15
20	0.92	0.16	1.18	3.79	2.44
21	0.60	0.50	18.14	11.28	9.23
22	0.22	0.37	40.93	17.51	18.06
23	0.69	0.48	6.55	7.65	16.72
24	0.64	0.23	7.97	6.62	20.90
25	0.43	0.24	20.43	13.80	21.45
26	0.66	0.41	8.12	10.73	14.43
27	0.94	0.08	1.18	1.97	2.52
28	0.14	0.13	65.77	8.60	10.65
29	0.75	0.26	7.81	12.93	4.42
30	0.62	0.47	8.91	17.11	11.36
31	0.83	0.33	2.92	7.26	5.99
32	0.51	0.31	23.66	17.19	7.65
33	0.50	0.39	16.43	18.30	13.88
34	0.70	0.32	5.13	14.59	9.62
35	0.58	0.40	8.52	12.62	20.11
36	0.45	0.20	17.03	6.39	30.99
37	0.57	0.39	24.13	8.44	9.78
38	0.40	0.56	8.99	27.05	22.40
39	0.53	0.30	19.72	12.22	13.64
40	0.32	0.12	12.38	37.93	16.17

ITEM	DIFFICULTY INDEX	DISCRIMINATION INDEX	DISTRIBUTION OF INCORRECT RESPONSES (%)					
41	0.76	0.19	1.66	3.08	5.52	18.85	0.00	
42	0.76	0.14	15.54	0.00	1.66			
43	0.45	0.33	28.86	9.86	6.62	18.30	20.58	
44	0.51	-0.01	9.07	11.59	11.75	18.06		
45	0.34	0.28	28.47	24.13	25.63	19.32	15.38	15.54
46	0.72	0.22	7.02	5.28	6.62	6.31	4.73	
47	0.71	0.33	8.12	16.40	23.19			
48	0.62	0.34	7.10	19.01	21.77			
49	0.80	0.20	4.02	21.06				
50	0.47	0.24	15.06	16.96	5.91			
51	0.80	0.34	6.07	29.26	18.22	2.21		
52	0.65	0.38	38.88	5.44	1.89	33.36		
53	0.87	0.22	2.37	1.18	2.68	2.29		
54	0.24	0.15	32.10	17.35	14.12	14.98		
55	0.45	0.40	18.45	31.39	13.41			
56	0.71	0.23	17.82	11.28	14.67			
57	0.43	0.24	2.68	8.91	56.55	8.28		
58	0.63	0.16	4.42	3.63	3.15	37.70		
59	0.51	0.25	60.41	54.73	49.13	23.74	9.46	56.94
60	0.35	0.12	17.67	37.93	20.66			

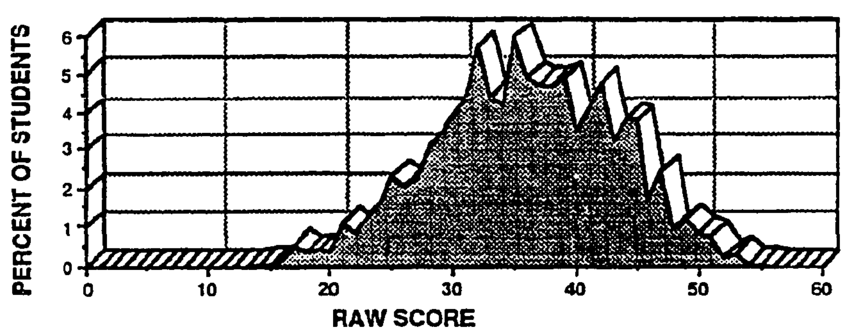
SCHOOLS SUPPLYING USABLE DATA FOR NORMS AND ITEM STATISTICS

Appleton West High School / Appleton, WI
Bangor High School / Bangor, ME
Brookline High School / Brookline, MA
Columbian High School /Tiffin, OH
Dreher High School / Columbia, SC
Ellington High School / Ellington, CT
Estes Park High School / Estes Park, CO
Eureka High School /Eureka, CA Forest
Hill High School / West Palm Beach, FL
Glasgow High School / Newark, DE
Glenbrook North High School / Northbrook, IL
The Hockaday School / Dallas, TX J
Jefferson High School / Rockford, IL
Lake Region High School / Bridgton, ME
Neenah High School / Neenah, WI
Newman High School / Mason City, IA Niles
West High School / Skokie, IL
Ramona Convent Secondary School / Alhambra, CA
Rich East High School / Park Forest, IL
Rolling Meadows High School / Rolling Meadows, IL
Spring Valley High School / Columbia, SC
Stillwater Senior High School / Stillwater, MN
Wiscasset High School / Wiscasset, ME

AMERICAN CHEMICAL SOCIETY
DIVISION OF CHEMICAL EDUCATION
COMPOSITE NORM--CHEMISTRY IN COMMUNITY *(ChemCom)*
FORM 1991

Score	Percentile	Score	Percentile	Score	Percentile
60	100	38	61	16	0
59	100	37	56	15	0
58	100	36	51	14	0
57	100	35	46	13	0
56	100	34	41	12	0
55	100	33	36	11	0
54	100	32	31	10	0
53	100	31	26	9	0
52	99	30	22	8	0
51	99	29	18	7	0
50	98	28	15	6	0
49	97	27	12	5	0
48	96	26	10	4	0
47	94	25	8	3	0
46	92	24	6	2	0
45	90	23	5	1	0
44	86	22	3		
43	82	21	2		
42	78	20	2	Mean	35.73
41	74	19	1	Std Deviation	7.35
40	70	18	1	Median	35.9
39	66	17	0	KR-21 reliability	0.74
				Std error/meas	3.71

Norms based on the scores of 1391 students.
Item statistics based on the responses of 1268 students.
23 high schools supplied usable data.



EXPLANATIONS

The difficulty index is the percentage of students who responded correctly to an item. The discrimination index measures the performance on the item of students who did well on the test overall relative to those who did poorly. the frequencies with which incorrect responses are chosen are expressed as percentages; for additional information, obtain *How to Interpret Test* Statistics from the ACS DivCHED Examinations Institute.

Notice to Users of the ACS *ChemCom* Examination

The *ChemCom* national examination differs from other ACS high school examinations in that most of the Part 2 questions have multiple correct responses. Hand scoring this part is straightforward if you use the *ChemCom* answer sheets and scoring template. You can pace a telephone order for both answer sheets and a scoring template quickly by calling the ACS DivCHED Examinations institute at (803) 656-1249 or by sending a FAX order to the Examinations institute at (803) 656-1250.

If you choose not to use the special *ChemCom* answer sheets, please follow these instructions to score the examination if you wish to compare your students with the national norms that have been established.

- In Part 1, tally the number of correct responses to obtain the PART I TOTAL. Do not count any questions containing more than one correct response.

- In Part 2, tally both the number of correct and incorrect responses for each question. Use this formula to calculate the student point credit on each question:

$$\text{Point credit for question} = \frac{\text{Correct Choices}}{A} - \frac{\text{Incorrect Choices}}{B}$$

- Use values for A and B from the table.

Question	A	B
41	1	5
42	2	4
43	2	5
44	3	4
45	1	6
46	2	5
47	3	3
48	2	3
49	3	2
50	3	3
51	2	4
52	2	4
53	2	4
54	1	4
55	2	3
56	2	3
57	2	4
58	2	4
59	2	7
60	2	3

- Round each value to one decimal place. Enter zero for any negative values. Sum the item scores to obtain the PART 2 TOTAL.
- Sum the part totals to calculate the overall test score.

How to Interpret Test Statistics

ACS DivCHED Examinations Institute

Introduction

The purpose of this booklet is to help ACS test committee members and all classroom teachers understand the test statistics used by the Examinations Institute. Overall test statistics and item statistics can be powerful tools for improving the quality of chemistry examinations. This booklet will review the definitions of commonly used statistical measures and offer some guidelines for their interpretation.

Your suggestions and comments about this publication are welcome. Please share your thoughts with us. You can reach us by mail, phone, or FAX.

ACS DivCHED Exams Institute
223 Brackett Hall
Clemson University
Box 341913
Clemson SC 29634-1913

Why Use Statistics?

The purpose of the American Chemical Society Division of Chemical Education's testing program is to provide the various standardized tests needed by chemical educators Well-constructed tests should be *valid;* that is, they should measure those student attributes the examiner wishes to assess. The tests should also be *reliable,* a term that refers to the internal consistency of test scores. The Examinations Institute seeks to insure the validity of its tests by using committees of content experts to delineate coverage and levels of understanding for each test. 'rest statistics and item statistics are valuable tools for insuring the reliability of a test, both in its preliminary phases of preparation and in its final form. Statistics can also help teachers make better use of test results.

Item Statistics

There are three types of item statistics that are relatively easy to obtain that are useful to teachers. These are the difficulty index the discrimination index, and the distribution of incorrect responses. The difficulty index as used by the Examinations Institute, is simply the percentage of students who responded correctly to an item. The symbol used is p-the proportion of correct answers on the item. If 350 of 500 students successfully answered any given question, the difficulty would be reported as 70.0. If only 150 of 500 students were successful, the difficulty would be 30.0.

$$p = \frac{\text{number correct}}{\text{number of answers}} \times 100$$

The lower mathematical limit of p is 0, which occurs if not even one student is successful on the item The upper limit is 100 if all students correctly answer an item. The larger the value of the difficulty index the easier the question. Items with either very high or very low proportions of success are usually eliminated from a standardized test of the Examinations Institute because such items obscure differences in levels of achievement among the students tested. Items with *p* factors greater than 70 or less than 30 are usually rejected, although you might decide to use such items in your classroom testing to achieve other objectives. For the purposes of designing a standardized achievement or diagnostic test, items that are either too easy or too hard also provide limited information to the examiner because they lack *discrimination.*

The **discrimination** index measures the performance on the item for students who did well on the test overall relative to those who did poorly. This index provides a mathematical expression for the intuitive understanding that a well-designed question should result in greater success for the top students than for those students whose overall achievement is lower. For example, if all of the top students answered the question correctly, and none of the low group students did so, the discrimination index would be at its maximum. Conversely, if all of the low-achieving students answered this question correctly, but all of the high-achieving students missed it, there must be something seriously wrong with the question. There may be a widespread misconception on the part of the students. Or, there may have been an error in marking the key!

As commonly used, the discrimination index, here represented by the symbol ***r*** is calculated by subtracting the number of right answers on that item given by students in the bottom 27% of achievers from the number of right answers given by students in the top 27% of achievers, and dividing by the number of students in one of these groups Sometimes groups of 25% or 33% are used, but the upper and lower 27% is considered to be the best compromise between the conflicting needs to make the comparison groups both as different as possible and still as large as possible.

$$r = \frac{\text{high group rights - low group rights}}{\text{number in one group}}$$

The discrimination index reveals the effectiveness of an item in differentiating among the achievement of the students who are most successful overall and those who are least successful. The higher the value of *r*, the greater the usefulness of the question in differentiating "good" and "poor" students. If the difficulty of the item is either 0 or 100, the discrimination index is zero and no discrimination can take place. If the difficulty of an item is around 50, the discrimination index can range from -1.00 and +1.00. Values of *r* in the range of 0.30-0.50 are typical for items in most standardized tests of the Examinations Institute, with items having values below 0.20 usually having been discarded after the trial test.

The **distribution of incorrect responses** is another useful indication of item effectiveness. This is most simply reported as a percentage, showing the relative frequency with which each alternative response has been chosen. A close inspection of incorrect response patterns often uncovers the reason for the low discriminating power of an item. Ideally, each of the distractors should attract some students particularly students in the low-achieving group. Much time must be spent in carefully crafting incorrect responses so they are actually plausible, result from logic associated with common misconceptions, and provide viable choices for students. They must never, of course, confuse or trap any student, just correctly reveal the areas of incomplete understanding or processing of data.

The first time item statistics are used by ACS test committees is during the evaluation of trial tests. When all trial test Scantron® answer sheets have been received, Examinations Institute staff analyze the data to determine the difficulty of each item, the ability of each item to discriminate, and the percentage of students who select each possible response. This data is essential to committee members who select items for the final version of the test. It is now the practice of the Examinations Institute to supply item statistics for all questions on new standardized tests.

Here is an example of a question used on a trial test. The resulting item statistics helped the test committee reach the decision not to use this question on the standardized test, and the patterns are here analyzed to show why the question is not suitable.

Question:

In the titration of iron(ll) sulfate, $FeSO_4$, with acidified potassium permanganate, $KMnO_4$, the pink color which signals the end point is caused by

(A) phenolphthalein (B) MnO_4^-

(C) MnO_2 (D) Fe^{3+}

Item statistics from the trial test

The difficulty index was 29.0, the discrimination index was 0.0 1, 54% chose (A), 29% chose (B), 9% chose (C), and 8% chose (D).There were 333 students who attempted this question and the correct answer is (B).

Analysis based on item statistics:

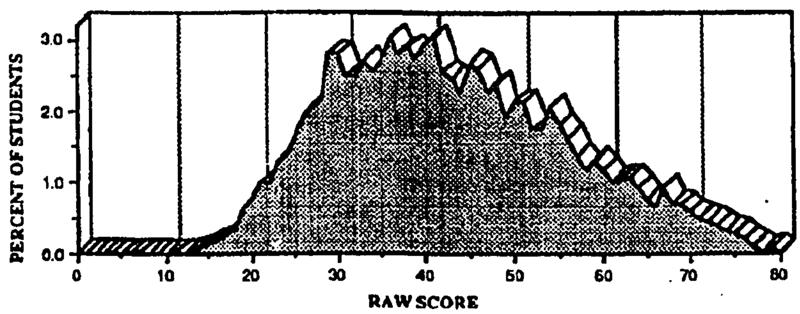
The question proved to be difficult for the students and did not discriminate at all. Nearly twice as many students chose the incorrect response (A) as the correct response (B), but the other two choices were not attractive to almost all students. It may be that the experience of the students does not include this particular redox titration, or that they are confused by their other laboratory experience with phenolphthalein.

Test Statistics

It has long been the practice of the Examinations Institute to publish composite norms for each new test. To be accurate, such norms must be based on a large, representative sample of students who have been administered the test under controlled conditions. The cooperation of many teachers is required, and voluntary submission of student answer sheets enable Examinations Institute staff to analyze the results and to compute the many useful statistics for the test.

Typically, the Institute is now reporting **composite norms, mean, standard deviation, median, KR2I reliability,** and the **standard error of measurement** for the each test. Also, schools supplying usable data to the Examinations Institute receive a detailed analysis of their students' performances.

Composite norms report how students perform overall on a test. Percentile ranks are Calculated by summing the number of students in the sample who achieve up to any particular score and then dividing by the number of students. For example, if a raw score of 55 Corresponds to the 86th Percentile, this means that 86% of the students who took this test had a score of less than 55, but 14% of the students had a higher score. The distribution of scores are also now presented graphically such as those below for the High School Chemistry Form 1989.



The *mean* and the *standard deviation* are both very reliable measures of the Central tendency in a distribution . The **mean** score is calculated by adding all of the scores in a set and dividing this sum by the total number of scores. It is the familiar "average" score, and is equal to 42 in this Case. Looking at the mean value will give you a quick idea of how students have performed. A very high mean relative to the number of possible points is an indication of an easy test, but a low mean does not always indicate a difficult test. It just may not be valid for the students to whom it was given.

The **standard deviation** is a measure of the variability of scores from the mean. A relatively small value for standard deviation means that scores are more tightly clustered about the mean. A large value shows scores to be spread Out over a larger range. For the test used in this example, the standard deviation is 13 points.

Standard deviation is calculated by first computing the deviation for each person's score from the mean score for the sample. These deviations are then squared and divided by the number of test scores. This process yields the quantity called the **variance**, and its square root is called the standard deviation, given the symbol s.

$$s = \sqrt{\frac{\Sigma(X-X)^2}{n}}$$

X is the individual test score

X is the mean test score

Σ is the summation

n is the number of scores

The **median** is the middle score and therefore half the students score better than the median and half below. The median appears at the 50th percentile, and is equal to a raw score of 41 in this case.

If a test is perfectly *reliable* then a student would score exactly the same it two equivalent forms of the test were administered, or if the same test were given on two occasions. Because these conditions are not practical in most testing situations, internal consistency methods are often used because they require only a single administration of a test. Formulas employing convenient approximations have been developed and one of the most widely used is called the **KR21 reliability estimate.** The formula allows calculation of test reliability from three pieces of information-the number of items on a test, the mean value, and the standard deviation.

$$KR21 = 1 - \frac{X(n-X)}{ns^2}$$

n is the number of test items

X is the mean value

s is the standard deviation

If there is a complete lack of correlation, the reliability coefficient would have a value of zero. The limiting upper value is 1.00. The reliability for standardized tests is frequently about 0.90 or greater, although classroom tests might be expected to range in reliability between 0.60 and 0.80 using this formula. If questions vary significantly in difficulty, this particular formula tends to underestimate reliability, so the value of 0.90 for the high school chemistry test in 1989 is, if anything, less than the true reliability.

Another factor to remember about reliability and its measurement is that it is an important indicator of the value of the test as applied to a particular group of students, rather than an attribute of only the test itself. If an uninstructed group of examinees were given this same test, the reliability would be much lower. This is why, for example, a separate standardized test is being developed for students in the new ACS *Chemistry in the Community* curriculum, rather than suggesting that they be given an existing high school chemistry test. Course objectives must match test objectives to achieve high reliability.

The **standard error of measurement (SEM)** expresses the uncertainty in the measurement in an individual test score. It therefore gives a way to interpret the uncertainty in any student's individual test score. This is the formula used.

$$SEM = s\sqrt{1-KR21}$$

s = standard deviation
KR21 = reliability estimate

The value of this parameter tells you that if a particular student receives a score of 52 on the high school 1989 test, which has a standard error of measurement of 4, then you could be reasonably sure that the range of scores 48-56 would actually include, the student's "true" score. The size of the scoring band reminds us not to over interpret test results, for a student scoring 52 is not proven superior to one scoring 50, due to the overlap of their scoring bands in this case.

Uses of Test Statistics in the Classroom

One reason to understand item and test statistics as they are commonly used with norm-referenced -tests is to be able to interpret the numbers reported for standardized tests. The mean, standard deviation, median, KR2l reliability, and standard error of measurement each give you different information about the overall test. The difficulty index, discrimination index, and pattern of incorrect responses give you information for each item on that test.

Another reason for using test statistics is to analyze your own objective tests. Gathering data and calculating some common statistical measures is a task made easier with the use of computer hardware and supporting software, and can help you to know the areas of strengths and weakness in your students' knowledge. You can also determine whether your objective tests are really evaluating what you expect, a necessary first step for improving the quality of your classroom tests.

APPENDIX E

Sokal and Rohlf, 1981

BOX 9.10 (*Continued*)

The Tukey–Kramer Method

1. Another method that can be applied to these data is the Tukey–Kramer method. Substitute into Expression (9.8) for MSD = (critical value) × SE as follows. For the critical value use $Q_{\alpha[k,\nu]}$, the studentized range from Table **18**. Set $k = a$, and employ the degrees of freedom of the MS_{within} for ν. In this case $k = 8$, and

   $\nu = 122$ as noted before. In Table **18** we find $Q_{.05[8,122]} = 4.362$. This valu will be used for all tests.

   The standard error is

$$SE_{ij} = \sqrt{\frac{MS_{\text{within}}\left(\frac{1}{n_i} + \frac{1}{n_j}\right)}{2}}$$

Thus for the comparison of the means of localities 3 and 4 we compute

$$SE_{3,4} = \sqrt{\frac{0.02645\left(\frac{1}{20} + \frac{1}{14}\right)}{2}}$$

$$= \sqrt{0.001606} = 0.040074$$

Therefore

$$MSD_{3,4} = 4.362(0.040074) = 0.17480$$

BOX 9.10 (*Continued*)

2. A pair of means ($\bar{Y}_i$, $\bar{Y}_j$) is declared significantly different at the experimentwise error rate α only if their difference equals or exceeds the critical difference MSD_{ij}, i.e., if $|\bar{Y}_j - \bar{Y}_i| \geq MSD_{ij}$.

   For example, means $\bar{Y}_3$ and $\bar{Y}_4$ are not significantly different from one another since $|\bar{Y}_4 - \bar{Y}_3| = 0.0006 \ll 0.17480$. Note that the *MSD* for this comparison is smaller than that obtained for the same comparison by both the GT2- and the T'-methods and thus yields the more powerful test.

   To test all pairs of means it is most convenient to prepare a table of $|\bar{Y}_j - \bar{Y}_i|$ and MSD_{ij} values, as was shown above for the GT2-method.

	Ranked localities							
	1	2	3	4	5	6	7	8
1	—	.1586	.1586	.1748	.1943	.1713	.1883	.1586
2	.1817*	—	.1586	.1748	.1943	.1713	.1883	.1586
3	.2100*	.0283	—	.1748	.1943	.1713	.1883	.1586
4	.2106*	.0289	.0006	—	.2077	.1864	.2021	.1748
5	.2253*	.0436	.0153	.0147	—	.2048	.2192	.1943
6	.2356*	.0539	.0256	.0250	.0103	—	.1991	.1713
7	.2720*	.0903	.0620	.0614	.0467	.0364	—	.1883
8	.3328*	.1511	.1228	.1222	.1075	.0972	.0608	—

The $|\bar{Y}_j - \bar{Y}_i|$ values are given below the diagonal, and MSD_{ij} values are given above the diagonal. Differences larger in absolute value than their *MSD* value are significant at the 0.05 level and are marked with an asterisk. In this case the results are the same as those obtained using the GT2-method.

APPENDIX F

Raw Data from Lawson Test and the ACS *ChemCom* Exam

Table F1

Class Data

LEVEL	YR	LAWSON SCORE	PROP REASON No./4	A1	G	A2	T	C	CHEMCOM EXAM FINAL	PART 1	PART 2
T1	SR	8	0.75					C	32.7	20	12.7
F15	S	11	1		G				32.3	18	14.3
F11	J	9	0.5						31.4	17	14.4
F3	S	9	1			A2			29.8	17	12.8
F4	J	9	0.5			A2			29.1	17	12.1
F12	S	9	1				T		28.8	17	11.8
F2	F	10	1		G				29.3	17	12.3
T25	J	8	0.75				T		28.2	16	12.2
C13	J	3	0.75			A2			27.9	16	11.9
T37	SR	8	0.75			A2			27.8	15	12.8
C23	J	4	0.25				T		27.6	17	10.6
T33	J	6	0.5		G				27.8	16	11.8
F8	J	9	1			A2			27.2	15	12.2
F18	J	9	1			A2			27.2	16	11.2
T2	J	8	0.75			A2			26.6	15	11.6
F7	J	9	1				T		26.8	15	11.8
C20	J	1	0	A1					26.3	13	13.3
F9	J	9	0.75		G				26.1	15	11.1
T46	J	7	0.75			A2			26.6	16	10.6
T8	S	6	0.5		G				25.9	17	8.9
C15	J	4	0.5			A2			25.6	13	12.6
F14	J	11	0.75		G				26.0	14	12.0
T6	J	7	0.25			A2			25.9	14	11.9
C14	S	3	0.5	A1					25.4	17	8.4
T31	J	6	0.25				T		25.0	12	13.0
F1	J	11	1			A2			25.3	14	11.3
F6	J	11	1			A2			25.3	15	10.3
T28	J	6	0.5		G				25.3	14	11.3
T12	J	6	0.75		G				24.6	15	9.6
T13	J	5	0.5			A2			24.4	15	9.4
C34	SR	4	0.25						24.6	15	9.6
F20	J	12	1			A2			24.6	15	9.6
C5	J	3	0.25			A2			24.1	17	7.1
F16	J	9	0.5			A2			24.0	12	12.0

Table F1 (cont.)

LEVEL	YR	LAWSON SCORE	PROP REASON No./4	MATH CLASS A1	G	A2	T	C	CHEMCOM EXAM FINAL	PART 1	PART 2
T24	S	8	1				T		24.4	15	9.4
C33	J	4	0.25			A2			24.4	16	8.4
T23	J	7	0.5		G				24.4	15	9.4
C17	J	4	0			A2			23.7	12	11.7
T10	J	6	0.25			A2			24.1	15	9.1
C21	J	2	0.25				T		23.5	15	8.5
T45	J	6	0.25			A2			23.5	15	8.5
T22	S	7	0.5		G				23.4	14	9.4
C27	J	3	0			A2			23.8	15	8.8
C19	J	0	0			A2			23.7	16	7.7
C36	J	4	0.5			A2			23.2	14	9.2
T7	J	7	0.25			A2			23.0	13	10.0
C2	J	4	0.25			A2			23.0	15	8.0
C16	SR	4	0		G				23.0	15	8.0
C8	S	1	0.25		G				23.4	15	8.4
T30	J	6	0.25				T		23.4	13	10.4
T20	J	6	0.25			A2			22.8	12	10.8
F19	J	10	0.5			A2			23.1	14	9.1
F13	SR	10	0.75						23.1	13	10.1
C28	J	3	0			A2			23.0	15	8.0
C1	J	4	0.5			A2			22.9	16	6.9
T9	S	6	0.5		G				22.0	15	7.0
T16	J	5	0.25		G				21.1	11	10.1
T14	J	5	0.5			A2			21.0	14	7.0
T40	J	5	0.25		G				21.4	13	8.4
C11	J	2	0.5		G				21.2	14	7.2
T5	J	7	0.75				T		21.1	14	7.1
C6	J	2	0.25			A2			20.6	12	8.6
T27	S	5	1			A2			21.0	11	10.0
C9	SR	0	O			A2			20.9	12	8.9
F10	J	9	1			A2			20.8	14	6.8
T35	J	8	0.25						20.8	11	9.8
T38	J	5	0.25			A2			20.7	14	6.7
T39	J	5	0.25			A2			20.5	14	6.5
T36	J	8	0.75		G				19.8	12	7.8
T44		6	0.25		G				20.2	11	9.2
C4	SR	3	0.5					C	20.0	12	8.0
C25	J	2	0.25			A2			19.8	11	8.8
C38	J	4	0.5			A2			19.7	9	10.7
T3	J	7	0.5		G				19.0	11	8.0
C32	J	3	0.25		G				19.4	10	9.4
C30	J	3	0.5		G				19.3	10	9.3

Table F1 (cont.)

LEVEL	YR	LAWSON SCORE	PROP REASON No./4	MATH CLASS A1	G	A2	T	C	CHEMCOM EXAM FINAL	PART 1	PART 2
C39		4	0.25			A2			19.3	11	8.3
T19	J	6	0.25			A2			19.0	12	7.0
T41	J	5	0.5			A2			19.0	10	9.0
C3	J	3	0.25			A2			18.9	16	2.9
F5	J	10	1			A2			17.9	8	9.9
T32	SR	7	0.5						17.9	12	5.9
C7	J	2	0.5		G				17.3	10	7.3
C24	J	4	0.25			A2			17.2	9	8.2
T29	SR	6	1						16.9	10	6.9
T26	J	5	0.5			A2			17.0	9	8.0
T21	J	7	0.5			A2			16.4	9	7.4
T17	S	5	0.75		G				15.9	8	7.9
C12	J	2	0.25			A2			16.3	10	6.3
F17		9	1						16.2	10	6.2
T34	J	7	0.5			A2			16.0	6	10.0
C26	J	2	0.25	A1					15.5	10	5.5
T4	J	7	0.5	A1					15.4	8	7.4
T18	SR	5	0.25		G				15.8	8	7.8
T43	D	6	0.5		G				15.5	6	9.5
T15	J	5	0.25			A2			14.6	7	7.6
C29	J	3	0.25		G				14.8	7	7.8
C 37	J	4	0.25			A2			13.9	7	6.9
C22		3	0.25			A2			13.5	8	5.5
C35	J	4	0	A1					12.5	6	6.5
C31		3	0.25		G				12.5	8	4.5
T42	J	6	0.5			A2			12.4	6	6.4
T11	J	6	0.25	A1					10.7	7	3.7
C18	J	4	0.5			A2			10.2	5	5.2
C10	SR	0	0			A2			8.0	3	5.0
TOT				**6**	**27**	**54**	**9**	**2**			
%		**4.74**	**0.41**						**21.76**	**12.7**	**9.1**
STD DEV		**2.09**	**0.24**						**4.98**	**3.42**	**2.32**

Table F2

Data by Piagetian Level

LEVEL	YR	LAWSON SCORE	PROP REASON No./4	MATH CLASS A1	G	A2	T	C	CHEMCOM EXAM FINAL	PART 1	PART 2
Formal											
F15	S	11	1		G				32.3	18	14.3
F11	J	9	0.5						31.4	17	14.4
F3	S	9	1			A2			29.8	17	12.8
F2	F	10	1		G				29.3	17	12.3
F4	J	9	0.5			A2			29.1	17	12.1
F12	S	9	1				T		28.8	17	11.8
F8	J	9	1			A2			27.2	15	12.2
F18	J	9	1			A2			27.2	16	11.2
F7	J	9	1				T		26.8	15	11.8
F9	J	9	0.75		G				26.1	15	11.1
F14	J	11	0.75		G				26	14	12.0
F1	J	11	1			A2			25.3	14	11.3
F6	J	11	1			A2			25.3	15	10.3
F20	J	12	1			A2			24.6	15	9.6
F16	J	9	0.5			A2			24	12	12.0
F19	J	10	0.5			A2			23.1	14	9.1
F13	SR	10	0.75						23.1	13	10.1
F10	J	9	1			A2			20.8	14	6.8
F5	J	10	1			A2			17.9	8	9.9
F17		9	1						16.2	10	6.2
TOT				**0**	**4**	**11**	**2**	**0**			
%			**0.863**						**25.7**	**14.65**	**11.1**
STD DEV			**0.206**						**4.14**	**2.498**	**2.1**

LEVEL	YR	LAWSON SCORE	PROP REASON No./4	MATH CLASS A1	G	A2	T	C	CHEMCOM EXAM FINAL	PART 1	PART 2
Transitional											
T1	SR	8	0.75					C	32.7	20	12.7
T25	J	8	0.75				T		28.2	16	12.2
T33	J	7	0.5		G				27.8	16	11.8
T37	SR	8	0.75			A2			27.8	15	12.8
T46	J	7	0.75			A2			26.6	16	10.6
T2	J	8	0.75			A2			26.6	15	11.6
T6	J	7	0.25			A2			25.9	14	11.9
T8	S	6	0.5		G				25.9	17	8.9
T28	J	6	0.5		G				25.3	14	11.3
T31	J	6	0.25				T		25	12	13.0
T12	J	6	0.75		G				24.6	15	9.6

Table F2 (cont.)

LEVEL	YR	LAWSON SCORE	PROP REASON No./4	MATH CLASS A1	G	A2	T	C	CHEMCOM EXAM FINAL	PART 1	PART 2
Transitional (cont.)											
T24	S	8	1				T		24.4	15	9.4
T13	J	5	0.5			A2			24.4	15	9.4
T23	J	7	0.5		G				24.4	15	9.4
T10	J	6	0.25			A2			24.1	15	9.1
T45	J	6	0.25			A2			23.5	15	8.5
T30	J	6	0.25				T		23.4	13	10.4
T22	S	7	0.5		G				23.4	14	9.4
T7	J	7	0.25			A2			23	13	10.0
T20	J	6	0.25			A2			22.8	12	10.8
T9	S	6	0.5		G				22	15	7.0
T40	J	5	0.25		G				21.4	13	8.4
T5	J	7	0.75				T		21.1	14	7.1
T16	J	5	0.25		G				21.1	11	10.1
T27	S	5	1			A2			21	11	10.0
T14	J	5	0.5			A2			21	14	7.0
T35	J	8	0.25						20.8	11	9.8
T38	J	5	0.25			A2			20.7	14	6.7
T39	J	5	0.25			A2			20.5	14	6.5
T44		6	0.25		G				20.2	11	9.2
T36	J	8	0.75		G				19.8	12	7.8
T19	J	6	0.25			A2			19	12	7.0
T3	J	7	0.5		G				19	11	8.0
T41	J	5	0.5			A2			19	10	9.0
T32	SR	6	0.5						17.9	12	5.9
T26	J	5	0.5			A2			17	9	8.0
T29	SR	6	1						16.9	10	6.9
T21	J	7	0.5			A2			16.4	9	7.4
T34	J	7	0.5			A2			16	6	10.0
T17	S	5	0.75		G				15.9	8	7.9
T18	SR	5	0.25		G				15.8	8	7.8
T43	D	6	0.5		G				15.5	6	9.5
T4	J	7	0.5	A1					15.4	8	7.4
T15	J	5	0.25			A2			14.6	7	7.6
T42	J	6	0.5			A2			12.4	6	6.4
T11	J	6	0.25	A1					10.7	7	3.7
TOT				**2**	**15**	**20**	**5**	**2**			
%			**0.49**						**21.3**	**12.3**	**9.0**
STD DEV			**0.23**						**4.57**	**3.27**	**2.0**

Table F2 (cont.)

			PROP	MATH CLASS					CHEMCOM EXAM		
LEVEL	YR	LAWSON	REASON	A1	G	A2	T	C	FINAL	PART	PART
Concrete		SCORE	No./4							1	2
C13	J	3	0.75			A2			27.9	16	11.9
C23	J	4	0.25				T		27.6	17	10.6
C20	J	1	0	A1					26.3	13	13.3
C15	J	4	0.5			A2			25.6	13	12.6
C14	S	3	0.5	A1					25.4	17	8.4
C34	SR	4	0.25						24.6	15	9.6
C33	J	4	0.25			A2			24.4	16	8.4
C5	J	3	0.25			A2			24.1	17	7.1
C27	J	3	0			A2			23.8	15	8.8
C19	J	0	0			A2			23.7	16	7.7
C17	J	4	0			A2			23.7	12	11.7
C21	J	2	0.25				T		23.5	15	8.5
C1	J	4	0.5			A2			23.4	16	7.4
C8	S	1	0.25		G				23.4	15	8.4
C36	J	4	0.5			A2			23.2	14	9.2
C2	J	4	0.25			A2			23	15	8.0
C16	SR	4	0		G				23	15	8.0
C28	J	3	0			A2			23	15	8.0
C11	J	2	0.5		G				21.2	14	7.2
C9	SR	0	O			A2			20.9	12	8.9
C6	J	2	0.25			A2			20.6	12	8.6
C4	SR	3	0.5					C	20	12	8.0
C25	J	2	0.25			A2			19.8	11	8.8
C38	J	4	0.5			A2			19.7	9	10.7
C32	J	3	0.25		G				19.4	10	9.4
C30	J	3	0.5		G				19.3	10	9.3
C39		4	0.25			A2			19.3	11	8.3
C3	J	3	0.25			A2			18.9	16	2.9
C7	J	2	0.5		G				17.3	10	7.3
C24	J	4	0.25			A2			17.2	9	8.2
C12	J	2	0.25			A2			16.3	10	6.3
C26	J	2	0.25	A1					15.5	10	5.5
C29	J	3	0.25		G				14.8	7	7.8
C 37	J	4	0.25			A2			13.9	7	6.9
C22		3	0.25			A2			13.5	8	5.5
C35	J	4	0	A1					12.5	6	6.5
C31		3	0.25		G				12.5	8	4.5
C18	J	4	0.5			A2			10.2	5	5.2
C10	SR	0	0			A2			8.03	3	5.0
TOT				**4**	**8**	**23**	**2**	**1**			
%		**2.87**	**0.28**						**20.3**	**12.1**	**8.2**
SD		**1.22**	**0.19**						**4.87**	**3.68**	**2.2**

Table F3

Data by Proportional Reasoning Score

LEVEL	YR	LAWSON SCORE	PROP REASON No./4	MATH CLASS A1	G	A2	T	C	CHEMCOM EXAM FINAL	PART 1	PART 2
4 out of 4											
F15	S	11	1		G				32.3	18	14.3
F3	S	9	1			A2			29.8	17	12.8
F12	S	9	1				T		28.8	17	11.8
F2	F	10	1		G				29.3	17	12.3
F8	J	9	1			A2			27.2	15	12.2
F18	J	9	1			A2			27.2	16	11.2
F7	J	9	1				T		26.8	15	11.8
F1	J	11	1			A2			25.3	14	11.3
F6	J	11	1			A2			25.3	15	10.3
F20	J	12	1			A2			24.6	15	9.6
T24	S	8	1				T		24.4	15	9.4
T27	S	5	1			A2			21.0	11	10.0
F10	J	9	1			A2			20.8	14	6.8
F5	J	10	1			A2			17.9	8	9.9
T29	SR	6	1						16.9	10	6.9
F17		9	1						16.2	10	6.2
Total				0	2	9	3	0	394	227	167
Mean									24.62	14.19	10.43
3 out of 4											
T											
T1	SR	8	0.75					C	32.7	20	12.7
T25	J	8	0.75				T		28.2	16	12.2
C13	J	3	0.75			A2			27.9	16	11.9
T37	SR	8	0.75			A2			27.8	15	12.8
T2	J	8	0.75			A2			26.6	15	11.6
F9	J	9	0.75		G				26.1	15	11.1
T46	J	7	0.75			A2			27.1	16	11.1
F14	J	11	0.75		G				26.0	14	12.0
T12	J	6	0.75		G				24.6	15	9.6
F13	SR	10	0.75						23.1	13	10.1
T5	J	7	0.75				T		21.1	14	7.1
T36	J	8	0.75		G				19.8	12	7.8
T17	S	5	0.75		G				15.9	8	7.9
Total					5	4	2	1	327	189	138
Mean									25.13	14.54	10.59

Table F3 (cont.)

LEVEL	YR	LAWSON SCORE	PROP REASON No./4	MATH CLASS A1	G	A2	T	C	CHEMCOM EXAM FINAL	PART 1	PART 2
2 out of 4											
F11	J	9	0.5						31.4	17	14.4
F4	J	9	0.5			A2			29.1	17	12.1
T33	J	6	0.5		G				27.8	16	11.8
T8	S	6	0.5		G				25.9	17	8.9
C15	J	4	0.5			A2			25.6	13	12.6
C14	S	3	0.5	A1					25.4	17	8.4
T28	J	6	0.5		G				25.3	14	11.3
T13	J	5	0.5			A2			24.4	15	9.4
F16	J	9	0.5			A2			24.0	12	12.0
T23	J	7	0.5		G				24.4	15	9.4
T22	S	7	0.5		G				23.4	14	9.4
C36	J	4	0.5			A2			23.2	14	9.2
F19	J	10	0.5			A2			23.1	14	9.1
C1	J	4	0.5			A2			22.9	16	6.9
T9	S	6	0.5		G				22.0	15	7.0
T14	J	5	0.5			A2			21.0	14	7.0
C11	J	2	0.5		G				21.2	14	7.2
C4	SR	3	0.5					C	20.0	12	8.0
C38	J	4	0.5			A2			19.7	9	10.7
T3	J	7	0.5		G				19.0	11	8.0
C30	J	3	0.5		G				19.3	10	9.3
T41	J	5	0.5			A2			19.0	10	9.0
T32	SR	7	0.5						17.9	12	5.9
C7	J	2	0.5		G				17.3	10	7.3
T26	J	5	0.5			A2			17.0	9	8.0
T21	J	7	0.5			A2			16.4	9	7.4
T34	J	7	0.5			A2			16.0	6	10.0
T4	J	7	0.5	A1					15.4	8	7.4
T43	D	6	0.5		G				15.5	6	9.5
T42	J	5	0.5			A2			12.4	6	6.4
C18	J	4	0.5			A2			10.2	5	5.2
Total				2	11	15	0	1	655.2	377.0	278.2
Mean									21.13	12.16	8.97

Table F3 (cont.)

LEVEL	YR	LAWSON SCORE	PROP REASON No./4	MATH CLASS A1	G	A2	T	C	CHEMCOM EXAM FINAL	PART 1	PART 2
1 out of 4											
C23	J	4	0.25				T		27.6	17	10.6
T6	J	7	0.25			A2			25.9	14	11.9
T31	J	6	0.25				T		25.0	12	13.0
C34	SR	4	0.25						24.6	15	9.6
C5	J	3	0.25			A2			24.1	17	7.1
C33	J	4	0.25			A2			24.4	16	8.4
T10	J	6	0.25			A2			24.1	15	9.1
C21	J	2	0.25				T		23.5	15	8.5
T45	J	6	0.25			A2			23.5	15	8.5
T7	J	7	0.25			A2			23.0	13	10.0
C2	J	4	0.25			A2			23.0	15	8.0
C8	S	1	0.25		G				23.4	15	8.4
T30	J	6	0.25				T		23.4	13	10.4
T20	J	6	0.25			A2			22.8	12	10.8
T16	J	5	0.25		G				21.1	11	10.1
T40	J	5	0.25		G				21.4	13	8.4
C6	J	2	0.25			A2			20.6	12	8.6
T35	J	8	0.25						20.8	11	9.8
T38	J	5	0.25			A2			20.7	14	6.7
T39	J	5	0.25			A2			20.5	14	6.5
T44		6	0.25		G				20.2	11	9.2
C25	J	2	0.25			A2			19.8	11	8.8
C32	J	3	0.25		G				19.4	10	9.4
C39		4	0.25			A2			19.3	11	8.3
T19	J	6	0.25			A2			19.0	12	7.0
C3	J	3	0.25			A2			18.9	16	2.9
C24	J	4	0.25			A2			17.2	9	8.2
C12	J	2	0.25			A2			16.3	10	6.3
C26	J	2	0.25	A1					15.5	10	5.5
T18	SR	5	0.25		G				15.8	8	7.8
T15	J	5	0.25			A2			14.6	7	7.6
C29	J	3	0.25		G				14.8	7	7.8
C 37	J	4	0.25			A2			13.9	7	6.9
C22		3	0.25			A2			13.5	8	5.5
C31		3	0.25		G				12.5	8	4.5
T11	J	6	0.25	A1					10.7	7	3.7
Total				2	8	20	4	0	724.4	431.0	293.4
Mean									20.12	11.97	8.15

Table F3 (cont.)

LEVEL	YR	LAWSON SCORE	PROP REASON C / 4	A1	G	A2	T	C	CHEMCOM EXAM FINAL	PART 1	PART 2
0 out of 4											
C20	J	1	0	A1					26.3	13	13.3
C27	J	3	0			A2			23.8	15	8.8
C19	J	0	0			A2			23.7	16	7.7
C17	J	4	0			A2			23.7	12	11.7
C16	SR	4	0		G				23.0	15	8.0
C28	J	3	0			A2			23.0	15	8.0
C9	SR	0	O			A2			20.9	12	8.9
C35	J	4	0	A1					12.5	6	6.5
C10	SR	0	0			A2			8.0	3	5.0
Total				2	1	6	0	0	185.0	107.0	78.0
Mean		2.1							20.6	11.9	8.7

<u>Data by Math Class</u>

Table F4

<u>Data for Algebra 1 Students</u>

LEVEL	YR	LAWSON SCORE	PROP REASON No./4	A1	G	A2	T	C	CHEMCOM EXAM FINAL	PART 1	PART 2
C20	J	1	0	A1					26.3	13	13.3
C14	S	3	0.5	A1					25.4	17	8.4
C26	J	2	0.25	A1					15.5	10	5.5
T4	J	7	0.5	A1					15.4	8	7.4
C35	J	4	0	A1					12.5	6	6.5
T11	J	6	0.25	A1					10.7	7	3.7
Total				6					105.8	61	44.8
%		3.83	0.25						17.64	10.17	7.47
std dv									6.60	4.17	3.26

Table F5

Data for Geometry Students

LEVEL	YR	LAWSON SCORE	PROP REASON No./4	A1	MATHCLASS G	A2	T	C	CHEMCOM EXAM FINAL	PART 1	PART 2
F15	S	11	1		G				32.3	18	14.3
F2	F	10	1		G				29.3	17	12.3
T33	J	7	0.5		G				27.8	16	11.8
F9	J	9	0.75		G				26.1	15	11.1
F14	J	11	0.75		G				26.0	14	12.0
T8	S	6	0.5		G				25.9	17	8.9
T28	J	6	0.5		G				25.3	14	11.3
T12	J	6	0.75		G				24.6	15	9.6
T23	J	7	0.5		G				24.4	15	9.4
C8	S	1	0.25		G				23.4	15	8.4
T22	S	7	0.5		G				23.4	14	9.4
C16	SR	4	0		G				23.0	15	8.0
T9	S	6	0.5		G				22.0	15	7.0
T40	J	5	0.25		G				21.4	13	8.4
C11	J	2	0.5		G				21.2	14	7.2
T16	J	5	0.25		G				21.1	11	10.1
T44	J	6	0.25		G				20.2	11	9.2
T36	J	8	0.75		G				19.8	12	7.8
C32	J	3	0.25		G				19.4	10	9.4
C30	J	3	0.5		G				19.3	10	9.3
T3	J	7	0.5		G				19.0	11	8.0
C7	J	2	0.5		G				17.3	10	7.3
T17	S	5	0.75		G				15.9	8	7.9
T18	SR	5	0.25		G				15.8	8	7.8
T43	S	6	0.5		G				15.5	6	9.5
C29	J	3	0.25		G				14.8	7	7.8
C31	J	3	0.25		G				12.5	8	4.5
Total					**27**				**586.5**	**339.0**	**247.5**
%									**21.72**	**12.56**	**9.17**
std dv									**4.73**	**3.33**	**2.02**

Table F6

Data for Algebra 2 Students

			PROP	MATHCLASS					CHEMCOM EXAM		
LEVEL	YR	LAWSON	REASON	A1	G	A2	T	C	FINAL	PART	PART
		SCORE	No./4							1	2
F3	S	9	1			A2			29.8	17	12.8
F4	J	9	0.5			A2			29.1	17	12.1
C13	J	3	0.75			A2			27.9	16	11.9
T37	SR	8	0.75			A2			27.8	15	12.8
F8	J	9	1			A2			27.2	15	12.2
F18	J	9	1			A2			27.2	16	11.2
T46	J	7	0.75			A2			26.6	16	10.6
T2	J	8	0.75			A2			26.6	15	11.6
T6	J	7	0.25			A2			25.9	14	11.9
C15	J	4	0.5			A2			25.6	13	12.6
F1	J	11	1			A2			25.3	14	11.3
F6	J	11	1			A2			25.3	15	10.3
F20	J	12	1			A2			24.6	15	9.6
T13	J	5	0.5			A2			24.4	15	9.4
C33	J	4	0.25			A2			24.4	16	8.4
T10	J	6	0.25			A2			24.1	15	9.1
C5	J	3	0.25			A2			24.1	17	7.1
F16	J	9	0.5			A2			24.0	12	12.0
C27	J	3	0			A2			23.8	15	8.8
C19	J	0	0			A2			23.7	16	7.7
C17	J	4	0			A2			23.7	12	11.7
T45	J	6	0.25			A2			23.5	15	8.5
C36	J	4	0.5			A2			23.2	14	9.2
F19	J	10	0.5			A2			23.1	14	9.1
T7	J	7	0.25			A2			23.0	13	10.0
C2	J	4	0.25			A2			23.0	15	8.0
C28	J	3	0			A2			23.0	15	8.0
C1	J	4	0.5			A2			22.9	16	6.9
T20	J	6	0.25			A2			22.8	12	10.8
T27	S	5	1			A2			21.0	11	10.0
T14	J	5	0.5			A2			21.0	14	7.0
C9	SR	0	O			A2			20.9	12	8.9
F10	J	9	1			A2			20.8	14	6.8
T38	J	5	0.25			A2			20.7	14	6.7
C6	J	2	0.25			A2			20.6	12	8.6
T39	J	5	0.25			A2			20.5	14	6.5
C25	J	2	0.25			A2			19.8	11	8.8
C38	J	4	0.5			A2			19.7	9	10.7
C39	J	4	0.25			A2			19.3	11	8.3

Table F6 (cont.)

LEVEL	YR	LAWSON SCORE	PROP REASON No./4	MATHCLASS A1	G	A2	T	C	CHEMCOM EXAM FINAL	PART 1	PART 2
T19	J	6	0.25			A2			19.0	12	7.0
T41	J	5	0.5			A2			19.0	10	9.0
C3	J	3	0.25			A2			18.9	16	2.9
F5	J	10	1			A2			17.9	8	9.9
C24	J	4	0.25			A2			17.2	9	8.2
T26	J	5	0.5			A2			17.0	9	8.0
T21	J	7	0.5			A2			16.4	9	7.4
C12	J	2	0.25			A2			16.3	10	6.3
T34	J	7	0.5			A2			16.0	6	10.0
T15	J	5	0.25			A2			14.6	7	7.6
C 37	J	4	0.25			A2			13.9	7	6.9
C22	J	3	0.25			A2			13.5	8	5.5
T42	J	6	0.5			A2			12.4	6	6.4
C18	J	4	0.5			A2			10.2	5	5.2
C10	SR	0	0			A2			8.0	3	5.0
Total						54			211.3	113.0	98.3
%									15.09	8.07	7.02
std dv									3.23	3.02	2.00

Table F7

Data for Math Analysis Students

LEVEL	YR	LAWSON SCORE	PROP REASON No./4	A1	MATHCLASS G	A2	T	C	CHEMCOM EXAM FINAL	PART 1	PART 2
F12	S	9	1				T		28.8	17	11.8
T25	J	8	0.75				T		28.2	16	12.2
C23	J	4	0.25				T		27.6	17	10.6
F7	J	9	1				T		26.8	15	11.8
T31	J	6	0.25				T		25.0	12	13.0
T24	S	8	1				T		24.4	15	9.4
C21	J	2	0.25				T		23.5	15	8.5
T30	J	6	0.25				T		23.4	13	10.4
T5	J	7	0.75				T		21.1	14	7.1
Total							9		228.7	134.0	94.7
%		6.56	0.61						25.41	14.89	10.52
std dv									2.58	1.69	1.91

Table F8

Data for Calculus Students

LEVEL	YR	LAWSON SCORE	PROP REASON No./4	MATHCLASS A1	G	A2	T	C	CHEMCOM EXAM FINAL	PART 1	PART 2
T1	SR	8	0.75					C	32.7	20	12.7
C4	SR	3	0.5					C	20.0	12	8.0
Total								**2**	**52.7**	**32.0**	**20.7**
%		**5.50**	**0.63**						**26.33**	**16.00**	**10.33**
std dv									**8.97**	**5.66**	**3.31**

Data by School Year

Table F9

Data for Freshman and Sophomores Students

LEVEL	YR	LAWSON SCORE	PROP REASON No./4	MATH CLASS A1	G	A2	T	C	CHEMCOM EXAM FINAL	PART 1	PART 2
Freshman											
F2	F	10	1		G				29.3	17	12.3
Sophomore											
C14	S	3	0.5	A1					25.4	17	8.4
C8	S	1	0.25		G				23.4	15	8.4
F12	S	9	1				T		28.8	17	11.8
F15	S	11	1		G				32.3	18	14.3
F3	S	9	1			A2			29.8	17	12.8
T17	S	5	0.75		G				15.9	8	7.9
T22	S	7	0.5		G				23.4	14	9.4
T24	S	8	1				T		24.4	15	9.4
T27	S	5	1			A2			21.0	11	10.0
T43	S	6	0.5		G				15.5	6	9.5
T8	S	6	0.5		G				25.9	17	8.9
T9	S	6	0.5		G				22.0	15	7.0
Total	**11**			**1**	**7**	**2**	**2**				
%		**6.33**	**0.71**						**23.98**	**14.17**	**9.81**

Table F10

Data for Junior Students

LEVEL	YR	LAWSON	PROP MATH REASON	CLASS A1	G	A2	T	C	CHEMCOM EXAM FINAL	PART	PART
Junior		SCORE	No./4							1	2
C 37	J	4	0.25			A2			13.9	7	6.9
C1	J	4	0.5			A2			22.9	16	6.9
C11	J	2	0.5		G				21.2	14	7.2
C12	J	2	0.25			A2			16.3	10	6.3
C13	J	3	0.75			A2			27.9	16	11.9
C15	J	4	0.5			A2			25.6	13	12.6
C17	J	4	0			A2			23.7	12	11.7
C18	J	4	0.5			A2			10.2	5	5.2
C19	J	0	0			A2			23.7	16	7.7
C2	J	4	0.25			A2			23.0	15	8.0
C20	J	1	0	A1					26.3	13	13.3
C21	J	2	0.25				T		23.5	15	8.5
C22	J	3	0.25			A2			13.5	8	5.5
C23	J	4	0.25				T		27.6	17	10.6
C24	J	4	0.25			A2			17.2	9	8.2
C25	J	2	0.25			A2			19.8	11	8.8
C26	J	2	0.25	A1					15.5	10	5.5
C27	J	3	0			A2			23.8	15	8.8
C28	J	3	0			A2			23.0	15	8.0
C29	J	3	0.25		G				14.8	7	7.8
C3	J	3	0.25			A2			18.9	16	2.9
C30	J	3	0.5		G				19.3	10	9.3
C31	J	3	0.25		G				12.5	8	4.5
C32	J	3	0.25		G				19.4	10	9.4
C33	J	4	0.25			A2			24.4	16	8.4
C35	J	4	0	A1					12.5	6	6.5
C36	J	4	0.5			A2			23.2	14	9.2
C38	J	4	0.5			A2			19.7	9	10.7
C39	J	4	0.25			A2			19.3	11	8.3
C5	J	3	0.25			A2			24.1	17	7.1
C6	J	2	0.25			A2			20.6	12	8.6
C7	J	2	0.5		G				17.3	10	7.3
F1	J	11	1			A2			25.3	14	11.3
F10	J	9	1			A2			20.8	14	6.8
F11	J	9	0.5						31.4	17	14.4
F14	J	11	0.75		G				26.0	14	12.0
F16	J	9	0.5			A2			24.0	12	12.0
F17	J	9	1						16.2	10	6.2
F18	J	9	1			A2			27.2	16	11.2

Table F10 (cont.)

LEVEL	YR	LAWSON SCORE	PROP REASON No./4	MATH CLASS A1	G	A2	T	C	CHEMCOM EXAM FINAL	PART 1	PART 2
F19	J	10	0.5			A2			23.1	14	9.1
F20	J	12	1			A2			24.6	15	9.6
F4	J	9	0.5			A2			29.1	17	12.1
F5	J	10	1			A2			17.9	8	9.9
F6	J	11	1			A2			25.3	15	10.3
F7	J	9	1				T		26.8	15	11.8
F8	J	9	1			A2			27.2	15	12.2
F9	J	9	0.75		G				26.1	15	11.1
T10	J	6	0.25			A2			24.1	15	9.1
T11	J	6	0.25	A1					10.7	7	3.7
T12	J	6	0.75		G				24.6	15	9.6
T13	J	5	0.5			A2			24.4	15	9.4
T14	J	5	0.5			A2			21.0	14	7.0
T15	J	5	0.25			A2			14.6	7	7.6
T16	J	5	0.25		G				21.1	11	10.1
T19	J	6	0.25			A2			19.0	12	7.0
T2	J	8	0.75			A2			26.6	15	11.6
T20	J	6	0.25			A2			22.8	12	10.8
T21	J	7	0.5			A2			16.4	9	7.4
T23	J	7	0.5		G				24.4	15	9.4
T25	J	8	0.75				T		28.2	16	12.2
T26	J	5	0.5			A2			17.0	9	8.0
T28	J	6	0.5		G				25.3	14	11.3
T3	J	7	0.5		G				19.0	11	8.0
T30	J	6	0.25				T		23.4	13	10.4
T31	J	6	0.25				T		25.0	12	13.0
T33	J	7	0.5		G				27.8	16	11.8
T34	J	7	0.5			A2			16.0	6	10.0
T35	J	8	0.25						20.8	11	9.8
T36	J	8	0.75		G				19.8	12	7.8
T38	J	5	0.25			A2			20.7	14	6.7
T39	J	5	0.25			A2			20.5	14	6.5
T4	J	7	0.5	A1					15.4	8	7.4
T40	J	5	0.25		G				21.4	13	8.4
T41	J	5	0.5			A2			19.0	10	9.0
T42	J	5	0.5			A2			12.4	6	6.4
T44	J	6	0.25		G				20.2	11	9.2
T45	J	6	0.25			A2			23.5	15	8.5
T46	J	7	0.75			A2			26.6	16	10.6
T5	J	7	0.75				T		21.1	14	7.1

Table F10 (cont.)

LEVEL	YR	LAWSON SCORE	PROP REASON No./4	MATH CLASS A1	G	A2	T	C	CHEMCOM EXAM FINAL	PART 1	PART 2
T6	J	7	0.25			A2			25.9	14	11.9
T7	J	7	0.25			A2			23.0	13	10.0
Total	81			5	17	49	7	0			
%		6.67	0.49						21.66	12.38	9.27

Table F11

Data for Senior Students

LEVEL	YR	LAWSON SCORE	PROP REASON No./4	MATH CLASS A1	G	A2	T	C	CHEMCOM EXAM FINAL	PART 1	PART 2
Senior											
C10	SR	0	0			A2			8.0	3	5.0
C16	SR	4	0		G				23.0	15	8.0
C34	SR	4	0.25						24.6	15	9.6
C4	SR	3	0.5					C	20.0	12	8.0
C9	SR	0	O			A2			20.9	12	8.9
F13	SR	10	0.75						23.1	13	10.1
T1	SR	8	0.75					C	32.7	20	12.7
T18	SR	5	0.25		G				15.8	8	7.8
T29	SR	6	1						16.9	10	6.9
T32	SR	6	0.5						17.9	12	5.9
T37	SR	8	0.75			A2			27.8	15	12.8
Total	12			0	2	3	0	2			
%		4.91	0.48						20.98	12.27	8.71