High School Math Level and its Influence on Science Achievement

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Abstract

The ability to use mathematics in chemistry is crucial for success. Students who struggle with mathematics may learn the conceptual foundation of chemistry, but may not have the mathematical foundation necessary for success in more computational topics. Students' test scores in chemistry and physics were compared to their enrollment in math classes. It was found that students in lower level math courses scored disproportionately lower on chemistry and physics tests than students in the higher level math courses. It can be concluded that there is a direct relationship between math level and chemistry and physics achievement. As the math level, ability, and exposure increases, the success on examinations in chemistry and physics also increases. Recommendations are included.

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Introduction

Background:

The researcher teaches chemistry at Prairie Ridge High School, in Crystal Lake, Illinois, which is approximately 45 miles northwest of Chicago, Illinois. The school serves about 1400 students, with approximately 130 faculty and staff members. The researcher is responsible for two Chemistry classes and two Honors Chemistry classes. Each class period is 45 minutes long, with two additional periods for each class occurring twice a week (where students meet for two periods in a row), for a total of 7 periods, or 315 minutes, of contact time per week. All science courses analyzed meet for the same amount of time per week.

Problem:

Over the course of the researcher's three years teaching chemistry, a common trend concerning student achievement has emerged. For many of current and former students, there seems to be a discrepancy in student achievement on tests and quizzes in chemistry classes. On a recent survey of student attitudes and concerns for the first semester of the 2003-2004 school year (Seiler 2004), a few students remarked that they had put a lot of effort into the course, but were not satisfied with the scores obtained on tests and quizzes. These students had one of the following comments about their own effort and achievement in the course: (1) they never understood the information when we covered the material and were too frustrated at not understanding the material that they stopped working altogether; (2) they understood the information in class or during notes, but couldn't do the homework because they didn't know where to begin; (3) they had a vague understanding of the concepts learned in class, yet could work together cooperatively with peers with sufficient understanding of the material, but could not apply that understanding to the testing situations; or (4) they understood the information in class and on the homework, even when working alone, but when the test came, they felt that the questions were totally different from what they expected (Seiler 2004).

The following are a few possible explanations as to why the students might perform poorly on chemistry tests: the students may have a superficial, rote, or partial understanding of the material; the students may not have the mathematical foundation necessary for success on a chemistry test; the students may have low attention spans or are not really concentrating during lectures or discussions; the students have difficulties learning chemistry in the style being taught; the students may have difficulties in applying their knowledge to new situations; the students may not be using good study or preparation techniques to prepare themselves for a cumulative examination; or, the students may have moderate to severe test anxiety.

Students may have a superficial, rote, or partial understanding of the material. This may be a result of a few possible sources. First, the students may be making incorrect or incomplete connections to previously learned material or to unrelated topics. This is evident with the students' concept of the process of boiling. A pretest was given in September and again as a posttest in January in order to determine the conceptual improvement of the students (see Appendix A). Question two on the exam dealt with the physical process of boiling:

2. *Assume that a beaker of pure water has been boiling for 30 minutes. Large bubbles are present in the boiling water. What are these bubbles made of?*
   (a) Air.
   (b) Oxygen gas and hydrogen gas.
   (c) Oxygen.
   (d) Water vapor.
   (e) Heat.

Many students believe that the process of boiling is when water molecules break apart in a decomposition reaction to form hydrogen and oxygen gas. In the beginning of the semester, 18 of 45 students (40%) believed that hydrogen and oxygen gases were present in the bubbles of boiling water. At the end of the semester, 23 of 45 students (51%) thought the same. While this number represents only a small number of test subjects for Honors Chemistry students, it is interesting that five more students had an incorrect concept of boiling AFTER completing the first semester. The only related concepts taught in class were intermolecular forces of attraction and (as an incorrect explanation of boiling) decomposition reactions (see appendix B for test results).

Higher intermolecular forces of attraction are responsible for higher boiling points. Molecules which are more attracted to other like molecules will tend to stay liquids at higher temperatures. Students should have been able to see that the process of boiling is merely the molecules gaining enough energy to overcome the intermolecular forces of attraction and move from the liquid phase to the gas phase. Incorrectly, over half of the students attributed the physical process, boiling, to a chemical process, a decomposition reaction. This may be a connection that students have made based on the emphasis placed on reaction chemistry covered during first semester. For the last two months of first semester, the students learned about stoichiometry, types of reactions, predicting products, and balancing reactions. Students may have wrongly attributed any change in phase to a chemical reaction, instead of to a physical process, and thus assumed that the heat was sufficient to decompose water into hydrogen and oxygen gas. Again, the conceptual associations that the students have made from new material to familiar material are incorrectly linked. As a result, the students have an incomplete or faulty view of the foundations of chemistry.

The students may not have the mathematical foundation necessary for success on a chemistry test. Topics and questions on exams given in the chemistry classroom are typically mathematic-based questions. Chemistry deals with ratios, algebra, fractions, three-dimensional visualizations, equations, and simple arithmetic. Some of the more challenging mathematic-based concepts are balancing equations, stoichiometry, gases, thermodynamics, kinetics, equilibrium, and acid/base chemistry. If students are deficient in understanding of any of these areas, it will be difficult to succeed in the course as a whole. Of the students taking chemistry (at any level) at Prairie Ridge High School, the vast majority are currently enrolled in Advanced Algebra during first semester and Trigonometry during second semester. A small fraction of students are enrolled in Geometry, and an even smaller percentage of students are not enrolled in math at all, or are enrolled in a lower level math class such as Algebra, Transitions to College Math, or Math III. Students enrolled in Algebra have either failed the course and are repeating for credit, or are two-years behind their peers in math. Students enrolled in Transitions to College Math are typically students who do not wish to proceed to higher level math, but still need some basic skills in order to be successful at the college level. Students enrolled in Math III are in a learning resource classroom taught by a special education instructor. If a student has not been exposed to higher level mathematics courses, perhaps the students will not have the mathematic foundation necessary for success. The ability to use mathematics in chemistry is imperative, and is used as a tool for success in chemistry. Students who struggle with mathematics may do well learning the conceptual foundation of chemistry, but will struggle with topics such as gases, stoichiometry, balancing reactions, kinetics, equilibrium, and acid/base chemistry.

For example, Honors Chemistry classes learn about the integrated rate laws during the study of kinetics. Solving these problems involve using natural log and the anti-natural log. Students without adequate schooling in the use and manipulation of logarithms are often frustrated when trying to understand why they are doing what they are doing. And, because of the nature of the mathematical operations, many of the students with a lower level math background will simply memorize techniques to solve problems rather than understanding the problem itself. In addition, acid/base chemistry involves using logarithms to determine the concentration of hydrogen ions in solution. This is commonly known as calculating the pH of a solution. Students learn about logarithms in Advanced Algebra, and for students in Geometry or other lower levels of math, this topic would be their first exposure to logarithms. Although it is a simple mathematical procedure, it is difficult for students who have never seen this concept to feel comfortable, and this may impact their success on chemistry examinations.

The students may have low attention spans or are not really concentrating during lectures or discussions. There have been numerous occasions when discussing topics in class in a lecture/discussion format, and all twenty-eight sets of eyes appear to be completely glazed over. Teachers can employ a wide variety of methods to combat this phenomenon, such as attempt to tell jokes, vary the volume of the voice, and use demonstrations to help capture the students' attention. However, there are some days where the students are just not paying attention. It seems as if some students just zone out or are thinking about many things other than chemistry. Other explanations for a student's lack of enthusiasm might be low levels of sleep, lack of food in their stomachs due to skipping breakfast, or other personal issues that cause the student to lose focus. Many students have jobs after school, and sometimes do not get home from work until after 10:00 pm. If these students still have homework to do, they will be up all night trying to get things done or they will simply not do the homework. The lack of sleep certainly would diminish a student's ability to focus, especially since the students must concentrate on not falling asleep rather than on the material being covered. Also, many students have admitted that they do not eat breakfast. Without proper nutrition and energy derived from eating breakfast, these students can't possibly have enough energy to feel awake and energized at 7:30 am. Additionally, there are many other factors involving a student's personal life that might impact the student's ability to focus in school. Certainly, if a student is attempting to resolve conflicts with parents, friends, or enemies, it seems reasonable that the student's mind might not be focused entirely on learning chemistry. Although many students are able to disconnect personal life from academic life, some students are not able to make that transition, and may be affected in the classroom.

The students have difficulties in learning chemistry in the style being taught. A typical seven period week of class for the researcher would involve two periods of notes, three periods of laboratory investigations, and two periods of working on problems, reading background information, viewing demonstrations, or other tasks. Different topics in chemistry call for different approaches to teaching. The daily agenda and assignments for the researcher's Chemistry students are written on the board at the beginning of each period. The agenda and assignments for the researcher's Honors Chemistry students are distributed as a handout on the first day of every week. This assignment sheet covers the topics of study and the corresponding assignments for the entire week.

A typical lecture might begin by reviewing what the students have learned about a particular topic, or, if it is the introduction, by identifying what the students already know or some of the background knowledge about a topic. Then, the big picture of the lesson would presented. This would allow students to focus on the reason for studying the topic. Depending on the lesson, perhaps new vocabulary is then defined and used in conjunction with theory regarding a topic. Or, the students might be shown a sample problem, and the methods for solving the problem would be discussed. Then, the students might try a sample problem working with a partner or alone, which would allow the teacher to help individuals with specific needs. Finally, a summary of what was covered would be given.

This may not be the optimal method for teaching all students. "Students whose [learning] styles are matched with those of their teachers report greater ease of learning" (Packer et al. 1978). This implies that students whose learning styles do not match those of their teachers might have more difficulties learning the topics. Gardner's theory of Multiple Intelligences (Gardner 1984) states that there are seven intelligences in which students might learn: bodily-kinesthetic, linguistic, spatial, musical, intrapersonal, interpersonal, and logical-mathematic. Each student may learn better in one way than in another. For instance, many students say that they cannot really learn the information until they are able to experiment in the laboratory. These types of students may be more prone to learning in a bodily-kinesthetic fashion, where they must physically touch and see the results. Other students may benefit more from solving mathematical problems. This type of student might learn best with the logical-mathematic methods, such as steps for solving problems.

Each style of intelligence brings its own unique mode of teaching and learning. Gardner acknowledges that most people use more than one of these intelligences, and therefore, to teach to any particular one type of intelligence would be to ignore the rest. There are also other learning style theories regarding four cognitive styles: concrete sequential (CS), abstract-sequential (AS), abstract-random (AR), and concrete-random (CR). If the teaching style does not match the learning style, students can become frustrated or won't be able to deeply internalize the information (Gregorc 1982). If there is a teaching/learning style mismatch, students must essentially suppress their instinctual learning style preferences and learn to modify their learning in order to succeed. Students must either cope with a style mismatch or they may not succeed (Butler 1984).

The students may have difficulties in applying their knowledge to new situations. Many students may have an algorithmic understanding of chemistry. These students understand the material enough that they can apply procedures or memorized steps to problems which are similar in structure. These students memorize a process or a means to solving a problem, an algorithm, rather than the conceptual foundation of how to solve the problem. Conceptual understanding requires a student to grasp the core idea or fundamental principle (the concept), whereas algorithmic understanding requires only that a student understand or memorize a process for deriving a solution. For example, the act of balancing a chemical reaction can reveal algorithmic or conceptual understanding. Instead of understanding the conceptual principle of conservation of mass in a chemical reaction, many students memorize techniques, or algorithms, for balancing these reactions. Students were asked the following question on the pre- and posttest.

1. *Which of the following must be the same before and after a chemical reaction?*
   (A) the sum of the masses of all substances involved.
   (B) the number of molecules of all substances involved.
   (C) the number of atoms of each type involved.
   (D) both (A) and (C)
   (E) each of the answers (A), (B), and (C) must be the same.

Before the semester of chemistry began, 9 of the 45 students (20%) incorrectly said that (C) was the correct answer. After the semester of chemistry, 13 of the 45 students (29%) incorrectly answered (C). The number of correct responses, (D), did not change from 10 out of 45 students (22%) between the pre- and the posttest (see appendix B for test results). After completing the semester in chemistry, many students had memorized a method for balancing chemical reactions. This consisted of counting the number of atoms on each side of the chemical equation. Instead of realizing that the masses and the numbers of atoms must be the same on both sides of the chemical reaction, many students incorrectly identified the procedure they follow for balancing reactions instead of the theory behind balancing reactions. These students may have simply learned to memorize techniques and procedures for solving problems of specific types, but cannot then apply their understanding when given a conceptual or application problem.

The students may not be using good study or preparation techniques to prepare themselves for a cumulative examination. One frequent comment on first semester reflections of the course (see Appendix C for survey questions) was that the majority of students spent little to no time studying for chemistry exams. Even some of the high achieving students remarked that they did not study for exams. One student "never really learned good study habits." One student would "start [studying] and usually give up." Another student said "I'll try and study, but I'll forget [the] material or it just won't click and I end up cramming the hour before." One other student said "I take the time to study, but that does not show on tests." Finally, one student remarked, "I don't really know how to [study]." Students don't really understand what it means to study and wouldn't know how to study if they wanted to (Seiler 2004). Cramming the hour before or skimming over notes might not be the best way to prepare one's self for a test.

The students may have moderate to severe test anxiety. On numerous occasions throughout the semester, students remarked that they thought they understood the material going before the test, but "completely blanked" upon opening the exam. One student commented that she had completely forgotten how to solve all of the problems until twenty minutes into the test, when she miraculously had a "stroke of genius" and remembered what she needed to do. Unfortunately, she did not have time to complete the entire test. Despite allowing students to use reference sheets during tests, many students still leave exams feeling like they could not remember anything during the test. These students may suffer from test anxiety, where the high levels of stress affect their ability to concentrate and remember key concepts.

Purpose:

In short, there are numerous factors that might influence a student's performance on my examinations. The students may have a superficial, rote, or partial understanding of the material. It seemed apparent based on a pre- and posttest that the students were not able to connect concepts learned in class regarding intermolecular forces to the concept of boiling. The students may not have the mathematical foundation necessary for success on a chemistry test. These students may not have the ability to solve complex, algebraic problems. Are these students capable of succeeding on tests based on their low math abilities? The students may have low attention spans or are not really concentrating during lectures or discussions. Each student has a life outside of chemistry which may influence how the students behave or operate in class. Perhaps they are not concentrating due to boredom, lack of sleep, tired from working long hours after school, lack of proper nutrition, or other personal reasons. The students have difficulties learning chemistry in the style being taught. It has been shown that students must either cope with a learning/teaching style mismatch or they will not succeed. If there is a mismatch, perhaps the students are not able to modify their needs to fit my teaching style. The students may have difficulties in applying their knowledge to new situations. Many students learn to go through the motions, and are not able to think "outside the box." The students may not be using good study or preparation techniques to prepare themselves for a cumulative examination. Many students have commented that they don't really know what studying is nor how to do it. The students may have moderate to severe test anxiety. When students experience stressors like test environments, their abilities to access knowledge may be diminished. Some students are not able to cope with the high-anxiety levels experienced during examinations.

What can, if anything, can be done to help students succeed in chemistry examinations? It is the opinion of the researcher that all students should have the opportunity to succeed. Students have the ability to alter study habits, test preparations, and other factors. The teacher can alter teaching methods in order to match students' learning styles and can adapt the instruction to develop students' conceptions of chemistry phenomenon. Teachers can even help reduce test anxiety through varying instruction methods and test preparation. However, neither the student nor the teacher can alter the math level of the student entering the chemistry classroom. While techniques could be developed to improve math skills, students cannot change their math background while enrolled in chemistry. If students are performing poorly on tests only because their math level is not sufficient, there is clearly a problem with the placement of these students.

Are students who are in lower math levels able to succeed on chemistry examinations? Is a student's level in math a sufficient predictor for success on chemistry tests? Bodner (1983) suggested that chemistry achievement is directly related to students' math and perception skills. There is a "fair amount of colinearity among math scores [on the SAT-M] and the tests of visualizations [a combination of four perceptual tests]. ...These findings suggest that visualization skills play a role in chemistry achievement..." (p. 5). The other factors seem to deal with student attitudes, preparation (studying, homework, etc), and teaching and learning styles. However, is it possible that the student's math ability is an overarching factor which determines a student's success on chemistry examinations? More importantly, are students with math deficiencies scoring disproportionately lower on tests than their peers? Are students with lower level math at a disadvantage in the chemistry classroom?

Research Question:

The research questions, then, must be: are the students with lower level math scoring disproportionately lower on tests than those students with higher level math, and what can be done to help these students be successful? If, indeed, it is found that these students are disproportionately scoring lower on chemistry tests because of their level of math, it seems only necessary to implement one of the following four strategies: (1) bring to attention of administration in an effort to schedule these students in an appropriate class for their math abilities; (2) change the teaching strategies to fit students' needs by emphasizing conceptual learning over algorithmic or problem-based learning; (3) change the method of testing to better assess understanding; (4) help the students themselves to work on test-taking strategies, extra help in deficient math areas, extra time on tests, test anxiety control, and other internal student issues.

Population:

Of the 1400 students at Prairie Ridge High School, 97.6 percent are White, 0.6 percent are Black, 1.3 percent are Hispanic, 0.5 percent are Asian/Pacific Islander, and 0.1 percent are Native American (Illinois State Board of Education, 2004). In terms of enrollment, 134 students are taking Honors Chemistry, 166 are taking Chemistry, 91 are taking Honors Physics, and 95 are taking Physics. See Table A for a complete breakdown of science and math classes. The students are randomly distributed among classes of each type. There are three different Chemistry teachers, three different Honors Chemistry teachers, two different Physics teachers, and two different Honors Physics teachers.

Table A	Math Class								
Science Class	No Math	Algebra	Math III	Geometry	Transitions To College Math	Advanced Algebra and Trigono-metry	College Algebra and Pre-Calculus	AP Calculus	AP Statistics
Honors Chemistry	0	0	0	16	0	114	4	0	1
Chemistry	3	1	2	18	2	129	11	0	0
Honors Physics	0	0	0	0	0	12	74	4	2
Physics	0	0	0	0	0	16	54	10	7

As freshmen, most students are enrolled in Earth Science and Algebra. Most sophomores take Biology and Geometry. Most juniors take Chemistry and Advanced Algebra and Trigonometry. Most seniors take Physics (many take Environmental Science or Physical Science) and College Algebra and Pre-Calculus. For the Honors track, freshman begin with Honors Biology and Geometry. Sophomores then take Honors Chemistry and Advanced Algebra and Trigonometry. Juniors would take Honors Physics and college algebra and Pre-Calculus. Seniors would take either AP biology, AP Chemistry, or Geoscience and either AP Calculus or AP Statistics.

There are small populations of students who are in mixed tracks or not on their grade level for math. For instance, a student might be placed in the standard math track (starting with Algebra, then Geometry, etc.), but might be placed in the Honors science track (starting with Honors Biology). This means that by the time the student enters the chemistry classroom, the student is taking Geometry as part of the standard math curriculum. Or, a student might take Pre-Algebra as a freshman, followed by Algebra, and then Geometry. As a junior, the student would take Chemistry and Geometry. This type of student is a full year behind the math of their peers, whereas in the previous example, the student was simply a year ahead of their peers in science and in the appropriate math class for the grade level.

Review of Literature

Are students with lower level math scoring disproportionately lower scores in chemistry examinations than students with higher level math? In order to answer this research question, it is necessary to analyze the factors that affect chemistry achievement. In a meta-analysis of factors influencing achievement in science, DeBaz (1994) found a correlation between science achievement and environmental, ability, attitude, and availability of educational items at home. In an analysis of nine different studies, males scored higher on tests than females. The study also analyzed parent's education, availability of educational facilities at home, plans and aspirations, and number of hours spent on homework per week. The results of the study indicate that the students are influenced by the education level of the parents. There is a positive relationship between available facilities at home and student achievement. In addition, a student's plans and aspirations positively influence their science achievement. Students with high achievement are typically those who will continue on to post secondary education. Hours of homework also seemed to "enhance students' achievement in science by offering students the opportunity to apply what they have learned in the classroom, and helping them develop good study habits" (p. 203). A student's scholastic abilities in math, language, and cognitive reasoning have strong positive correlations to the student's achievement in science and student attitudes towards science. It is also apparent that students with more positive attitude towards science and science learning achieved better in science. DeBaz asserts that "ability and past learning are among the best predictors of achievement" (p. 225).

If the students are not effectively using their time inside and outside of class, are they at a disadvantage when test time comes? According to Lin (1970), the students, regardless of math ability, represent a wide range of the following habits and skills: utilizing class time, taking and organizing class notes, preparing for the examinations and integrating the subject matter. With any population of students, the range of good to poor students will be present, regardless of math ability. A good student is defined as a student with good study habits, utilizes class time well, takes and organizes class notes, prepares for examinations, and attempts to integrate the subject matter. A poor student would have just the opposite: poor class time utilization, does not take notes or takes unorganized class notes, does not prepare effectively for examinations, and makes little to no effort to integrate the subject matter. It was shown that "students with good study habits achieved significantly higher grades than comparable poor study habits." In addition, "student study habits contributed to academic achievement independently of college aptitude." It is further suggested that "...student achievement should be a function of teacher skill, the interaction of student motivation and teacher cues, student ability, student habits, and other social and personality variables" (p. 1).

Achievement in chemistry can be determined based on a variety of factors. Higher grades in chemistry were a result of the students' academic preparedness, mastery orientation, and high levels of effort. Lower grades in chemistry were the result of high test anxiety and use of rote rehearsal strategies (Garcia, 1993). Can one assume that those successful in the course have the intellectual capacity and the desirable work habits, skills, preparedness, and effort? Can one also assume that those who are unsuccessful in the course are deficient in one area or another? Based on this information, it would be reasonable to assume that students will be unsuccessful in the following ways: (1) the student is intellectually deficient, despite possessing good work habits, study skills, effort, and attitudes; or (2), the student is intellectually sufficient, but lacks good work habits, study skills, effort, or attitude. Even students with high aptitudes can have low rates of achievement if their intelligence is not supported with proper study habits at home [or in school], as seen in Duckett (1983): "... if you... can provide a clue or suggestion which will help him to figure the problem out for himself, he will learn to depend on his own abilities, and yet will be more likely to persevere" (p. 3-6). Certainly, good and poor students can exist within each set of math abilities. According to Pascarella (1991), grades tend to reflect not only the required intellectual skills but also the desirable work habits and attitudes (p. 388). Without both, success in a course may not be attainable.

Additionally, students of all math abilities may struggle when faced with conceptual challenges. Students many times use algorithms or memorized patterns or behaviors to solve numerical problems without actually understanding the concept behind the process. Mazur (1996) reports that students in his Physics class had memorized equations and problem-solving skills, but performed poorly on tests of conceptual understanding. Students can even produce correct answers by using an algorithmic approach founded on inadequate concepts (Lythcott, 1990). "Chemistry teachers have assumed implicitly that being able to solve problems is equivalent to understanding molecular concepts" (Nurrenburn, 1987, p. 508). And, according to Pickering (1990), the ability to solve a problem does not imply real understanding of what is happening at a molecular level. Teachers can emphasize either problem solving, conceptual chemistry, both, or neither. Scores will reflect emphasis (p. 254). The assumption is that it is the teacher's class setup which will influence how well students will perform in a course, not the inherent abilities of the students.

A study of a Taiwanese school indicated students did much better solving algorithmic problems than they did understanding conceptual questions. However, the researchers found that not many students were determined to be good problem solvers but poor conceptual thinkers. Most of students were found to be both good problem solvers and good conceptual thinkers (Chiu, 2001). Again, depending on the emphasis of the teacher, students will excel either at algorithmic problem solving, conceptual understanding, or both. Nakhleh and Mitchell (1993) studied sixty students in an introductory course for chemistry majors. In an exam which paired an algorithmic problem with a conceptual question on the same topic, only 49% of those students classified as having high algorithmic ability were able to answer the parallel conceptual question. As of yet, it has not been found whether or not poor problem solvers are good conceptual thinkers.

In a study by Silberman (1983), freshman chemistry students listed and ranked in order of importance the reasons why they thought chemistry problems were difficult to solve. Students were first asked to list reasons why they had difficulty with chemistry problems and to list suggestions for overcoming these difficulties. Students listed 83 reasons for problem solving difficulties and 64 suggestions for decreasing those difficulties. The reasons ranged from facetious (ridiculous test), reasonable (not enough time spent on explanations), to puzzling (chemistry is inherently difficult; therefore uninteresting). The twelve (ranked in order) most important reasons for student difficulties are as follows: not enough study and practice, problems with abstract concepts, lack of incentive and motivation, poor study skills, inadequate time, chemistry is inherently difficult, inadequate teaching, poor reading comprehension, impersonal instructor and course, poor math skills, inadequate text and course materials, inadequate study facilities on campus. The twelve (ranked in order) most common suggestions for improvement of chemistry courses are as follows: greater emphasis on problems in lecture, small group problem work sessions, post worked-out problems, tutorial sessions, review notes, tutorial tapes, mini-lecture on special topics, more course materials (study aids, manuals, worksheets, etc.), ungraded pretests, improve personal contact with instructors, more individual study and practice, student-run tutoring sessions (p. 1036). This study seems to suggest that the problems are not internal but rather external. Clearly there must exist methods to improve instruction and learning in the classroom.

There have also been studies, particularly at the college level, which indicate factors that might predict a student's success in chemistry. "Greater chemistry achievement is predicted for students who have more subject prior knowledge, are at higher logical reasoning levels, and have an attitude toward the subject that involves intrinsic motivation to student and a desire to grasp the deeper meaning of the material such as how ideas and topics relate to one another," regardless of sex (BouJaoude, 1991). Nordstrom (1989) analyzed engineering students to predict success in accelerated general chemistry course. "The factors that were identified as best predicting performance in chemistry... were found to be the SAT/ACT mathematics test score, high school GPA, grade in high school chemistry, high school mathematics GPA, and grade in high school English"(p. 9).

More importantly, there are certain math abilities which are tied to success in chemistry. The ability to manipulate symbols and the ability to use and maneuver algebraic symbols is necessary for success in chemistry. Comprehending basic geometry is particularly important for chemistry achievement. The ability to process numerical data shows no relationship to chemistry achievement (Fisher, 1996, p. 9). This means that students' computational skills do not influence student achievement, but students must be able to use algebra to solve problems and understand simple geometrical relationships. Additionally, Chandran (1985) compared cognitive factors and chemistry achievement, and found that greater formal reasoning ability was correlated with greater chemistry achievement (p. 11).

Spencer (1996) related scores on mathematical SAT test (SAT-M) and grades in first and second semester general chemistry at Oberlin College. "A clear linear relationship between chemistry grade and SAT-M scores was demonstrated for each course. For first semester, a SAT-M score of 500 predicts a C, 600 a C+, and 700 a B. Georgakakos (1997) experimented with predicting success in a college chemistry course using a variety of factors. Each student took a pretest known as the California Chemistry Diagnostic Test (p. 2). This test is used to gauge a student's readiness in terms of knowledge, skills, and ability for being successful in a traditional general chemistry course (Russell, 1994). Georgakakos found that a college GPA greater than 3.0, doing well on the CCDT, and earning a B or better in high school algebra, geometry, and biology were all predictors of student success in a freshman chemistry course (Georgakakos, 1997, p. 37). A study by Sanchez and Betkouski (1986) also verified that students with higher algebra grades tended to be more successful in chemistry than students with lower algebra grades. In addition, they contend that lower achieving students tended to have low math scores on the SAT (p.1).

A wide variety of factors influence a student's success in chemistry. Students with the intellectual ability have a greater chance of succeeding in chemistry than those without intellectual ability. However, a student's understanding of the content can be divided into two separate categories: conceptual understanding and algorithmic understanding. Neither seems to be entirely responsible for low test achievement. Nor does work ethic and study habits; students with the intellectual capacity can succeed despite poor preparation techniques. Success or failure in chemistry is dependent on more factors than simply knowledge of the subject. However, it has been shown that comprehending basic geometry is important for success in chemistry, and a good score in high school algebra is an indication of success in chemistry. If a student has not completed a course in geometry before taking chemistry, the student may be at a disadvantage. Therefore, the student's math level must be a significant factor in achievement on chemistry tests.

Method

In order to assess whether students with low level math score disproportionately lower on chemistry examinations than students with high level math, the researcher collected test score data for students taking Chemistry and Honors Chemistry during the fall semester of 2003. In order to widen the sample, each of the Chemistry and Honors Chemistry instructors at Prairie Ridge High School were contacted, and each agreed to provide information regarding student achievement during the fall semester of 2003. This information included each student's name and test scores, as well as total points for tests in the class. In order to determine if the phenomenon was exclusively chemistry-related, Honors Physics and Physics instructors were contacted and agreed to share the same test score information as provided by the Chemistry and Honors Chemistry instructors.

Next, each student's math level was determined using Skyward, an online database which includes class schedules for all students enrolled in classes within Community High School District 155. In Skyward, the students' last names were entered into search fields, and the students' current class schedules were given for the 2003-2004 school year. If the student had an incomplete schedule or had transferred to another school not in Community High School District 155, the student's class schedules from the 2002-2003 school year were analyzed to determine the math level. The information for Physics was used to determine if this phenomenon was unique to Chemistry courses, or, if math abilities impacted other math-based science courses as well.

Next, the data was entered into spreadsheets by teacher. An average test percentage was determined for each student by dividing the total points earned on tests by the total test points for the class. The student scores, math level, and test scores were then compiled in a spreadsheet for each course. Finally, a test of significance was performed on each class to determine if the differences in test score percentage between students enrolled in varying math levels were significant. A test of significance is used to determine if two arrays of test scores have a possibility of occurring randomly. This test of significance asks the question, does the result reflect math differences, or would the result occur just by chance alone? The null hypothesis is that math ability has no effect on test scores, and the alternative hypothesis is that math ability does influence achievement. This test of significance would determine if the students with lower levels of math are scoring lower than those students with higher levels of math, or if the test score distribution is a result of chance. "The lower this probability, the more surprising our result, and the stronger the evidence against the null hypothesis." A p-value less than 0.05 is considered statistically significant, which is a way of saying "that chance alone would rarely produce so extreme a result" (Yates et al. 560-563). Test scores for each math level in Chemistry, Honors Chemistry, Physics, and Honors Physics were compared to each other using a test of significance to determine if there was any statistical difference between math groups.

The pretest for the Concepts Inventory was given on August 26, 2003, and the posttest was given on January 9, 2004. The test scores and math levels for Chemistry and Honors Chemistry students were collected between February 15, 2004, and March 6, 2004. The test scores and math levels for Physics and Honors Physics students were collected between March 7, 2004, and March 20, 2004. The data analysis was performed between March 20, 2004 and April 18, 2004.

Data Analysis

A research method was employed in order to determine whether or not students in lower math levels scored disproportionately lower than students with higher math levels. Data was collected regarding test scores and math level between February 15, 2004 and March 20, 2004. The data was then analyzed between March 20, 2004 and April 18, 2004.

The results, in tabular and bar graph form, are displayed.

Table B and Graphs A - C show the average test scores for Honors Chemistry students. Students enrolled in Geometry, on average, scored 65% on all tests, whereas students enrolled in Advanced Algebra, on average, scored 79% on all tests. Students in higher level math scored as well or better than students in the other levels of math.

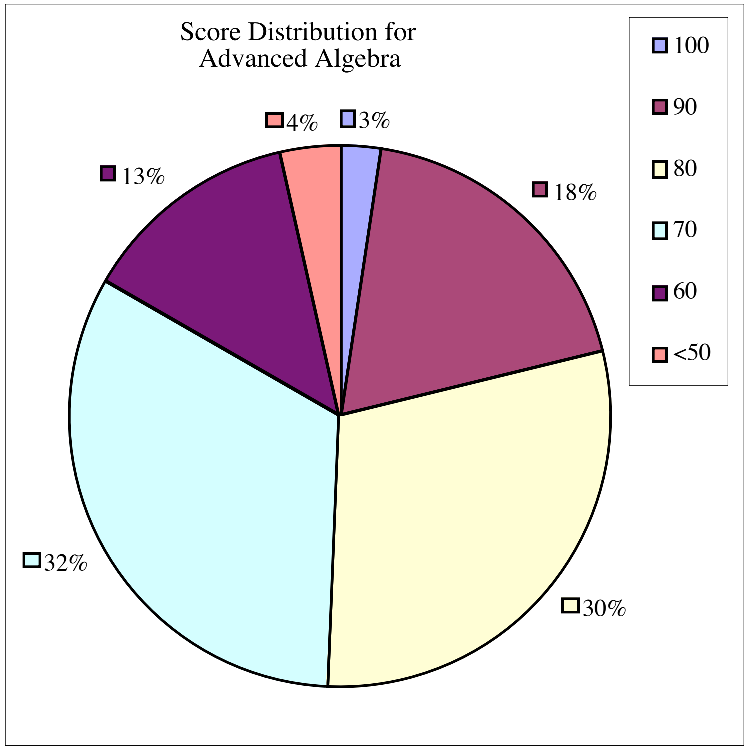
Table B: Results for Honors Chemistry Classes

Table B	Math Class								
Science Class	No Math	Algebra	Math III	Geometry	Transitions To College Math	Advanced Algebra and Trigono-metry	College Algebra and Pre-Calculus	AP Calculus	AP Statistics
Honors Chemistry	0	0	0	16	0	114	4	0	1
Average Test Scores	-	-	-	65%	-	79%	79%	-	86%

Graph A: Honors Chemistry Score Distribution for Advanced Algebra Students.

Score	Students
100	3
90	21
80	34
70	37
60	15
< 50	4
Total	114

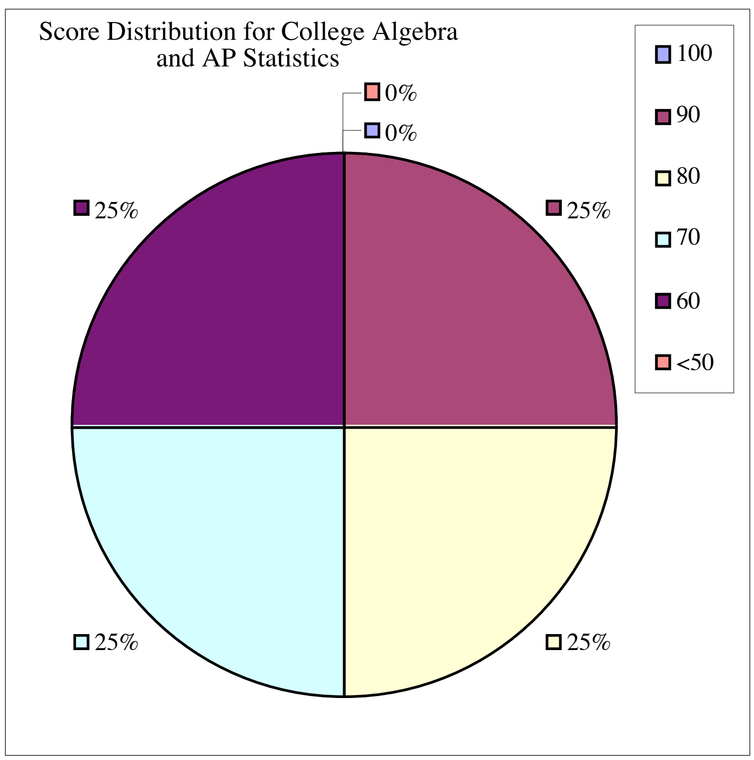
Score	Percentage
100	2.6%
90	18.4%
80	29.8%
70	32.5%
60	13.2%
< 50	3.5%
Average	**79%**



Graph B: Honors Chemistry Score Distributions for Higher Level Math Students

Score	Students
100	0
90	1
80	1
70	1
60	1
< 50	0
Total	4

Score	Percentage
100	0.0%
90	25.0%
80	25.0%
70	25.0%
60	25.0%
< 50	0.0%
Average	**81%**



Graph C: Honors Chemistry Score Distribution for Geometry Students

Score	**Students**
100	0
90	0
80	3
70	2
60	7
< 50	4
Total	16

Score	**Percentage**
100	0.0%
90	0.0%
80	18.8%
70	12.5%
60	43.8%
< 50	25.0%

Average **65%**

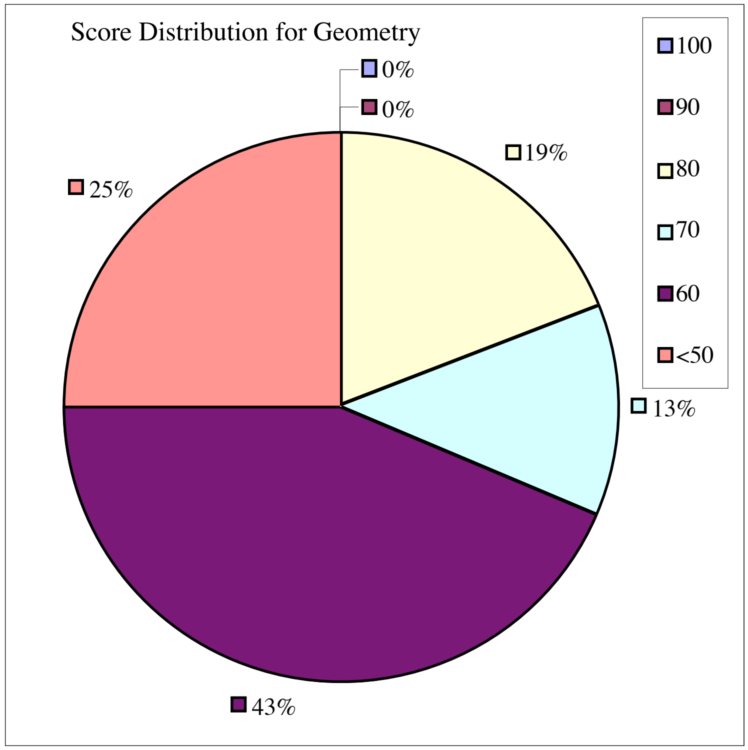


Table C and Graphs D - F show the average test scores for Chemistry students. Students enrolled in Geometry, on average, scored 59% on all tests, whereas students enrolled in Advanced Algebra, on average, scored 77% on all tests. Students in higher level math scored much better than students in the other levels of math.

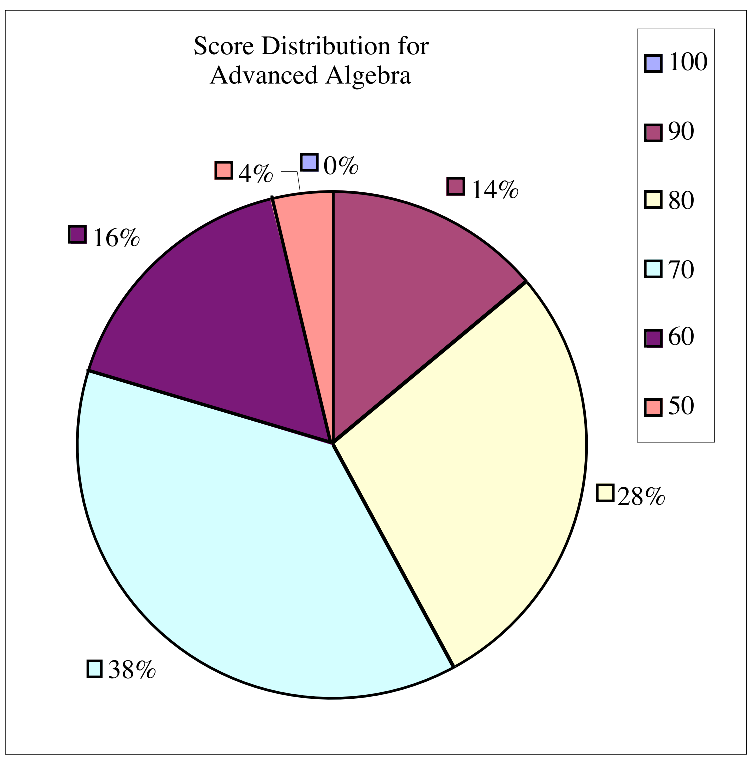
Table C: Results for Chemistry Classes

Table C	Math Class								
Science Class	No Math	Algebra	Math III	Geometry	Transitions To College Math	Advanced Algebra and Trigono-metry	College Algebra and Pre-Calculus	AP Calculus	AP Statistics
Chemistry	3	1	2	18	2	129	11	0	0
Average Test Scores	39%	55%	68%	59%	65%	77%	89%	-	-

Graph D: Chemistry Score Distribution for Advanced Algebra Students

Score	**Students**
100	0
90	18
80	36
70	49
60	21
< 50	5
Total	129

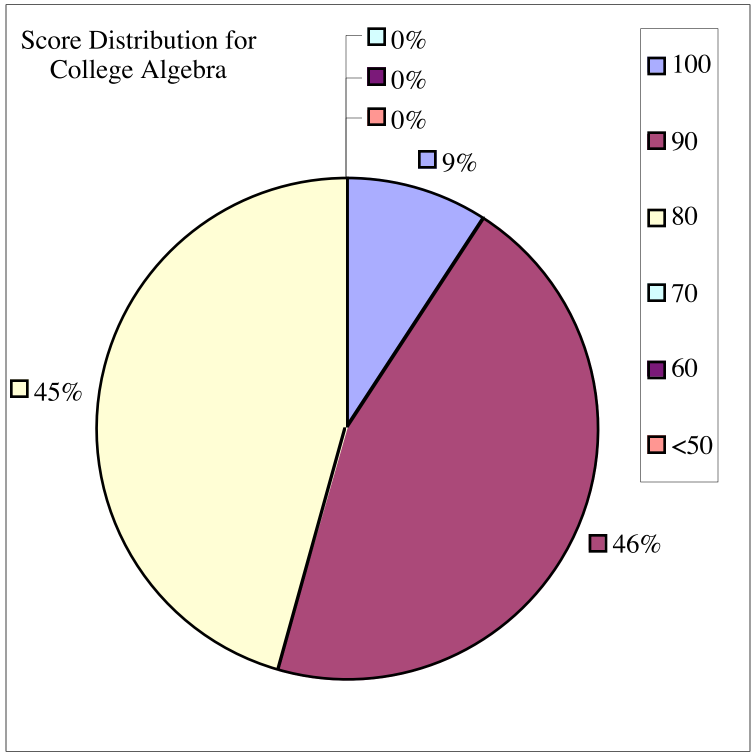
Score	**Percentage**
100	0.0%
90	12.9%
80	25.7%
70	35.0%
60	15.0%
< 50	3.6%
Average	**77%**



Graph E: Chemistry Score Distribution for College Algebra Students

Score	Students
100	1
90	5
80	5
70	0
60	0
< 50	0
Total	11

Score	Percentage
100	9.1%
90	45.5%
80	45.5%
70	0.0%
60	0.0%
< 50	0.0%
Average	**89%**



Graph F: Chemistry Score Distribution for All Lower Level Math Students

Score	Students
100	0
90	1
80	1
70	3
60	7
< 50	14
Total	26

Score	Percentage
100	0.0%
90	3.8%
80	3.8%
70	11.5%
60	26.9%
< 50	53.8%
Average	**57%**

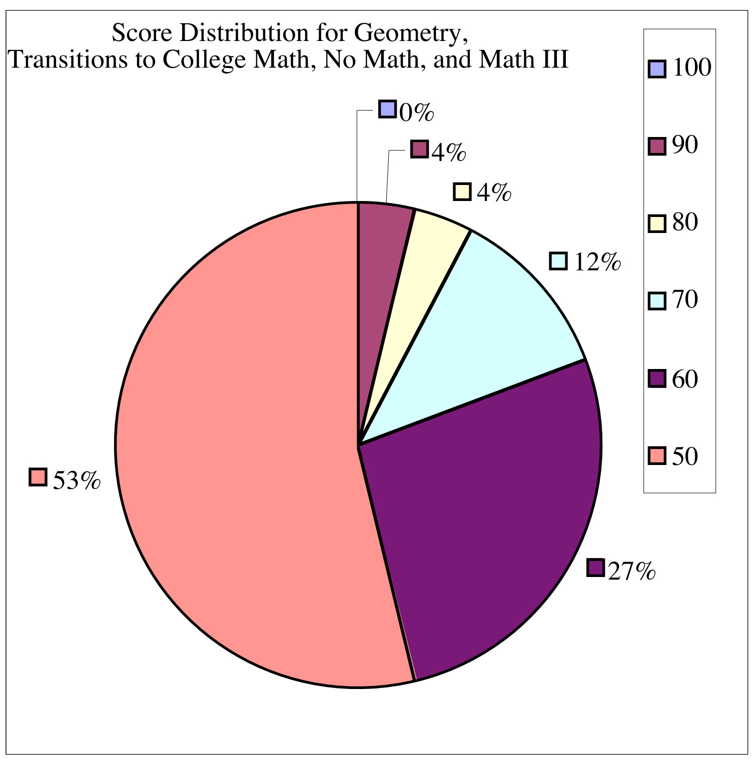


Table D and Graphs G - I show the average test scores for Honors Physics students. Students enrolled in Advanced Algebra, on average, scored 73% on all tests, whereas students enrolled in College Algebra, on average, scored 85% on all tests. Students in higher level math scored as well or better than students in the other levels of math.

Table D: Results for Honors Physics Classes

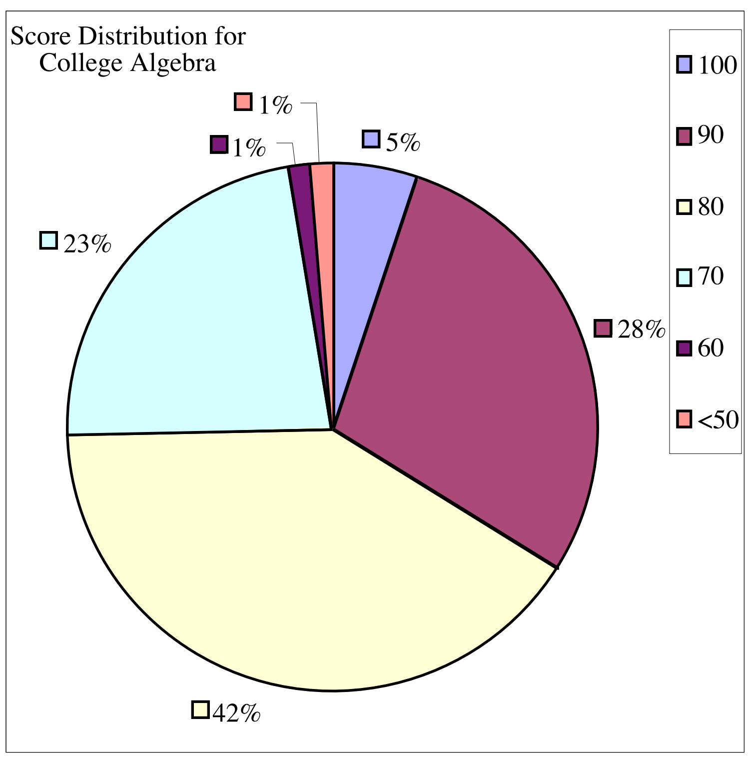
Table D	Math Class								
Science Class	No Math	Algebra	Math III	Geometry	Transitions To College Math	Advanced Algebra and Trigono-metry	College Algebra and Pre-Calculus	AP Calculus	AP Statistics
Honors Physics	0	0	0	0	0	12	74	4	2
Average Test Scores	-	-	-	-	-	73%	85%	103%	86%

Graph G: Honors Physics Score Distribution for College Algebra Students

Score	**Students**
100	4
90	21
80	30
70	17
60	1
< 50	1
Total	74

Score	**Percentage**
100	5.4%
90	28.4%
80	40.5%
70	23.0%
60	1.4%
< 50	1.4%

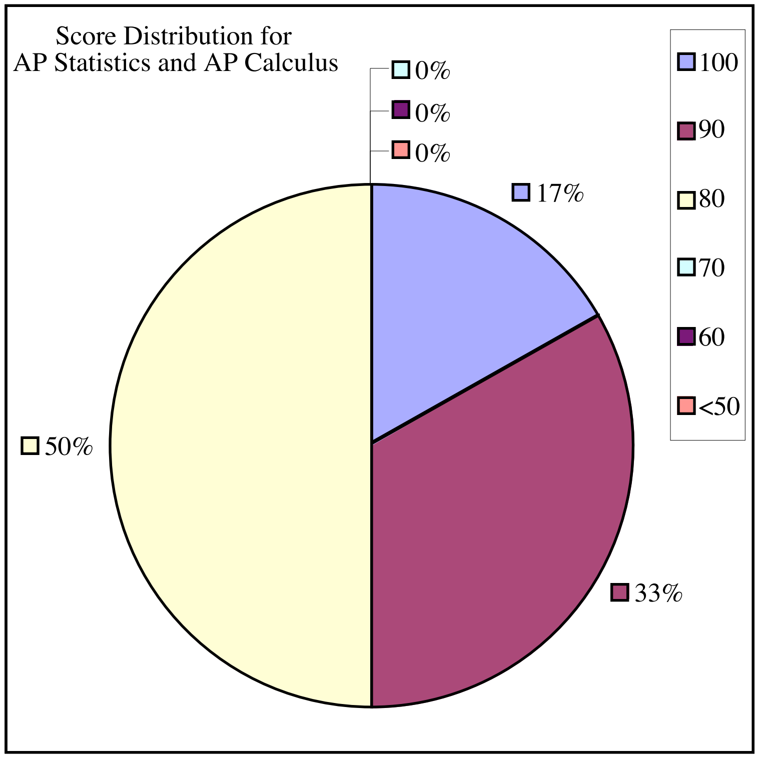
Average **85%**



Graph H: Honors Physics Score Distribution for Higher Level Math Students

Score	Students
100	1
90	2
80	3
70	0
60	0
< 50	0
Total	6

Score	Percentage
100	16.7%
90	33.3%
80	50.0%
70	0.0%
60	0.0%
< 50	0.0%
Average	**91%**



Graph I: Honors Physics Score Distribution for Advanced Algebra Students

Score	Students
100	0
90	1
80	2
70	5
60	4
< 50	1
Total	13

Score	Percentage
100	0.0%
90	7.7%
80	15.4%
70	38.5%
60	30.8%
< 50	7.7%
Average	**73%**

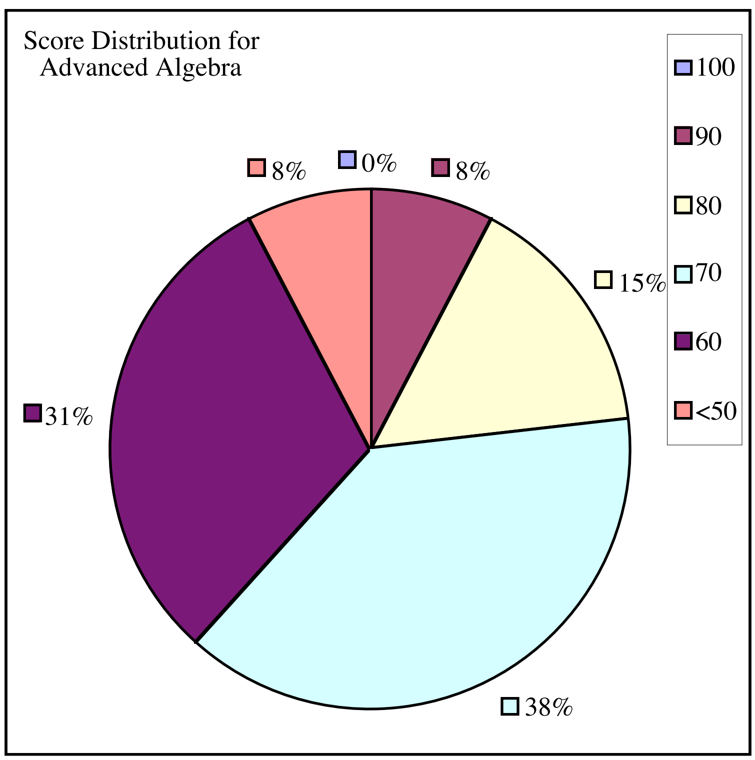


Table E and Graphs J - L show the average test scores for Physics students. Students enrolled in Advanced Algebra, on average, scored 73% on all tests, whereas students enrolled in Advanced Algebra, on average, scored 77% on all tests. Students in higher level math, on average, scored better than students in the other levels of math.

Table E: Results for Physics Classes

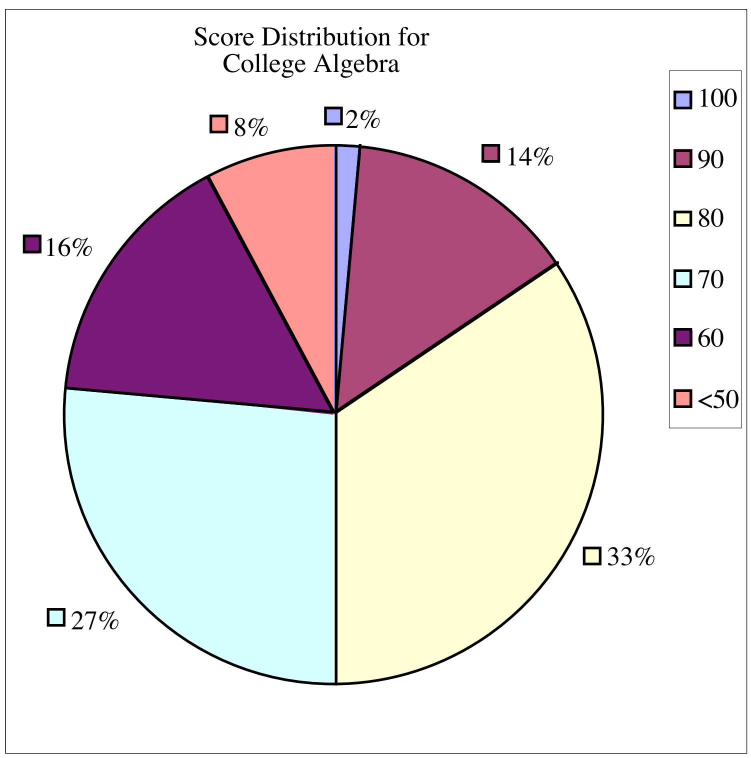
Table E	Math Class								
Science Class	No Math	Algebra	Math III	Geometry	Transitions To College Math	Advanced Algebra and Trigono-metry	College Algebra and Pre-Calculus	AP Calculus	AP Statistics
Physics	0	0	0	0	0	16	54	10	7
Average Test Scores	-	-	-	-	-	73%	77%	84%	86%

Graph J: Physics Score Distribution for College Algebra Students

Score	**Students**
100	1
90	9
80	22
70	17
60	10
< 50	5
Total	64

Score	**Percentage**
100	1.6%
90	14.1%
80	34.4%
70	26.6%
60	15.6%
< 50	7.8%

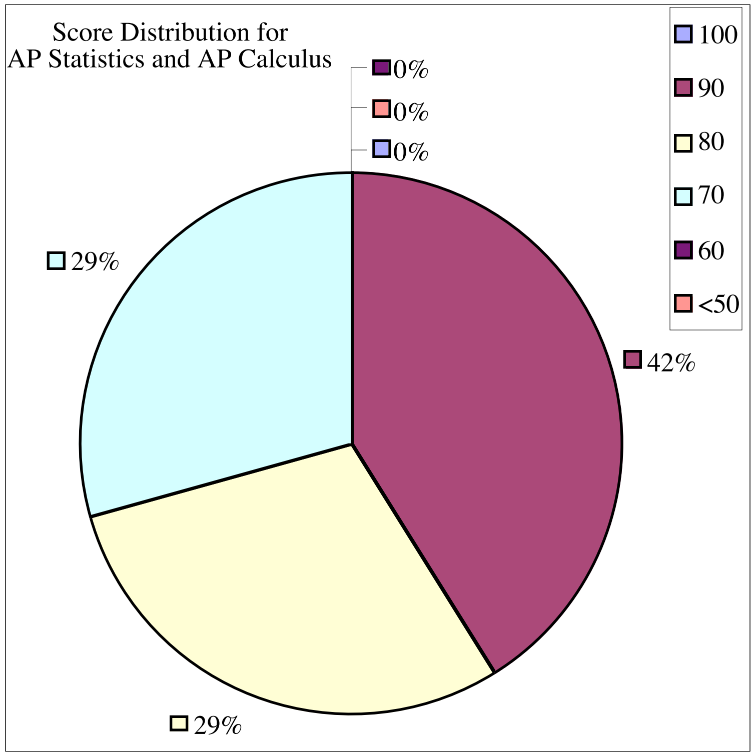
Average **77%**



Graph K: Physics Score Distribution for Higher Level Math Students

Score	Students
100	0
90	1
80	3
70	6
60	4
< 50	2
Total	16

Score	Percentage
100	0.0%
90	41.2%
80	29.4%
70	29.4%
60	0.0%
< 50	0.0%
Average	**73%**



Graph L: Physics Score Distribution for Advanced Algebra Students

Score	Students
100	0
90	7
80	5
70	5
60	0
< 50	0
Total	17

Score	Percentage
100	0.0%
90	6.3%
80	18.8%
70	37.5%
60	25.0%
< 50	12.5%
Average	**85%**

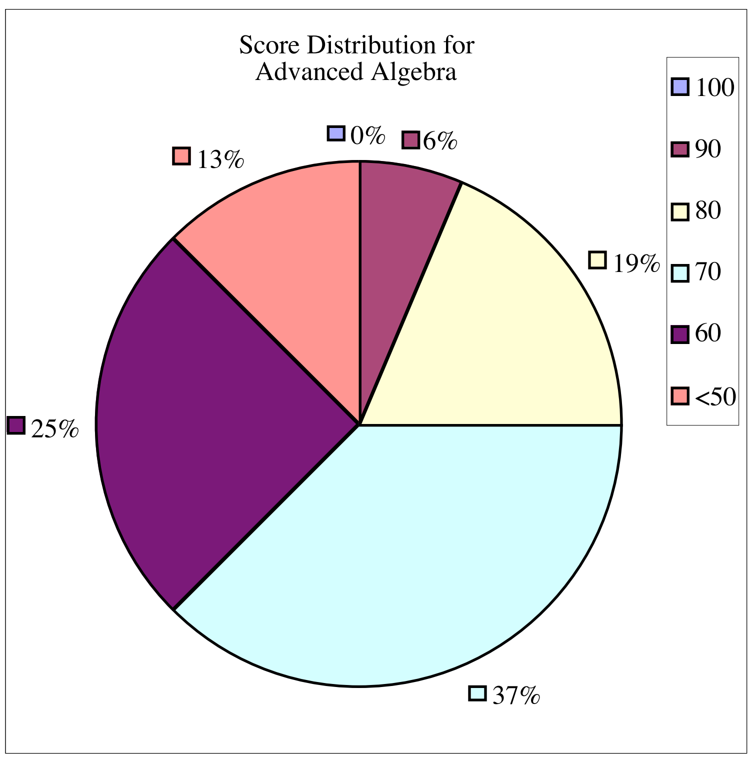


Table F shows the average test scores for all students in chemistry and physics sorted by math class. Students enrolled in Geometry, on average, scored 62% on all tests. Students enrolled in Advanced Algebra, on average, scored 78% on all tests. Students in higher level math scored as well or better than students in the other levels of math. In total, students with math levels below Advanced Algebra scored 61% on science exams, compared to an 80% average for all other higher levels of math.

Table F: Results for All Math Levels

Table F	Math Class								
Science Class	No Math	Algebra	Math III	Geometry	Transitions To College Math	Advanced Algebra and Trigono-metry	College Algebra and Pre-Calculus	AP Calculus	AP Statistics
Honors Chemistry	0	0	0	16	0	114	4	0	1
Chemistry	3	1	2	18	2	129	11	0	0
Honors Physics	0	0	0	0	0	12	74	4	2
Physics	0	0	0	0	0	16	54	10	7
Average Test Scores	39%	55%	68%	62%	65%	78%	82%	84%	86%

The following p-values were determined using the TTEST function for the Microsoft Excel for Macintosh software program. The entire list of scores for each sample were compared to each other using a two-tailed, two sample unequal variance test. Any p-values listed as a number followed by "E" represent a number in scientific notation. For example, 1.5E-3 is equivalent to 1.5×10^{-3}, or, in other words, 0.0015.

Table G: Honors Chemistry Tests of Significance

Table G	Test of Significance Geometry to Advanced Algebra	Test of Significance Advanced Algebra to College Algebra
Honors Chemistry	p = 0.00213902	p = 0.75489439

The score distribution for Advanced Algebra students (114) and Geometry students (16) is such that the probability of scores occurs with a 0.2% likelihood. The score distribution for Advanced Algebra students (114) and College Algebra students (4) is such that the probability of scores occurs with a 75% likelihood. The data implies that the Geometry students should not be scoring as low as they are compared with the Advanced Algebra students. The College Algebra students are not at all statistically significant, for they are scoring as well as Advanced Algebra students. However, it should be noted that the population for this group is only 4, which is not an extremely representative group.

Table H: Honors Chemistry Tests of Significance

Table H	Test of Significance All Lower Levels of Math to Advanced Algebra	Test of Significance Advanced Algebra to College Algebra
Chemistry	p = 1.70372E-07	p = 3.38449E-06

The score distribution for Advanced Algebra students (129) and lower level math students students (26) is such that the probability of scores occurs with a 0.000017% likelihood. The score distribution for Advanced Algebra students (129) and College Algebra students (11) is such that the probability of scores occurs with a 0.00034% likelihood. The data implies that the Geometry students are definitely statistically significant compared with the Advanced Algebra students, with an extremely low p-value. The College Algebra students are also statistically significant, with an extremely low p-value as well. These values represent the most statistically significant values of the study.

Table I: Honors Chemistry Tests of Significance

Table I	Test of Significance Advanced Algebra to College Algebra	Test of Significance College Algebra to Higher Levels of Math
Honors Physics	p = 0.001968846	p = 0.245832125

The score distribution for College Algebra students (74) and Advanced Algebra students (12) is such that the probability of scores occurs with a 0.19% likelihood. The score distribution for College Algebra students (74) and higher level math students students (6) is such that the probability of scores occurs with a 25% likelihood. The data implies that the Advanced Algebra students are statistically significant compared to the College Algebra students, with a very low probability that the two score distributions might happen by chance. The advanced math students are not statistically significant, scoring as well as the College Algebra students.

Table J: Honors Chemistry Tests of Significance

Table J	Test of Significance Advanced Algebra to College Algebra	Test of Significance College Algebra to Higher Levels of Math
Physics	p = 0.0995273	p = 0.009934961

The score distribution for College Algebra students (54) and Advanced Algebra students (16) is such that the probability of scores occurs with a 10.0% likelihood. The score distribution for College Algebra students (54) and higher level math students students (17) is such that the probability of scores occurs with a 0.99% likelihood. The data implies that the Advanced Algebra students are not statistically different from College Algebra students, although the probability is fairly low. The advanced math students are statistically significant, scoring better than the College Algebra students.

The p-values indicate that for Honors Chemistry and Chemistry, it is statistically significant for students to be enrolled in a math level lower than Advanced Algebra. The score distributions would not be probable purely by chance, which implies that the low level of math is a significant factor in chemistry achievement. In addition, for Chemistry, it is statistically significant for the students to be enrolled in a math level higher than Advanced Algebra. The score distributions, again, would not be probable purely by chance, which implies that the high level of math is a significant factor in chemistry achievement.

The p-values also indicate that for Honors Physics, it is statistically significant for students to be enrolled in a math level lower than College Algebra. For Physics, it is statistically significant to be enrolled in a math level higher than College Algebra. However, it is not statistically significant to be enrolled in Advanced Algebra in Honors Physics, and it is not statistically significant to be enrolled in higher level math courses in Physics.

Based on the p-values and the average test scores, there is a linearity between math level and chemistry and physics achievement. As the math ability and exposure increases, the success on tests in chemistry and physics increases. Students with higher level math enrollment score higher on chemistry and physics tests than students with lower level math enrollment. Of the students with lower level math enrollment, students with deficient math levels in Chemistry appear to have the most discrepancy between higher level math students, and students in Physics with deficient math levels appear to have the least discrepancy between higher level math students. Between chemistry and physics, the data implies that students in Honors Chemistry and Chemistry are more affected by changes in math level than students in Honors Physics and Physics. Based on this data, it may be reasonable to conclude that completion of Geometry and the enrollment in Advanced Algebra is a significant predictor of chemistry achievement. Students who are have completed courses in Geometry scored significantly higher than students without or concurrently enrolled in Geometry. In short, students taking chemistry who are enrolled in lower level math are at a disadvantage when taking an examination. These students do not have the necessary math background to handle the mathematic-based rigor of chemistry.

Recommendations

The data suggests that students in chemistry with lower levels of math score significantly lower than students with higher levels of math. According to the data, the more math background a student has while taking chemistry, the better the student will perform on examinations. As the math ability and exposure increases, the success on tests in chemistry and physics increases. It is the researcher's recommendation that students with lower levels of math than Advanced Algebra should not enroll in any level of chemistry until the student has completed Geometry and enrolled in Advanced Algebra.

Based on the relatively small number of test scores analyzed, this study should also be repeated analyzing future classes in chemistry and physics to determine if the phenomenon is student-specific, or if it is a systematic scheduling error which occurs annually as students are scheduled into science classes. It is the researcher's recommendation to change the scheduling of students with lower level math backgrounds if it is determined that the phenomenon is an annual problem. Students who are taking Geometry or lower should be advised that their math level may make it difficult to succeed on examinations in Chemistry. These students should either begin at a lower level of science or withhold from taking science until the math level is sufficient.

One recommendation for further research would be for each teacher to examine the tests administered in the classroom to see if there is an emphasis on conceptual understanding or problem solving. If it is found that test scores are lower and the test emphasizes one style or the other, it warrants investigation into whether or not the mode of teaching matches the mode of testing. In addition, each course should examine its taught and tested curriculum to make sure there is a match. If science teachers are teaching conceptual understanding, the students should be tested on conceptual understanding. If the science teachers are teaching problem solving, the students should be tested on problem solving. It is possible that the test scores reflect a mismatch between the emphasis of the courses and the methods and styles of the testing.

This study did not examine any correlation between math test scores and chemistry test scores. It might be useful to examine students' math grades as compared to their science grades to see if there is a correlation between low achievement in math and low achievement in science. Additionally, there was no analysis of high school GPA in relation to chemistry or math achievement, and this warrants additional consideration. Finally, a further study might develop tools and methods for improving reasoning and mathematical ability to be used with students enrolled in lower level math courses. Such preparation might allow these students to succeed on chemistry tests despite the students' lower level math abilities.

Appendix A: Concepts Inventory

The following test was given in September to two classes of Honors Chemistry. The students were given 45 minutes to complete the 33-question examination, and most students finished within 30 minutes. The same test was then given in January at the end of the first semester.

1. Which of the following must be the same before and after a chemical reaction?

   (a) The sum of the masses of all substances involved.
   (b) The number of molecules of all substances involved.
   (c) The number of atoms of each type involved.
   (d) Both (a) and (c) must be the same.
   (e) Each of the answers (a), (b), and (c) must be the same.

2. Assume that a beaker of pure water has been boiling for 30 minutes. Large bubbles are present in the boiling water. What are these bubbles made of?

   (a) Air.
   (b) Oxygen gas and hydrogen gas.
   (c) Oxygen.
   (d) Water vapor.
   (e) Heat.

3. A glass of cold milk sometimes forms a coat of water on the outside of the glass (Often referred to as "sweat"). How does most of the water get there?

   (a) Water evaporates from the milk and condenses on the outside of the glass.
   (b) The glass acts like a semi-permeable membrane and allows the water to pass, but not the milk.
   (c) Water vapor condenses from the air.
   (d) The coldness causes the oxygen and hydrogen from the air to combine on the glass to form water.

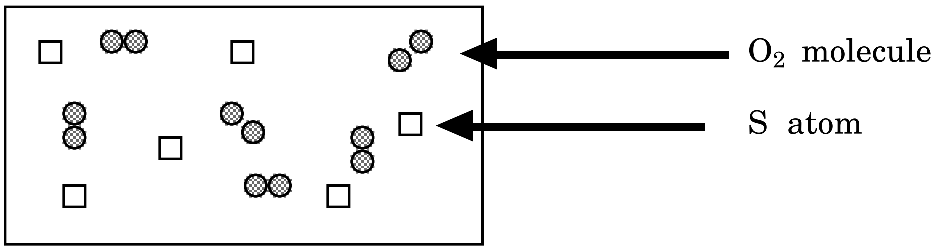
4. What is the mass of the solution when 1 pound of salt is dissolved in 20 pounds of water?

   (a) 19 pounds.
   (b) 20 pounds.
   (c) Between 20 and 21 pounds.
   (d) 21 pounds.
   (e) More than 21 pounds.

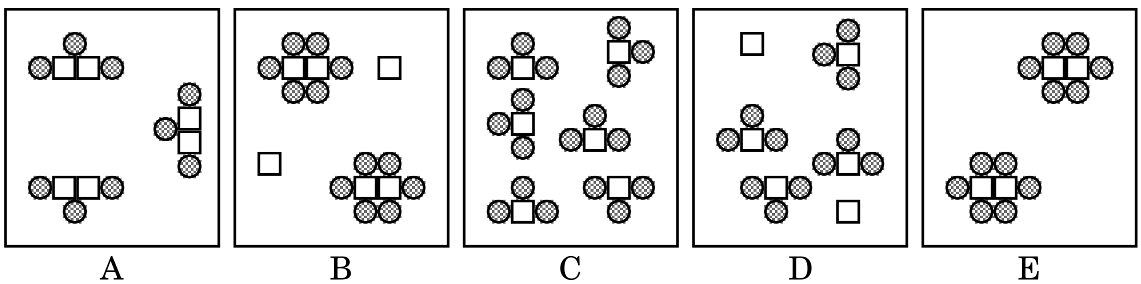
5. Compare the temperatures of three different beakers of boiling alcohol. One sample has been boiling for 5 minutes, another for 10 minutes, and the third has been boiling for 15 minutes.
   Which beaker would be at the highest temperature?

   (a) All of the beakers would be at the same temperature.
   (b) The beaker that has been boiling for 5 minutes.
   (c) The beaker that has been boiling for 10 minutes.
   (d) The beaker that has been boiling for 15 minutes.

6. The diagram below represents a mixture of S atoms and O_2 molecules inside a closed container.



Which diagram below shows the results after the mixture reacts as completely as possible according the following chemical equation: $2\ S + 3\ O_2 \dashrightarrow 2\ SO_3$.



7. True or False? When a match burns, some matter is destroyed.

   (a) True
   (b) False

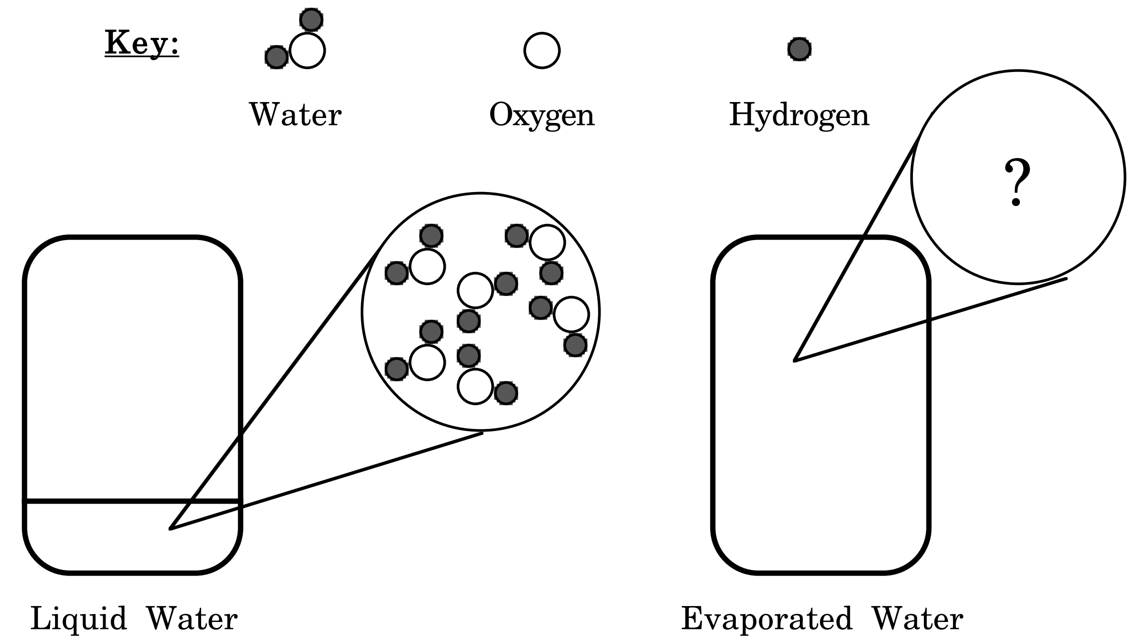
8. What is your reason for your answer to the previous question?

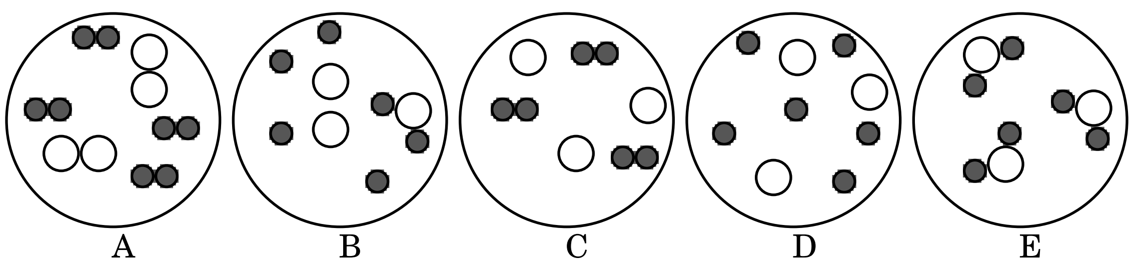
   (a) This chemical reaction destroys matter.
   (b) Matter is consumed by the flame.
   (c) The mass of the ash is less than the match it came from.
   (d) The atoms are not destroyed; they are only rearranged.
   (e) The match weighs less after burning.

9. A teaspoon of sugar, which has the chemical formula $C_{12}H_{22}O_{11}$, is dissolved in a cup of warm water. Which statement below best represents what is happening on the microscopic level?

   (a) The sugar molecules break apart into separate atoms of C, H, and O.
   (b) The water molecules surround each sugar molecule.
   (c) The sugar undergoes a chemical change by reacting with the water.
   (d) The warm water melts the sugar making it become a liquid.

10. The circle on the left shows a magnified view of a very small portion of liquid water in a closed (sealed) container. What would the magnified view show after the water evaporates?

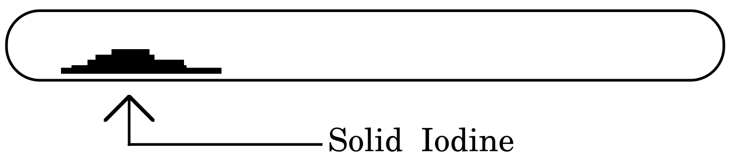




11. Consider a beaker full of water at a temperature of 90°C. A person quickly pours out some of the water, and the temperature of the water remaining in the beaker is instantly measured. Which of the following statements is true?
    (a) The temperature of the water left in the beaker has significantly decreased.
    (b) The temperature of the water in the beaker is the same.
    (c) The temperature has increased.
    (d) The temperature change depends on exactly how much water was poured out.

12. Consider a common 9-volt battery used in many toys. How does a battery provide power to a toy?
(a) The battery provides a source of neutrons to power the toy.
(b) The battery contains acids which slowly leak through the wires inside the toy.
(c) The battery is a source of nuclear energy.
(d) The battery provides a source of energy to make electrons flow through the wires in the toy.

13. A 1.0-gram sample of solid iodine is placed in a tube and the tube is sealed after all of the air is removed. The tube and the solid iodine together weigh 27.0 grams.



The tube is then heated until all of the solid iodine sublimes (changes from solid to gas) and the tube is filled with iodine gas. The total weight of the system will be:
(a) Less than 26.0 grams.
(b) 26.0 grams.
(c) 27.0 grams.
(d) 28.0 grams.
(e) more than 28.0 grams.

14. What is your reason for your answer to the previous question?
(a) A gas weighs less than a solid.
(b) Mass is conserved.
(c) Iodine gas is less dense than solid iodine.
(d) Gases rise.
(e) Iodine gas is lighter than air.

15. Iron combines with oxygen and water from the air to form rust. If an iron nail were allowed to rust completely, one should find that the rust weighs:
(a) less than the original nail it came from.
(b) the same as the original nail it came from.
(c) more than the original nail it came from.
(d) It is impossible to predict.

16. What is your reason for your answer to the previous question?
    (a) Rusting makes the nail lighter.
    (b) Rust contains iron and oxygen.
    (c) The nail flakes away.
    (d) The iron from the nail is destroyed.
    (e) The flaky rust weighs less than iron.

17. A student picks up a wooden spoon and then grabs a metal spoon with her other hand. If both spoons were initially at room temperature, why does the metal spoon feel colder?
    (a) The wooden spoon is not very shiny so heat is not reflected into the air.
    (b) The wooden spoon evenly distributes its heat energy.
    (c) The metal spoon attracts the coldness from the air.
    (d) The metal spoon conducts heat energy better than wood.

18. Figure 1 represents a 1.0-Liter solution of sugar dissolved in water. The ovals in the magnification circle represent the sugar molecules. To simplify the diagram, the water molecules have not been shown.

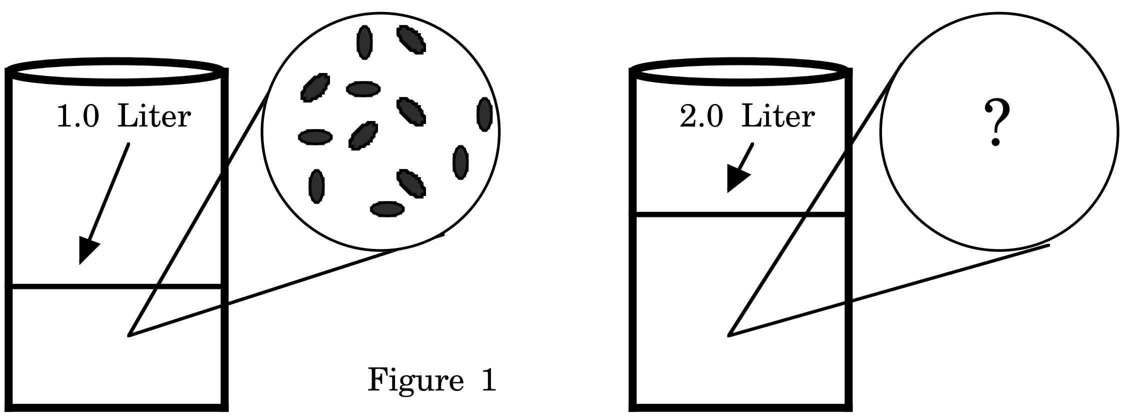
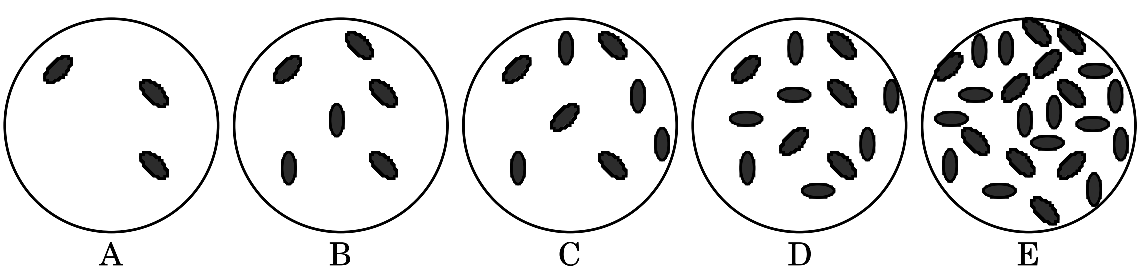


Figure 1

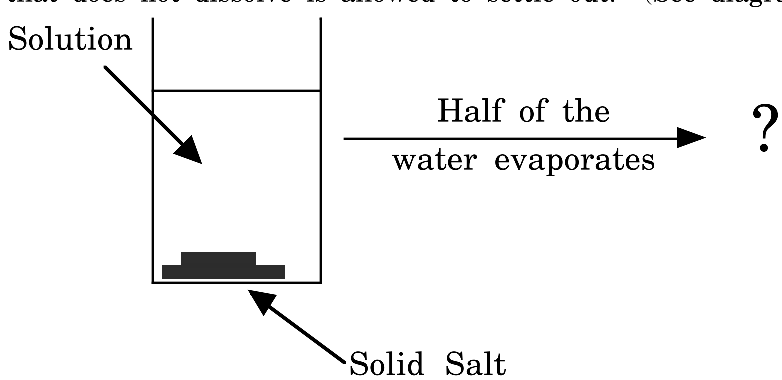
Exactly 1.0 Liter of water was added, and the mixture was then stirred for 5 minutes. Which response below represents the magnified view after the 1.0 Liter of water was added to the original solution?



19. Exactly 100 mL of water at 25°C and exactly 100 mL of alcohol at 25°C are both heated at the same rate under identical conditions. After three minutes, the temperature of the alcohol is 50°C. After five minutes, the temperature of the water reaches 50°C.
    Which liquid received more heat as it warmed to 50°C?
    (a) The water.
    (b) The alcohol.
    (c) Both received the same amount of heat.
    (d) It is impossible to tell from the given information.

20. What is your reason for your answer to the previous question?
    (a) Water has a higher boiling point than the alcohol.
    (b) Water takes longer to change its temperature than the alcohol.
    (c) Both increased their temperatures by 25°C.
    (d) Alcohol has a lower density and vapor pressure.
    (e) Alcohol has a higher specific heat capacity so it heats faster.

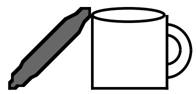
21. Salt is added to water and the mixture is stirred until no more salt dissolves. The salt that does not dissolve is allowed to settle out. (See diagram)



    What happens to the concentration of the salt in the solution if the water evaporates until the volume of the solution is half the original volume? (Assume the temperature remains constant.)
    (a) The concentration of salt solution increases.
    (b) The concentration of the salt solution decreases.
    (c) The concentration stays the same.

22. What is your reason for your answer to the previous question?
    (a) There is the same amount of salt in less water.
    (b) More solid salt forms.
    (c) Salt does not evaporate and is left in solution.
    (d) There is less water.

23. A wet saucer is leaned against an empty coffee cup after being washed. The saucer eventually dries.



What happens to the water that does not drip onto the counter?

(a) It goes into the saucer.

(b) It just dries up and no longer exists as anything.

(c) It changes into oxygen and hydrogen in the air.

(d) It goes into the air as separate molecules of water.

24. Which formula is followed by its correct name?

(a) $FeCl_2$, iron(III) chloride

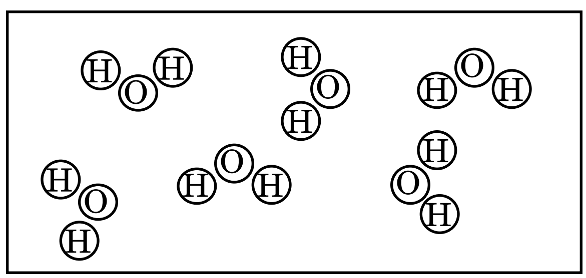
(b) Mg_3N_2, trimagnesium dinitrogen

(c) KNO_2, potassium nitrite

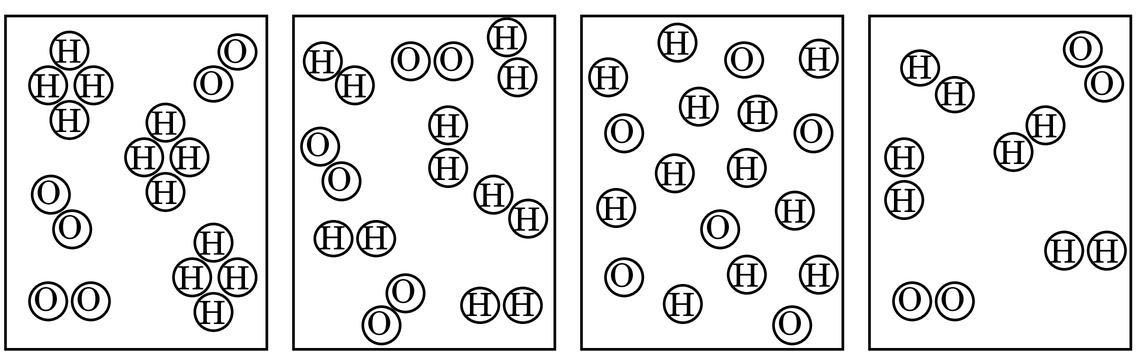
(d) HIO, hydroiodous oxide

(e) SiO_2, silicon oxide

25. The diagram below represents a sample of water molecules inside a closed container.



Which diagram below shows the results after all of the water molecules have reacted according to the following chemical equation: $2\ H_2O \dashrightarrow 2\ H_2 + O_2$



A B C D

26. The most stable geometry of a central atom bonded to four other atoms would be:
    (a) square-shaped
    (b) cross-shaped
    (c) tetrahedral
    (d) quadrahedral
    (e) none of the above.

27. Ions like O^{-2}, NH^{-2}, and SO_4^{-2} are all similar in that they have
    (a) gained two electrons
    (b) gained two protons
    (c) lost two electrons
    (d) lost two protons
    (e) none of the above.

28. Which set consists of only compounds?
    (a) O^{-2}, Na^{+}, and Cl^{-}
    (b) H_3O^{+}, Cl_2, and I_3^{-}
    (c) NaCl, CH_4, and Br_2
    (d) H_2S, $CuCl_2$, and KI
    (e) SiO_2, H_2, and S

29. In the modern periodic table, elements are ordered according to
    (a) increasing atomic number
    (b) date of discovery
    (c) decreasing atomic mass
    (d) Mendeleev's original design
    (e) none of the above.

30. Molar mass
    (a) refers to the mass in grams of one mole of a substance
    (b) is the same as the average atomic mass of the element
    (c) both a and b
    (d) neither a nor b

31. Based on their location on the periodic table, oxygen and selenium have
    (a) the same number of neutrons
    (b) similar chemical properties
    (c) the same number of electron orbitals
    (d) similar physical properties
    (e) all of the above

32. Carbon-14 has more ____________ than carbon-12.
    (a) electrons
    (b) protons
    (c) neutrons
    (d) electrons and protons
    (e) electrons and neutrons

33. Which of the following elements will replace copper in copper (II) sulfate, $CuSO_4$?
    (a) iron
    (b) argon
    (c) silver
    (d) gold
    (e) phosphorus

Appendix B: Concept Inventory Results

The following pretest and posttest results were tabulated for the Concepts Inventory given in September and again in January for two Honors Chemistry classes.

			Pre								Post				
	A	B	C	D	E	Total	Correct		A	B	C	D	E	Total	Correct
1	5	8	9	10	**13**	45	22%	1	3	8	**13**	10	11	45	22%
2	3	**18**	12	11	1	45	24%	2	0	**23**	8	14	0	45	31%
3	7	1	18	**19**	0	45	40%	3	8	1	**19**	17	0	45	42%
4	3	12	10	**18**	2	45	40%	4	1	5	12	**27**	0	45	60%
5	**34**	0	1	10	0	45	76%	5	**30**	1	2	12	0	45	67%
6	**11**	8	3	7	16	45	16%	6	3	5	6	9	**21**	44	20%
7	14	**31**	0	0	0	45	69%	7	11	**34**	0	0	0	45	76%
8	3	7	3	**32**	0	45	71%	8	4	4	2	**32**	3	45	71%
9	**16**	9	**16**	4	0	45	20%	9	**22**	12	8	3	0	45	27%
10	10	0	9	**19**	7	45	16%	10	12	2	3	**21**	7	45	16%
11	2	**33**	2	8	0	45	73%	11	7	**29**	2	7	0	45	64%
12	1	0	0	**44**	0	45	98%	12	2	1	3	**39**	0	45	87%
13	**25**	6	14	0	0	45	31%	13	18	5	**20**	2	0	45	44%
14	**20**	14	10	0	1	45	31%	14	16	**22**	7	0	0	45	49%
15	17	4	**23**	1	0	45	51%	15	19	2	**22**	2	0	45	49%
16	1	**27**	4	10	3	45	60%	16	4	**25**	7	2	7	45	56%
17	5	13	12	**15**	0	45	33%	17	4	10	8	**23**	0	45	51%
18	4	**33**	3	4	1	45	73%	18	2	**33**	5	3	2	45	73%
19	8	15	**20**	2	0	45	18%	19	8	5	**32**	0	0	45	18%
20	10	**12**	9	4	10	45	27%	20	**13**	10	10	3	9	45	22%
21	**30**	2	13	0	0	45	29%	21	**29**	2	14	0	0	45	31%
22	14	4	**23**	4	0	45	9%	22	**22**	6	14	3	0	45	13%
23	0	0	**28**	17	0	45	38%	23	0	1	24	**20**	0	45	44%
24	**13**	3	**13**	3	**13**	45	29%	24	3	16	**17**	2	7	45	38%
25	**16**	12	5	12	0	45	27%	25	11	**18**	6	10	0	45	40%
26	9	**15**	3	7	11	45	7%	26	1	7	**20**	9	8	45	44%
27	11	2	**22**	6	4	45	24%	27	**36**	0	3	5	1	45	80%
28	3	1	13	**27**	1	45	60%	28	1	1	2	**41**	0	45	91%
29	**38**	0	2	2	3	45	84%	29	**38**	1	0	3	3	45	84%
30	**21**	4	7	13	0	45	16%	30	**26**	4	9	6	0	45	20%
31	4	8	4	8	**21**	45	18%	31	0	13	9	5	**18**	45	29%
32	**18**	10	12	2	3	45	27%	32	10	6	**18**	8	3	45	40%
33	13	7	**14**	6	5	45	29%	33	12	10	**15**	5	3	45	27%

Highest number of responses is in bold type. | **Correct answers** (highlighted)

- same percentage pre/post
- small increase in percentage between pre/post
- mid-range increase in percentage between pre/post (10 - 20%)
- large increase in percentage between pre/post (20% or more)
- decrease in percentage between pre/post

Appendix C: Semester Reflections Survey

The following survey was given for students in the researcher's Chemistry and Honors Chemistry during the week of January 20, 2004.

For all of the following questions, answer each using complete sentences.

First Semester Reflections:

1. What topics/activities did you enjoy the most during first semester chemistry? The least? Why?

2. On a scale of one to ten (with ten being the highest) for EACH category, how would you rate your effort in the areas below. Please write a brief explanation for your answer to each.

   class participation _____ / 10

   taking notes _____ / 10

   completion of homework/labs _____ / 10

   studying for tests/quizzes _____ / 10

3. What were two frustrating things about chemistry last semester? Why?

Second Semester Goals:

1. What are three goals you have for yourself this semester in chemistry? What will you need to do in order to achieve these goals?

2. What are two specific things your teacher can do this semester to help you better understand material and achieve greater success in this course?

3. What types of activities (notes, labs, demos, group work, etc) help you learn the material the best? Why?

4. Do you plan on taking a science course next year? If so, what course? If not, why not?

5. What are your long-term plans after graduating [hopefully] from high school?

References

Bodner, George (1983). *Verbal, Numerical and Perceptual Skills Related to Chemistry Achievement*. Paper presented at the Annual Convention of the American Psychological Association (91st, Anaheim, CA, August 1983).

BouJaoude, S.B. & Giuliano, F.J. (1991). Measurement Error in Social and Educational Research. *ACE Research Reports 7(2)*. Washington, DC: American Council on Education.

Bracken, J. (2003). *High School Chemical Concepts Inventory*. Purdue University.

Butler, K. (1984). *Learning and Teaching Style in Theory and Practice*. Maynard, MA: Gabriel Systems, Inc.

Chandran, S. (1985). *The Role of Cognitive Factors in Chemistry Achievement*. Western Australian Institute of Technology, Perth.

Chiu, M.H. (2001). Algorithmic Problem Solving and Conceptual Understanding of Chemistry by Students at a Local High School in Taiwan. *Proceedings of the. National Science Council, ROC(D), 11*(1), 20-38, from http://nr.stic.gov.tw/ejournal/ProceedingD/v11n1/20-38.pdf

DeBaz, T.P. (1994). *Meta-analysis of the Relationships Between Students' Characteristics and Achievement and Attitudes Toward Science*. Doctoral dissertation, Ohio State University. (ERIC Document Reproduction Service No. ED 377 079)

Duckett, J. (1983). *Helping Children Develop Good Study Habits: A Parents' Guide*. (ERIC Document Reproduction Service No. ED 240 061)

Fisher, G. (1996). *The Validity of Pre-Calculus Multiple Choice and Performance-Based Testing as a Predictor of Undergraduate Mathematics and Chemistry Achievement*. Master's Thesis, University of California, Santa Barbara. (ERIC Document Reproduction Service No. ED 409 369)

Garcia, T., Yu, S.L., & Coppola, B.P. (1993). *Women and Minorities in Science: Motivational and Cognitive Correlates of Achievement*. Paper presented at the annual meeting of the American Educational Research Association, Atlanta, GA, April. (ERIC Document Reproduction Service No. ED 359 235)

Gardner, H. (1984). *The Development and Education of Intelligences*. Chicago: Spencer Foundation.

Georgakakos, J.H. (1997). *Using the California Chemistry Diagnostic Test and Other Student Background Factors to Predict Grades and Success in General Chemistry I*. Riverside Community College, CA. (ERIC Document Reproduction Service No. ED 407 957).

Guthrie, J.M. (1991). *Proportional Reasoning in the Solution of Problems in High School Chemistry and its Impact on Developing Critical Thinking Skills*. M.S. Practicum, Nova University. June 1991. (ERIC Document Reproduction Service No. ED 351 183).

Illinois State Board of Education. (April, 2004). School Report Card. http://206.230.157.60/publicsite/reports/2003/school/english/4406315500004_2003_e.pdf

Lin, Y. (1970). Aptitude, Anxiety, Study Habits, and Academic Achievement. *Journal of Counseling Psychology, 17*(4), 306-309

Lythcott, J. (1990). Problem Solving and Requisite Knowledge of Chemistry. *Journal of Chemical Education, 67*, 248-252.

Mazur, E. (1996). *Concept Tests*. Englewood Cliffs, N.J.: Prentice-Hall.

Nakhleh, M. B., & Mitchell, R. C. (1993). Concept Learning Versus Problem Solving: There is a Difference. *Journal of Chemical Education 70*(3),190-192.

Nordstrom, B.H. (1989). *Predicting Performance in Freshman Chemistry*. (ERIC

Document Reproduction Service No. ED 347 065).

Nurrenbern, S.C. & Pickering, M. (1987). Concept Learning Versus Problem Solving: Is There a Difference? *Journal of Chemical Education, 64*(6), 508-510.

O'Brien, T. (1994). Cognitive Learning Styles and Academic Achievement in Secondary Education. *Journal of Research and Development in Education, 28*(1), 11-21.

Packer, J. and Bain, J.D. (1978) Cognitive Style and Teacher-Student Compatibility. *Journal of Educational Psychology, 70*, 864-871.

Pascarella, E.T. & Terenzini, P.T. (1991). *How College Affects Students*. San Francisco; Jossey-Bass.

Pickering, M. (1990). Further Studies on Concept Learning Versus Problem Solving. *Journal of Chemical Education, 67*(3), 254.

Russell, A.A. (1994). A Rationally Designed General Chemistry Diagnostic Test. *Journal of Chemical Education*. *73*(12), 1150-1153.

Sanchez, K. and Betkouski, M. (1986). *A Study of Factors Affecting Student Performance in Community College General Chemistry Courses*. Paper presented at the Annual Meeting of the National Association for Research in Science Teaching (59th, San Francisco, CA, March 28 - April 1, 1986).

Seiler, J. (2004). [Surveys of Student Dispositions of First Semester and Second Semester Chemistry]. Unpublished raw data.

Silberman, R. (1981). Problems with Chemistry Problems: Student Perception and Suggestions. *Journal of Chemical Education, 58*(12), 1036.

Spencer, H.E. (1996). Mathematical SAT Test Scores and College Chemistry Grades. *Journal of Chemical Education*. *73*(12), 1050-1153

Yates, D.S, Moore, D.S., and Starnes, D.S. (2003). The Practice of Statistics. 2nd ed. New York: WH Freeman, 2003.