THE EFFECTS OF DIRECT MATHEMATICS INSTRUCTION ON ATTITUDES AND SUCCESS IN GENERAL CHEMISTRY

by

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ABSTRACT

In this investigation direct instruction on mathematical topics critical to the general chemistry curriculum was delivered by the chemistry teacher and members of the math department as part of a Proportions Project. Changes in student attitude and performance were measured using pre and post treatment surveys and assessments. After the Proportions Project, student performance improved by up to 28% at tasks incorporating multiple variables and unit conversions. The majority of students also reported better study skills, better understanding of the role of mathematics in the study of chemistry, and a perception of chemistry as more relevant to their daily lives.

INTRODUCTION AND BACKGROUND

Project Background

Teaching Experience & Classroom Environment

I work at a rural girls boarding school called the Foxcroft School in Middleburg, Virginia. I am in my fourth year at the school, which is my first teaching job. The school has an enrollment of slightly less than two hundred girls, of which about twenty percent are international students and whose English skills range from fair to excellent. The majority of international students are from China and Korea. Most of the American students are Caucasian, with about 10-15% African American students and a few Hispanics. About half of the American students are from Virginia, with the remainder coming from twenty-three states across the country. Almost all of the students who attend the school are from families of high socio-economic status, though some financial aid is granted and a few students do attend on scholarships.

My classroom research project investigated the intersection of mathematics and introductory level chemistry. The intention of the study was to improve student performance in chemistry by explicitly connecting the mathematics covered in the chemistry curriculum to concepts and examples the students experienced in math class. The intent of the treatment was to increase student self-confidence with the mathematics in the chemistry curriculum in order to improve student understanding and performance on assessments. Since the project focused on the general chemistry curriculum, I worked with students enrolled in general chemistry throughout the project.

Chemistry is traditionally an 11^{th} grade course at the school. In general, the academic ability of the students ranges from average to excellent. The school does not have honors classes, although gifted students may choose to accelerate by taking two sciences during their sophomore year. Sophomores enrolled in this program account for around one quarter of the total enrollment in the chemistry course. At Foxcroft, enrollment in chemistry is highly recommended but not required for graduation. Students with documented learning differences or poor performance in previous math classes generally take science electives during their junior year instead of enrolling in chemistry, which accounts for the fact that there are very few students with exceptionally poor math skills in the class. Foxcroft is a college preparatory school, and the academic climate is very supportive. Getting good grades is socially acceptable and often a source of heated competition.

An initial set of Pre-Treatment Interviews was conducted with a set of eight students enrolled in general chemistry during the 2009-2010 school year. The interviews focused on the students' perceptions of science and math in general and chemistry in particular (Appendix A). The results of this survey confirmed the rationale for my study. Of the eight students I interviewed, five mentioned math or equations as being the most difficult part of the course. The perception of liking math had a much better correlation to good grades in chemistry than the perception of liking science did. There was also a strong correlation between liking or being good at math and considering the math-based portions of the chemistry curriculum easier.

Three of the eight students interviewed thought that mathematically based portions of the curriculum were harder than other parts. Of the eight students interviewed, these three had three of the four lowest grades in the course. Three other students, including the fourth student with a poor grade, reported that math-based sections were easier. The last two students originally stated that both were the same, then after some reflection but without any kind of prompting declared that the math-based portions were easier. These answers provide an intriguing suggestion of connection between the perception of poor math skills and struggles in chemistry.

The interview questions also addressed the connection between the chemistry and math curriculums taught at our school. Three of the eight students interviewed recognized all of the material covered in chemistry from previous math classes, and four more recognized most of it. Only one student, who was not finding much success in the class, stated that she recognized only a little. Students reported that they recalled the math they were expected to know in chemistry class being taught to them mainly during pre-Algebra and Algebra I. It appeared that my students were making connections between the math curriculum and chemistry pre-treatment, but the interview data left me concerned that students were not making these connections until late in the school year, and that changes could still be made to assist students in making stronger connections earlier in the process of learning chemistry.

The most common connections made between math and chemistry were conversions (mentioned by four students), cross multiplication (mentioned by four students) and isolation of a variable (mentioned by three students). Other connections made included basic skills of multiplication and division, which two of the students thought were reinforced in chemistry, and proportions and ratios.

Focus Question

The primary question that was addressed by this research was, How does direct instruction in mathematics in the chemistry classroom affect student perception of the difficulty of the mathematical components of chemistry, self-confidence in the subject of chemistry, and performance on mathematics-related assessments?

In order to answer this question, data was also collected to answer the following sub-questions,

Sub Question One: Are students competent at the level of mathematics and critical thinking required for success in the chemistry curriculum?

Sub Question Two: Are students confident with their understanding and use of the math concepts used in the chemistry classroom?

CONCEPTUAL FRAMEWORK

The connections between chemistry and mathematics include the use of multiple and related variables, graphical analysis, ratios and proportions, geometry and spatial relationships, and exponents and logarithms. Most high school students will have completed at least an introductory overview of all of these concepts by their sophomore year. However, upper level high school and even college chemistry students consistently report that the difficulty of the underlying mathematics is a significant cause of difficulty with the subject (Bardeen, Freeman, Lederman, Marshall, Thompson, and Young, 1998).

Attempts to address this difficulty have ranged from new methods for teaching the quantitatively based units in the chemistry curriculum to fully integrated curricula for the entire math and science sequence in both high school (Bardeen et al., 1998) and college classrooms (White & Carpenter, 2008). The rationale espoused by the originators of these integrated curricula is instructive. Bardeen et al. (1998) speak of a transition from a mechanistic paradigm where the brain is expected to behave as a serial computer, learning takes place as an accumulation of facts, and the mind begins as a blank slate to a modern more complex paradigm. In the new paradigm suggested by the authors, the brain acts as a parallel processor. The mind is a plastic system which functions far more efficiently when new information can be placed in a known context, and learning is "an internally and socially mediated process of constructing meaning from patterns created through multiple representation of knowledge" (Bardeen et al., 1998, p. 8). This new paradigm is especially appropriate for understanding the learning process in single-sex female institutions, as Zohar (2006) points out by referring to research demonstrating that women learn best in a context of connected knowledge where they can form an attachment to the knowledge being presented. This works best when structure and function of a new concept are presented simultaneously. Mathematics and science are very suitable for combination in this way, as science creates myriad possibilities to demonstrate real-world applications of mathematical concepts. Presenting concepts in this way can also improve the self-confidence and attitude of students, which enhances problem solving skills (Drummond & Selvaratnam, 2008).

The difficulty of translating concepts which have been mastered, or at least memorized, in math class to the science context has several explanations. The first problem with making the connections between math and science concepts is vocabulary. Fensham and Lui (2001) point out that the word *equation* is used regularly in both math and chemistry, but that it has a fairly definite meaning in math and two different meanings in the chemistry classroom, one of which is the same as the math definition and one of which is completely unrelated. Conversely, Wink, Glslason, McNicholas, Zusman, and Mebane (2000) point out that the exact same concept is called a *constant of proportionality* in algebra but is sometimes called a *conversion factor* and sometimes just a *constant* in chemistry. It is not surprising that this confusing vocabulary should serve as a barrier to concepts from the math classroom becoming integrated into a student's understanding of science.

Another problem noted by several authors is the difficulty students have with recognizing the relationships between variables (Selvaratnam & Kumarasinghe, 1991; Dori & Hameiri, 2003). Students have this difficulty when presented either with statements or with experimental data. They do not know how to transfer the relationships between concepts to the relationships between quantities. To combat this difficulty, O'Connor (2003) recommends content-specific integrations, where math teachers use examples involving science concepts in class instead of unitless numbers, and science teachers describe concepts in the vocabulary used in math classes, tying this vocabulary in with the traditional scientific jargon used in textbooks.

The final obstacle to student transference of mathematical knowledge from math class to chemistry is the different ways that students are asked to apply the concepts they know in the different classes. Many students are proficient either at performing calculations or at concept knowledge. However, algorithmic and conceptual knowledge are separate skills (Paphagotis & Tsaportis, 2008). The challenge many students experience for the first time in high school science is the integration of both types of knowledge into a single problem. As described by Wagner (2001), the use of purely algorithmic thinking is the hallmark of an exercise, and this is what is mainly done in algebra class. Chemistry students are more successful with this type of work as well, which is why it is popularly assigned as homework. However, students become much less successful when the integration of algorithmic and conceptual thinking is required, which according to Wagner makes a question into a problem. Zoller (1993) explains the difference in difficulty experienced by students with the fact that exercises require only lower-order cognitive skills, while problems require the use of higher-order cognitive skills.

A class dependent only on exercises, or only on problems, would not prepare students adequately for the real world or for future experiences in the sciences. According to Heyworth (1998), those students who are most successful at solving all levels of chemistry questions approach them algorithmically, at least originally. Wagner (2001) explains this by the fact that development and use of working algorithms by students frees working memory to integrate conceptual material. Cook and Cook (2005) have had success in helping students make the transition from algorithmic to conceptual thinking by phrasing ratio and conversion problems as "if...then" statements.

The list of potential connections between algebra, geometry, and chemistry is long, and teachers and educational researchers have published a variety of studies concerning the utility of such connections. Specific connections that have been drawn to algebra include the use of linear algebra and matrices to help students conceive a more complete understanding of balancing equations and the conservation of mass (Ceyhun & Karagolge, 2009; Croteau, Fox, & Varazo, 2007), quadratic equations to determine equilibrium concentrations (Brilleslyper, 2004), pH to illustrate logarithms (Watters & Watters, 2006), and nuclear decay equations to demonstrate linear regression and exponential functions (Crippen & Curtwright, 1998). Connections to geometry have been used in lesson plans connecting valence shell electron repulsion theory to trigonometry (Pleacher, 1998) and the unit cell concept to three-dimensional geometry and volume problems (Pacyga, 1995). Basic statistics can also be integrated with the chemistry curriculum during the units on gas laws and kinetics (Matsumoto, 2006).

The most important part of the chemistry curriculum for a strong basis in mathematics is in the study of the mole concept and stoichiometry. College chemistry students report that stoichiometry is both the most useful and best remembered concept from high school chemistry studies. However, it is also the concept which is consistently named the hardest (Tai,Ward, & Sadler, 2006). Methods for improving student understanding of this unit include a mole ratio flow chart (Wagner, 2001) and particulate representations of chemical reactions and stoichiometric relationships (Sanger, 2005). A particulate representation has been found to be particularly useful in resolving student confusion about superscripts and subscripts in chemical formulas (Marais & Combrinck, 2009).

The connection of concepts from math and chemistry is a valuable tool in increasing student understanding and success in both disciplines. The combination also has the potential to increase the perceived relevancy of math and chemistry to student lives. Student awareness of practical applications for the mathematical concepts which they learn in school, whether those applications occur in other courses such as the sciences or in daily life as with unit conversions, can also increase student motivation in the math and science classrooms and retention of math concepts.

METHODOLOGY

Before the treatment period began, data was collected concerning the mathematics placement and grades of the students enrolled in the treatment chemistry classes. This information was used to assign students (without their knowledge) to three categories. The categories chosen were weak math students, with current and past math grades in the range of 60-77 (Group C), strong math students, with current and past math grades in the range of 90-100 (Group A), and average math students, with current and past math grades in the range of 78-89 (Group B).

Students were administered the Colorado Learning Attitudes About Science Survey (CLASS) (Barbera, Adams, Wieman, & Perkins, 2008) to gain information related to student perceptions of chemistry (Appendix B). This was supplemented by interviews with students in the treatment classes where the students were asked the same set of questions used in the Preliminary Survey (Appendix A). The students had been exposed to a limited amount of mathematically oriented topics before the treatment began, which gave them a basis for answering the questions. A small amount of extra credit was offered for participation, and an alternative extra credit opportunity was available for those students who did not wish to participate in the survey. A total of 26 surveys were collected, 11 from group A, 10 from group B, and 5 from group C. After the collection of pre-treatment data, the second semester treatment period began with the non-graded Pure Math Assessment covering simple math concepts that are commonly used in chemistry (Appendix C). Some problems were purely based on numbers and variables, while others were word problems. The questions included problems with and without units and with and without scientific and chemical vocabulary. There was a small amount of extra credit provided for thoughtful participation. The data collected was analyzed to determine the strengths and weaknesses of each group of students and of the students as a group. The categories which were assessed were skills with the order of operations, solving for a single variable, solving for a variable in an equation with multiple variables, and unit conversions. Twenty-five Pure Math Assessments were collected, 13 from Group A, 8 from Group B, and 4 from Group C.

The information collected on areas of weakness was used to select the topics to be covered during the treatment period. The concepts identified by the math assessment as being of particular difficulty for students were equations with multiple variables and identifying and manipulating proportional relationships. In order to address these weaknesses, the Proportions Project was developed in cooperation with the math department (Appendix D). This project included portions graded by both myself and by several math faculty, and the grades for the project were included as 10% of the semester grade for each student in both chemistry and their concurrently enrolled math course. The project included lectures on proportionality, problem and equation solving strategies, and unit conversion and dimensional analysis, which were divided between class time in the chemistry course and in math classes. The same lectures were given in each of the three math courses which included chemistry students. In order to facilitate this project, I worked with several teachers in the math department to learn the vocabulary used in math class and either substituted this vocabulary into chemistry instruction or specifically explained the correlation between terms in concepts where it is important to maintain traditional chemistry vocabulary. For this project, the most important vocabulary terms to coordinate with the math faculty were *proportion, inverse, direct, constant, conversion factor, and dimensional analysis.*

The treatment took place during the third and fourth units of the general chemistry course, beginning after the holiday break in January. The first unit covered the gas laws. The mathematics covered during this unit focused on the analysis of proportional relationships using data, equations, and graphical analysis. There was also significant coverage of strategies for solving equations with multiple variables. The second unit during the treatment period covered the mole concept, molarity, and stoichiometry. The mathematics was tied into that of the first unit using the concepts of molarity and dilution as a bridge to the proportional relationships discussed in the gas law unit. The discussion of proportionality and constants was expanded to include conversion factors, unit conversions, and dimensional analysis in the context of stoichiometry.

During the course of the treatment period, the mathematical and scientific concepts addressed by the Proportions Project were continually reinforced with both formative and graded assessments. The curriculum in use in the chemistry course involves daily worksheets completed alternately individually and in groups with a guided inquiry format, followed by daily homework assignments to reinforce the concepts introduced each day. Instructional time during almost every lesson was used to reinforce the relevant mathematical concepts for each concept.

At the end of the treatment period, near the conclusion of the second semester, the Colorado Learning Attitudes about Science Survey (CLASS) was re-administered. To encourage student participation and effort, there was again an opportunity to earn a few extra credit points. The data from the surveys was analyzed for statistical trends using a student's t-test with a significance level of <0.1. Only questions where at least one group had a statistically significant difference pre- and post- treatment are described in the analysis. Trends observed in the survey data were supported with information gathered in the interview process, where 9 interviews were conducted in the pre-treatment period (three from each group) and an additional 11 were conducted post-treatment (four from group A, four from group B, and three from group C). Interview subjects were selected randomly from volunteers. The categories based on math scores created at the beginning of the treatment were compared to see if trends differed. The interview data was also used to identify outliers.

Also at the end of the treatment period, the Math in Context Assessment was given to the students (Appendix E). This was a revised version of the Pure Math Assessment given at the beginning of the study period, with increased focus on the concepts which were emphasized in the Proportions Project and with the word problems and unit conversions altered to incorporate some of the chemical terms and concepts taught during the semester. Twenty-two Math in Context Assessments were collected, including eight from Group A, 11 from Group B, and three from Group C. The results of this assessment were compared to the results of the Pure Math Assessment to look for trends in each group of students and in the class as a whole, again using a student's t-test with a significance level of <0.1.

The research methodology for this project received an exemption by Montana State University's Institutional Review Board and compliance for working with human subjects was maintained. The data collected was used to answer the focus question and sub questions of my action research project according to the Data Triangulation Matrix (Table 1).

Table 1
Data Triangulation Matrix

Focus Questions	Data Source 1	Data Source 2	Data Source 3
1. Are students competent at the level of mathematics and critical thinking required for success in the chemistry curriculum?	Math Assessment	Project Data	Math Grades
2. Are students confident with their understanding and use of the math concepts used in the chemistry classroom?	CLASS	Interviews	Classroom Data
3. How does direct instruction on mathematics concepts in the chemistry classroom impact student success and confidence in mathematically based chemistry problems?	CLASS and Interviews	Quizzes and Tests	Math Assessment

DATA AND ANALYSIS

The data from the Math Skills Assessments was divided into four categories. The first two categories included questions covering the order of operations and solving simple equations for a single variable. Both of these concepts are covered in early math courses and were not covered in math or science classes during the treatment period. The results of the Math Skills Assessment indicated that order of operations skills did not vary significantly (p = 0.4 to 0.9) from pre to post-treatment (*N*=26). While group A gained about 6%, the other groups lost between 5 and 8% in proficiency (Figure 1).

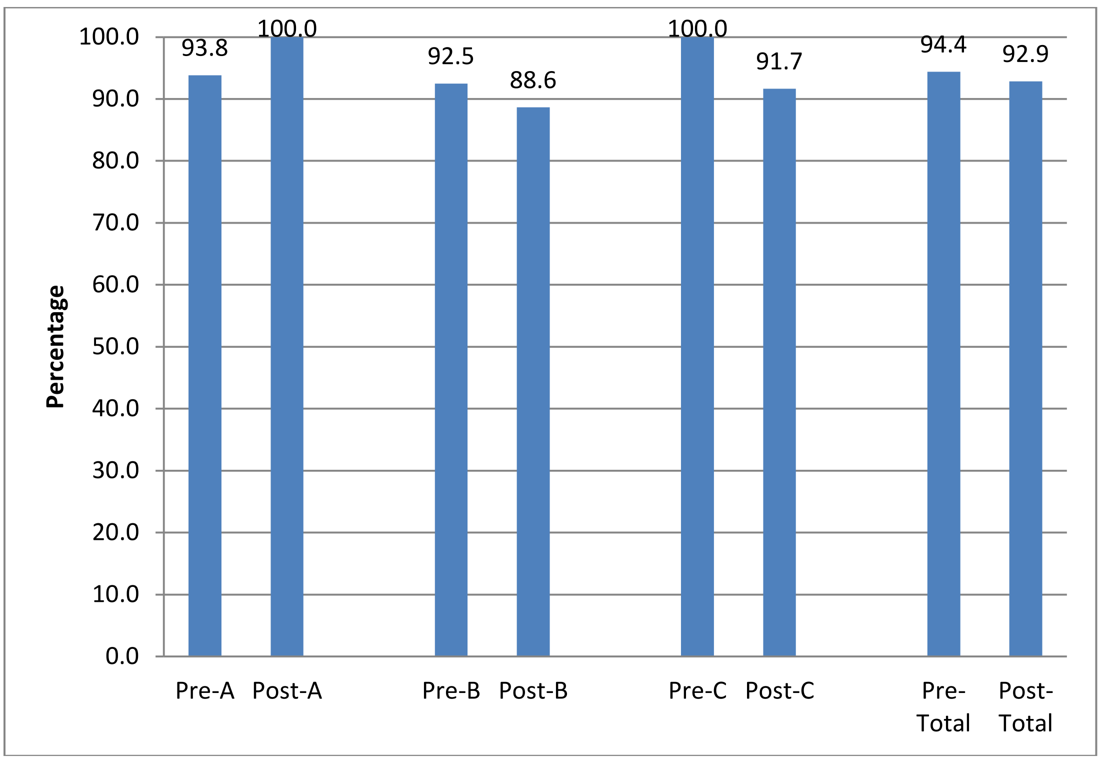

Figure 1. Order of Operations Data from the Math Skill Assessments, (*N*=25).

The data from the analysis of questions dealing with solving equations with a single variable showed an increase of 8-13% in Groups A and B and a decrease of 13% in group C, but again these changes are not statistically significant by students t-test (p= 0.2-0.6) (Figure 2).

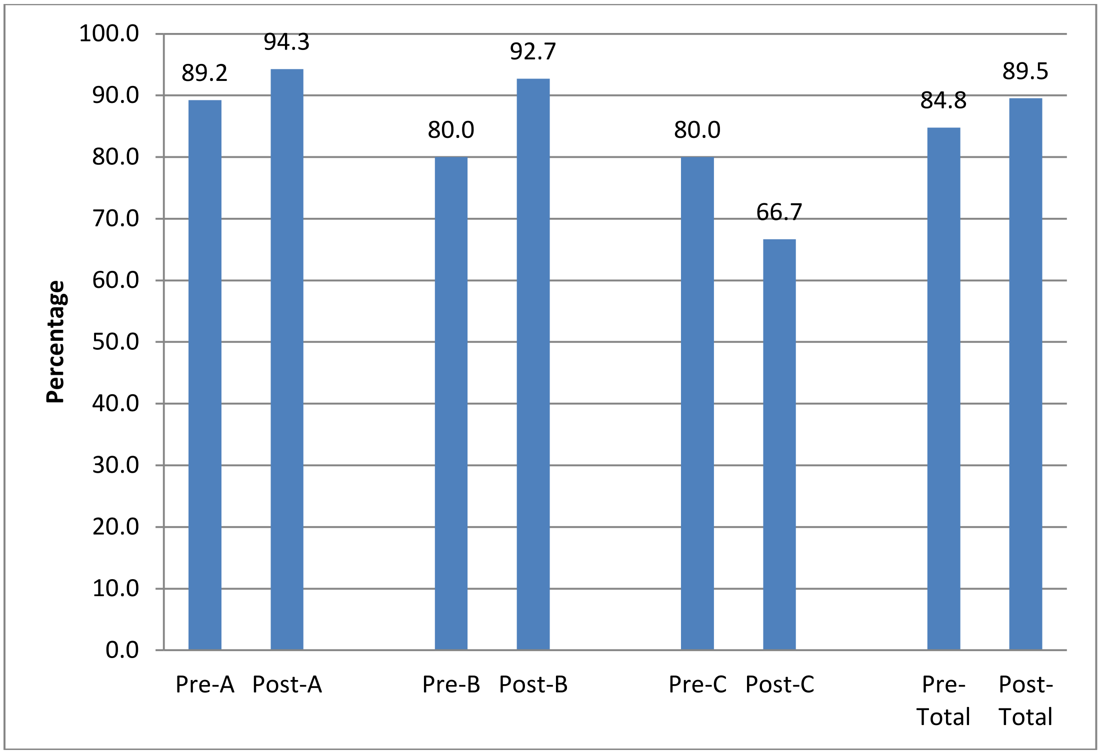

Figure 2. Solving for a Single Variable Data from Math Skill Assessments, (*N*=25).

The other two skill sets measured by the assessment were solving equations involving multiple variables and proportions and unit conversions. Both of these skills were covered by direct instruction as part of the Proportions Project. The data for solving problems with multiple variables and proportions shows statistically significant improvement across all groups by students t-test. Groups A and B had improvements in proficiency of 27% (p=0.38 and 0.48 respectively), while Group C had a smaller improvement of 7% (p=0.56) (Figure 3). The mean improvement across the entire study group was 24% (p=0.61)

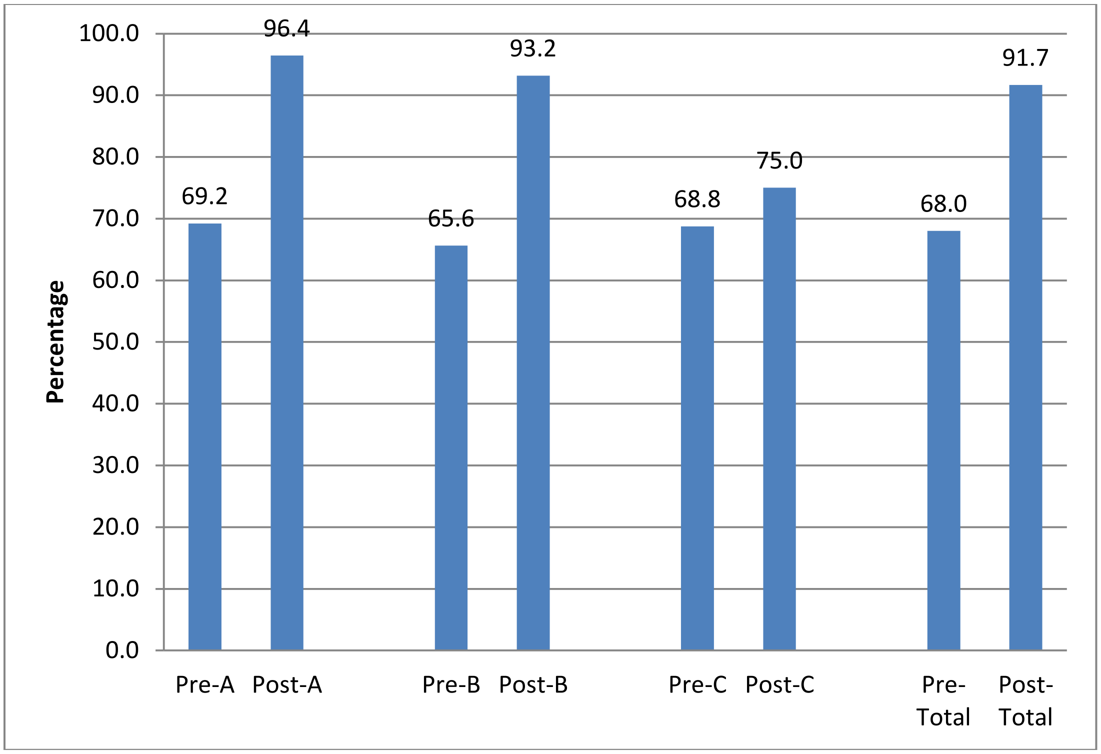

Figure 3. Solving for Multiple Variables and Proportions Data from Math Skill Assessments, (*N*=25).

The data collected on the skill of unit conversion problems shows that Groups A and B improved (by 25% and 12% respectively, with p = 0.079 and 0.048), while Group C appears to have lost ability, with a decrease in proficiency of 30% (Figure 4). However, the change in Group C is not statistically significant due to small sample size (p= 0.73). The mean increase across the class of 24% is statisically significant (p= 0.071)

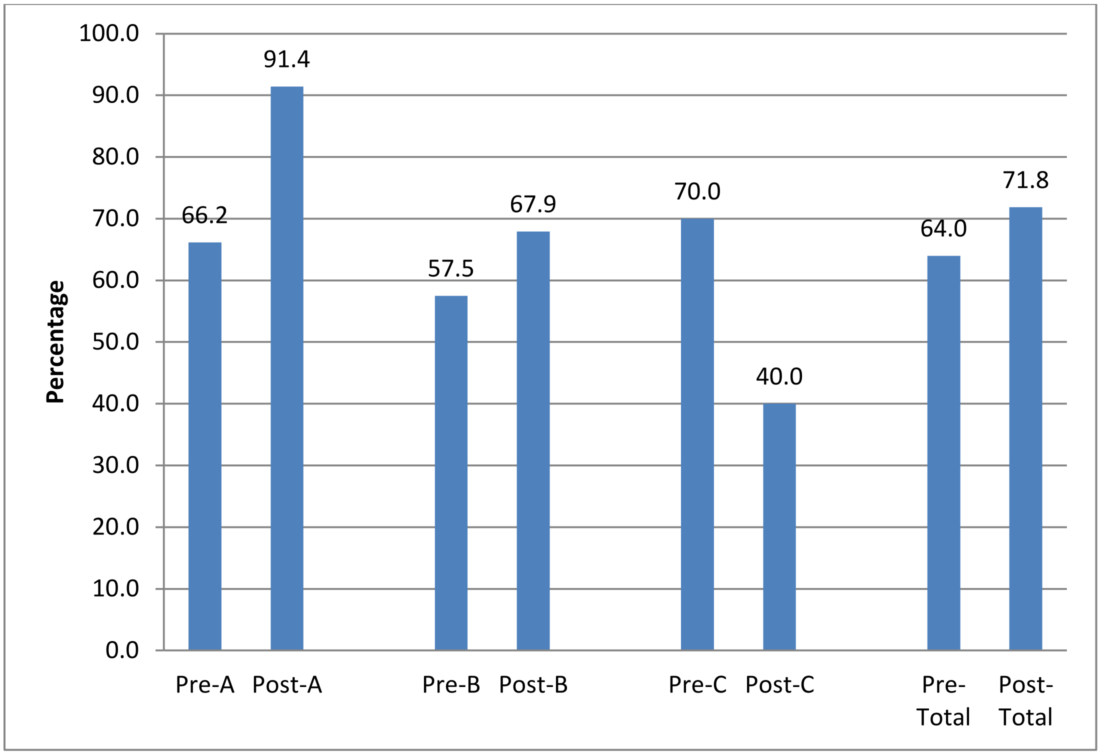

Figure 4. Unit Conversion Data from Math Skill Assessments, (*N*=25).

Throughout the math skills data, there are two clear trends. The first is no significant change in math skills not addressed by the Proportions Project and a substantial increase in proficiency in those skills targeted for direct instruction. The second is a clear similarity in the results for groups A and B, with Group C data demonstrating differences from that of the rest of the class.

The Colorado Learning Attitudes About Science Survey (CLAS survey) and interview data revealed a number of trends. The first is a decrease in student perception of the importance of non-mathematical methods of analysis, particularly atomic and molecular theory. The differences in these perceptions did not vary substantially between groups A, B, and C, and the differences among all the study groups were statistically significant for the three questions shown in Figure 5 (all p values < 0.10). The largest change, of more than one and a half units on the 1-5 Likert Scale used in the CLAS Survey, was when students we asked if they thought about the three dimensional structure of molecules in order to understand chemical processes. This material was covered early in the fall semester and was not mentioned or reinforced during the treatment period. The trend of attaching less importance to atomic and molecular theory as fundamental to the understanding of chemistry was supported by the fact that all four of the students who mentioned atomic theory or structures in the interview (3 from group A and one from group C) mentioned these concepts in the context of "the easiest thing about chemistry."

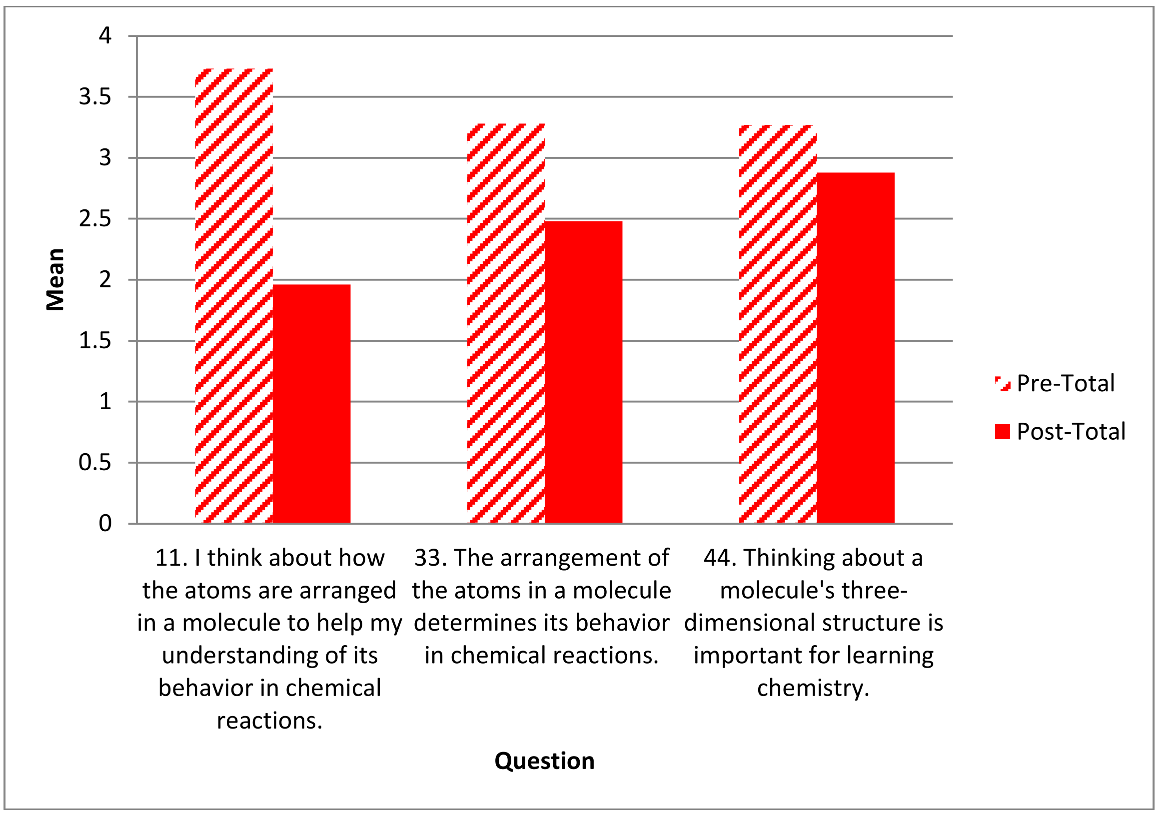

Figure 5. Atomic and Molecular Theory Question Data from CLAS Survey, (*N*=26).

Another trend visible in the survey data was a loss of student confidence in their ability to work alone and to complete work without help. When asked questions about their ability to work independently, only group A responded with increased confidence (Figure 6). The only change that was statistically significant was the decrease by two units of the Likert scale in the confidence in group C (p= 0.09). All groups reported decreased confidence in their ability to solve a problem once they had become "stuck." The changes in groups B and C were statistically significant (p= 0.067, 0.047). The Group C students were the only students to mention a lack of confidence in working alone in their interviews. Two students mentioned dependence on extra help for success. A typical comment was, "It makes sense when I do it with you, but it's harder when I get home, and I then I totally forget on the test."

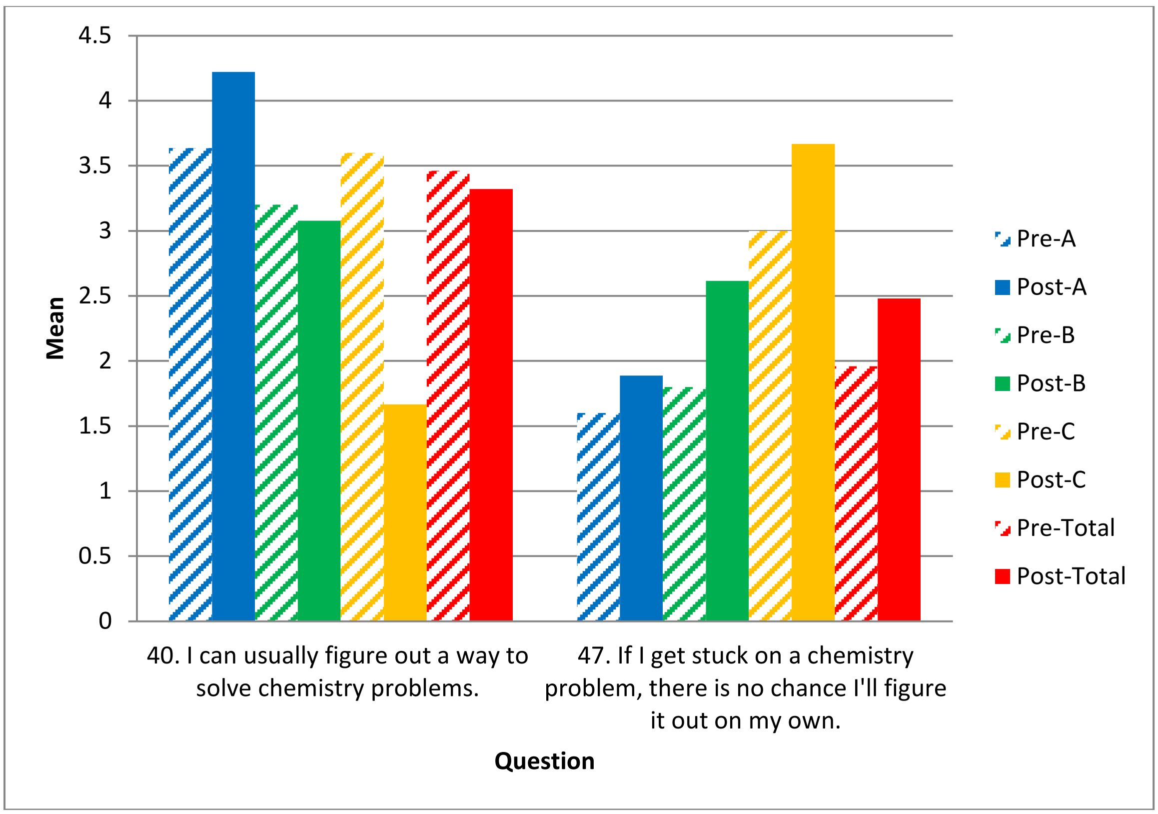

Figure 6. Independence Question Data from CLAS Survey (*N*=26).

A similar trend in student attitudes was also visible in the data collected on questions having to do with problem solving skills and strategies. Students in groups B and C reported that they were now less likely to attempt a different strategy to solve a difficult problem. Only students in group A reported an increased likelihood to attempt multiple problem solving strategies (Figure 7). Only the one Likert scale unit decrease in group C was statistically significant ($p=0.035$). Students in group C also reported increased trust in calculations, regardless of the logical nature of the result, while groups A and B were now more likely to return to a calculation that gave an illogical answer. All of the groups were significantly (p for the total study group = 0.011) less likely to expressly consider “chemical ideas” when doing problems. Finally, the students in group A felt that they had a significantly ($p= 0.09$) better idea of what they were doing, where as group C students felt that they more often did not understand what they were doing ($p=0.08$). Information from interviews expands on the difficulty of group C students. Eight of the 11 students interviewed expressed that interpreting questions and determining what process or equation to apply was “the hardest thing” about chemistry. This included all of the Group C students interviewed, as well as several students from Groups A and B.

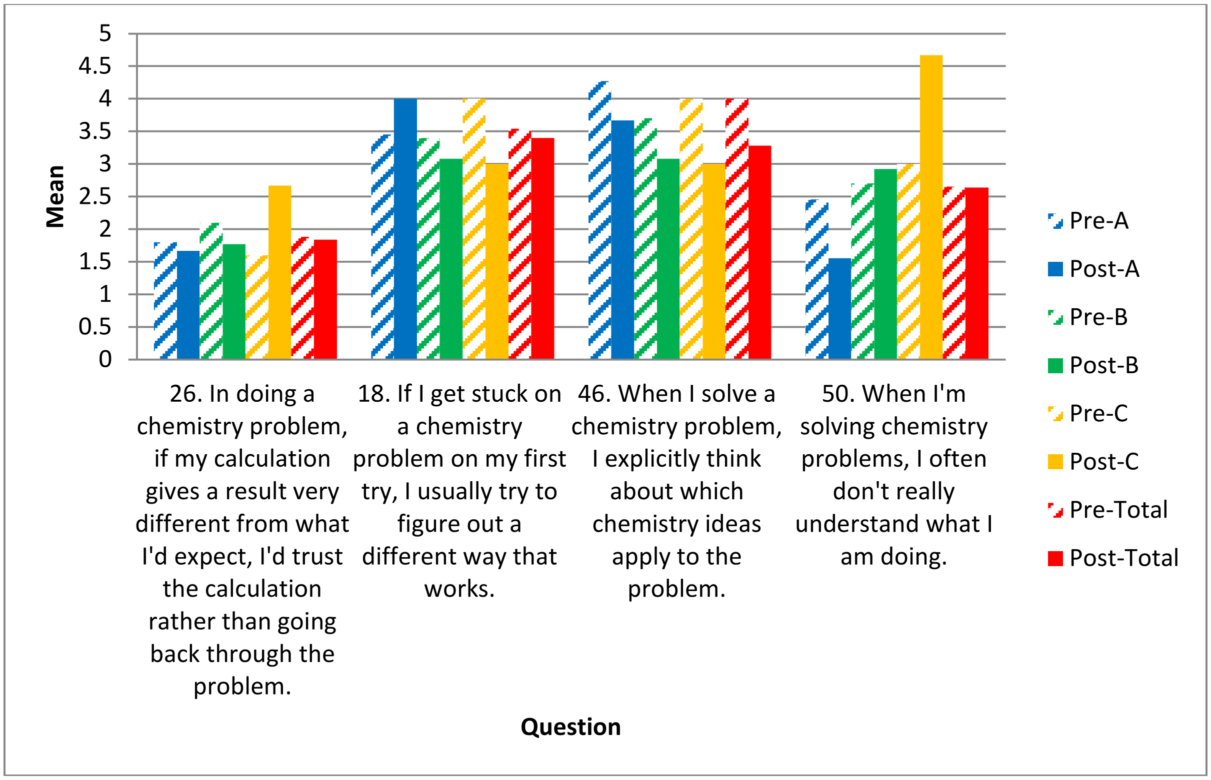

Figure 7. Problem Solving Question Data from CLAS Survey, (*N*=26).

CLAS data collected using questions concerning study skills and the role of memorization demonstrate a shift from rote learning and memorization to analysis as a strategy for problem solving. Students in all groups reported a decrease in the perception that memorization was sufficient for success in chemistry, and all the decreases were statistically significant (p value for entire study group = 0.077) (Figure 8). Though all the groups except for C also reported an increase in their percieved need for memorization, several interview comments demonstrate that these results are not contradictory. For instance, one group A student said, “It’s not about having to memorize facts, but you have to remember equations and how to use them, which is harder.” One group B student commented that “equations are hard to memorize, but once you understand the equation you can do all the problems, not just the one in the book.”

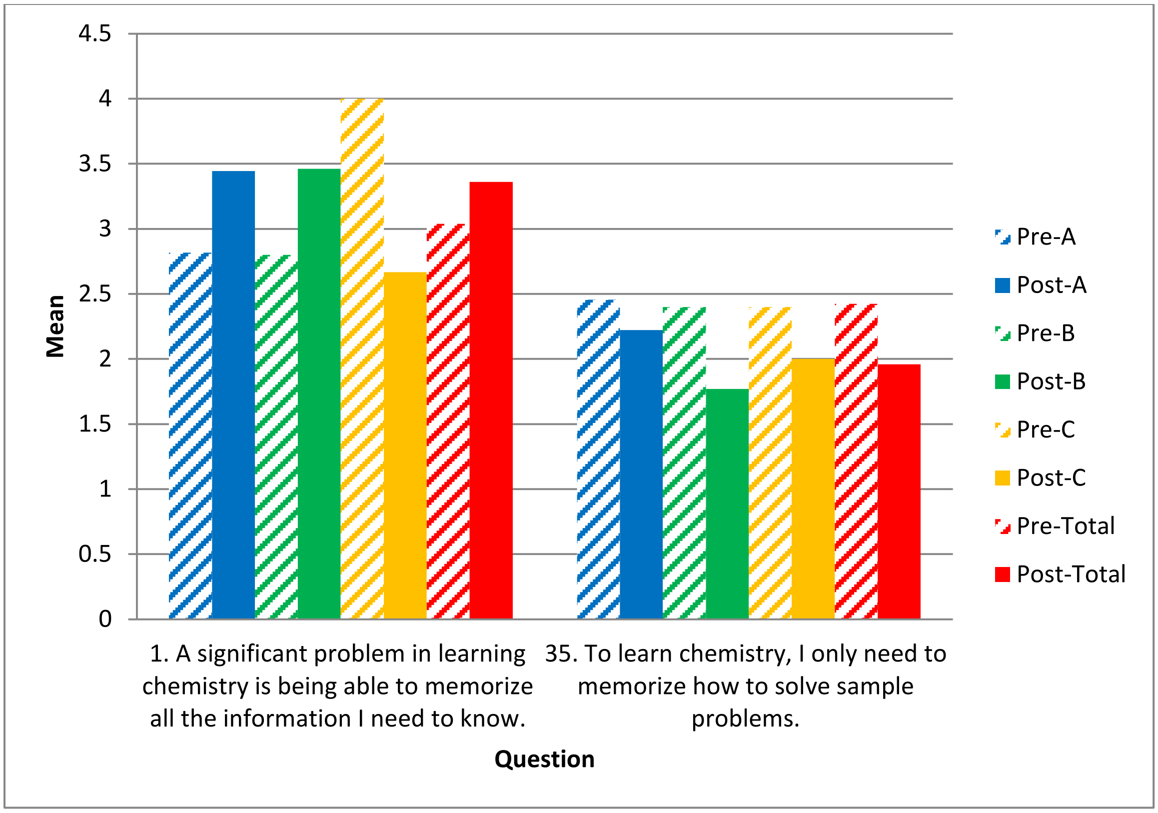

Figure 8. Memorization Question Data from CLAS Survey, (*N*=26).

Student study skills and strategies have also undergone some changes. Different groups have had different changes in study strategy. Students in Groups A and B have shifted to doing multiple problems to increase learning, while students in Group C have shifted in the direction of doing deeper analysis of fewer problems (Figure 9). The changes in groups A and C are both significant (p= 0.10 and 0.023 respectively). All three groups had statistically significant increases in their perception of the use of peer discussion as a learning tool (p value for entire study group = 0.052). During the interviews three students (two from group A and one from group B) mentioned practice problems as their best study tool. Two students mentioned the Proportions Project in specific as a source of practice problems which they had found useful for study.

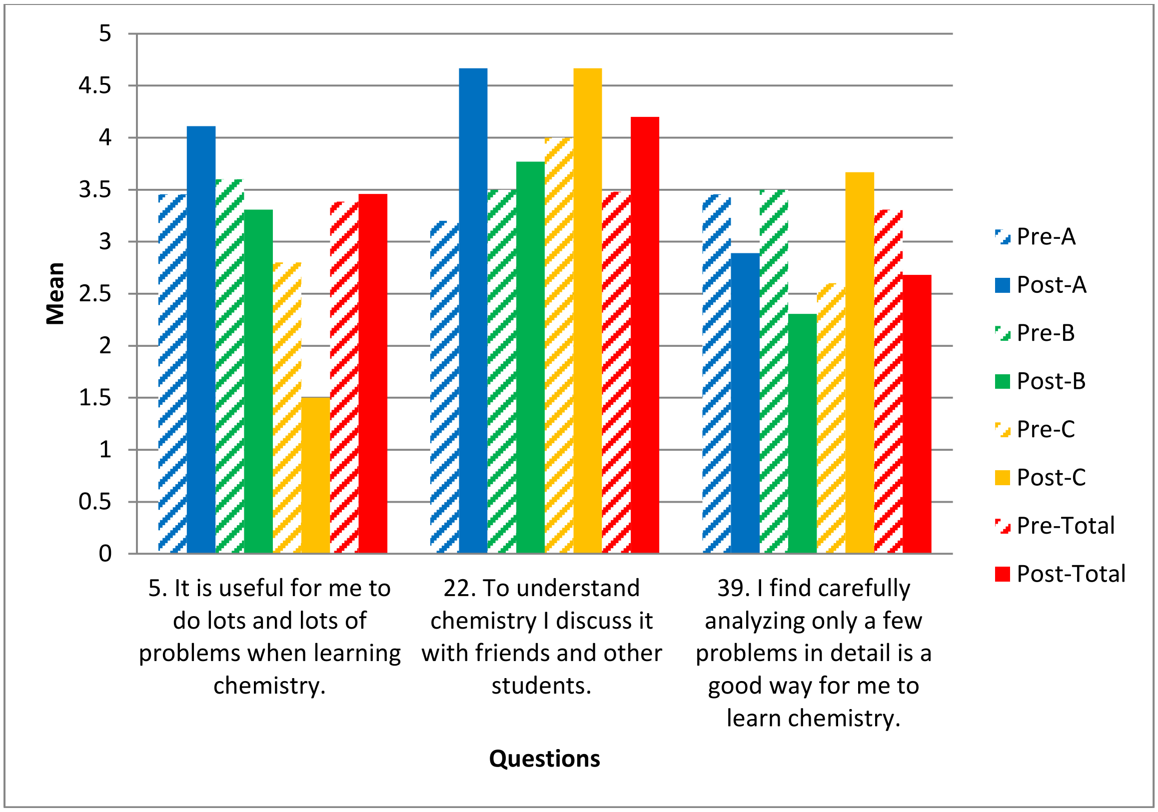

Figure 9. Study Skills Question Data from CLAS Survey, (*N*=26).

The activities conducted during the study period also had an effect on student perceptions of the relevance of chemistry to their daily lives. Students in groups A and B reported an increase in the relationships they recognized between chemistry and their real world experiences (Figure 10). Group A reported an increased ability to use reasoning skills from the chemistry classroom in their daily lives. Both group A changes were statistically significant (p=0.1). Group C found reasoning skills significantly and substantially less useful in daily life after the treatment, with a change of more than two points on the Likert scale (p=0.063). Group C students also had a significant shift in the perceived relevance of chemistry to their lives, which also changed by more than two Likert-scale units (p= 0.062). All the groups of students found by the end of the study period that understanding the behavior of chemicals in reactions was "a waste of time."

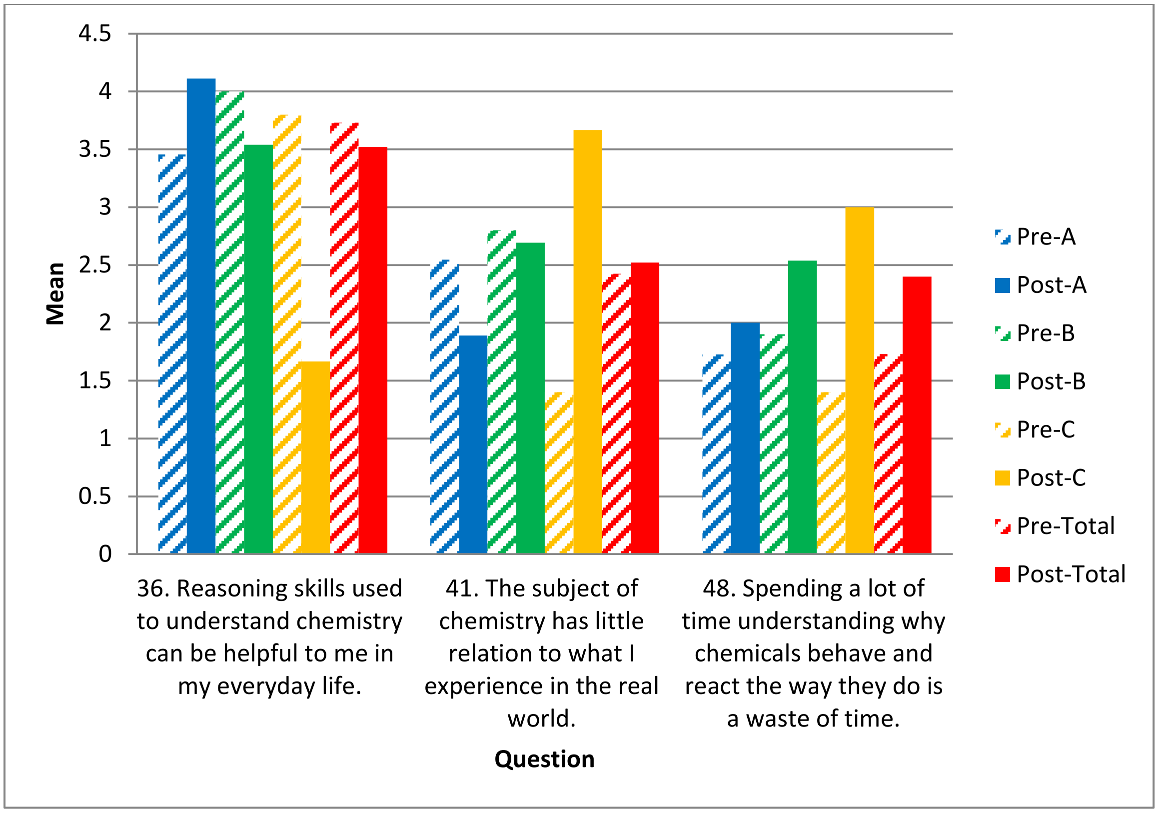

Figure 10. Relevance Question Data from CLAS Survey, (*N*=26).

Data from the CLAS survey highlights shifts in student use of mathematics in their understanding of chemical concepts. Students in groups A and B reported an increase in the use of the strategy of locating an equation by looking for one which relates the units and variables provided in the problem. Nine of the eleven students interviewed mentioned this strategy, including students from each of the three Groups. All of them listed it as "one of the hardest parts" of chemistry. They used words such as "applying the correct equation,", "translating and applying formulas" and "understanding what the question is asking…what math." Several of the students qualified their comments on the difficulty of this strategy by also mentioning that "It's hard, but it's critical," and "There's no way to understand chemistry without figuring out how to put the numbers in the formulas…you just have to learn it." The difference between pre and post treatment use of this strategy was statistically significant in groups A and B (p= 0.0092 and 0.092

respectively). The trend in group C was in the opposite direction, but was not significant ($p= 0.42$) (Figure 11).

Continuing the trend of students finding greater appilcation of their math knowledge in the chemistry classroom, students reported differences in their perception of the importance of mathematical formulas and equations in the study of chemistry. The increase of more than one point on the Likert scale in the group B responses is statistically significant ($p= .045$). All of the groups had significant shifts in their responses to the final two questions. Students are no longer as likely to believe that understanding formulas is a waste of time ($p= 0.015$), or that is is possible to explain chemical concepts without incorporating mathematical forumulas ($p= 0.042$). When asked specifically about their impressions of the Proportions Project, eight of eleven interviewed students, across all three groups had positive impressions. One student went so far as to reply to a question about the whether the project helped her to connect math with chemistry with “Totally. 100%” The remaining students (two from Group C and one from Group A) were neutral. None of the students considered the project to be a waste of time.

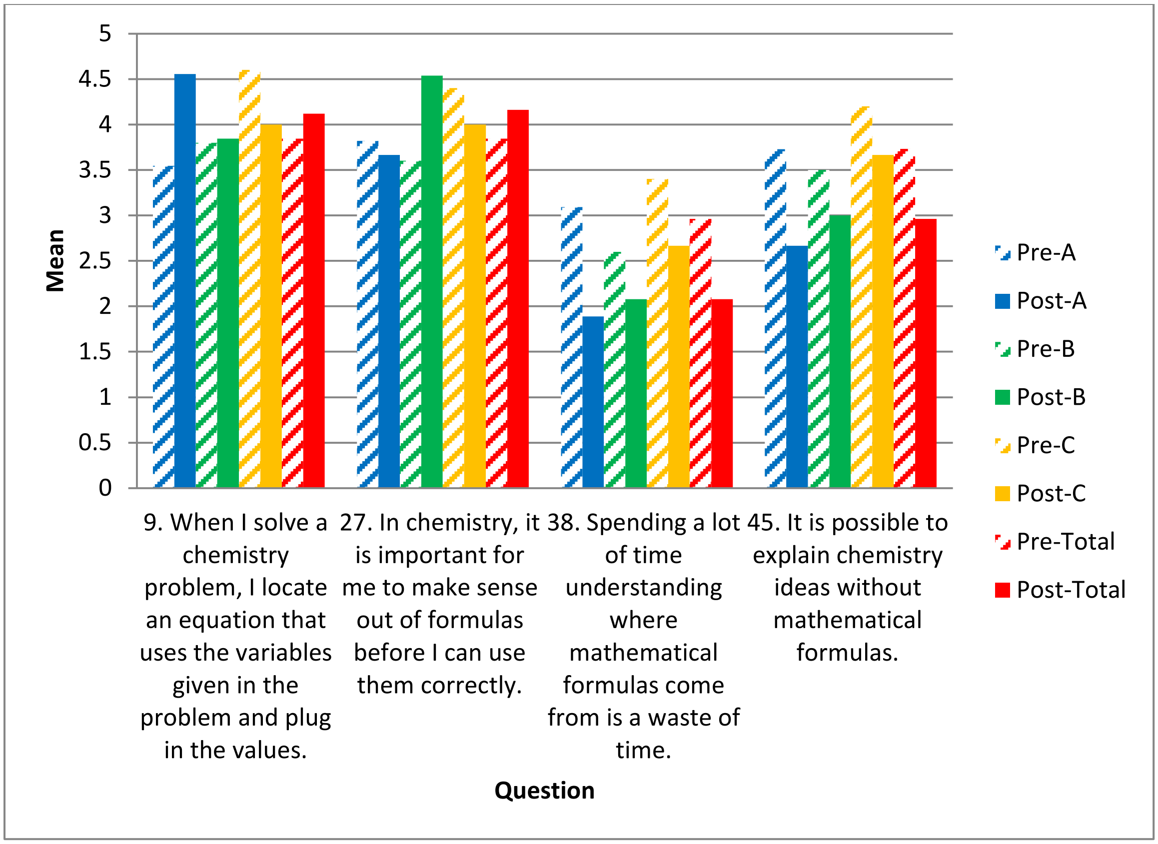

Figure 11. Mathematics Question Data from CLAS Survey, (*N*=26).

The data collected using the CLAS survey and the math assessments combined to reveal several important themes. All groups of students had an improved understanding of the importance of mathematics to the understanding of chemical principles. The students also improved in the mathematical skills which were directly covered by math and science teachers as part of the project treatment. For those questions which represented student attitudes, study skills, and the percieved relevance of chemistry to their lives, students in groups A and B showed development towards better critical thinking skills and more sucessful study habits. Students in group C showed either no trend or the opposite of the trends displayed in groups A and B.

INTERPRETATION AND CONCLUSION

The significant gains in skills as measured by the math assessment demonstrate that one of the main goals of the project was definitely met. The order of operations data serves as a good control to examine the data on proportions and unit conversions against, and the increases in both were substantial. These increases also translated into increased facility on homework assignments and tests, which involved these concepts. After consultation with the math faculty, we believe that the difference in improvement between the students in Group C and the rest of the students in the study is in large part related to effort. Many of these students are enrolled in chemistry only because the school did not give them a choice, and they are the students who said in interviews that they did not enjoy the course. Some of the students in Group C are hard workers who have learning differences or simply a very weak background in math. The rest are students who have displayed a pattern in previous coursework of doing just enough to get by. Their lack of motivation and investment in the project is demonstrated by the very small sample size for most of the instruments for group C. Many of the students, even with the offer of extra credit, were not motivated to turn in the survey or math assessment. I am disappointed with the fact that the study treatment did not have a more positive effect on the group C students, but after analyzing the data in its entirety and supplementing with interviews, I do not believe that was entirely due to weakness in the study treatment.

I do plan to continue to use this project, and I do plan to include increased scaffolding for the concepts covered, with additional help and information available in both math and science classes for weaker students. Hopefully in this way the problems with being “overwhelmed” and “lost” in the later portions of the unit expressed by several group C students can be minimized, and these students will be able to benefit from the same gains as their peers.

I believe that the lack of motivation of some group C students, combined with the learning disabilities and other weaknesses of many of the rest, caused the data for this group to be so inconsistent. These factors led to some of these students giving up partway through the project. A minority of group C students did show improvement, but still reported difficulties with understanding and application.

The integration of the math and chemistry curriculums to work on the Proportions Project was successful in increasing student competence on the math skills covered. It was also successful in improving understanding, study habits, and critical thinking skills in the majority of the students. The minority of students who did not show improvements had a variety of additional challenges to face, so their lack of improvement does not negate the positive impact of the treatment.

I was concerned to see the drop in the level of importance of the other aspects of chemistry reported by the students, such as atomic theory. I will endeavor next year to continue to emphasize other aspects more so that students do not come away with the mistaken impression that mathematics is the only important skill for success in chemistry.

VALUE

The main lesson I learned in the process of doing this research project was the power of focused teaching. Focusing instruction on a certain aspect or portion of the curriculum can have simultaneous positive and negative consequences. In my study, the students became better at the tasks and skills I had asked them to focus on, but unexpectedly lost proficiency at other skills, which they had previously mastered. They also picked up the attitude that the mathematical skills which were a subject of focus were much more important than other skills, and that they could use less attention for other portions of the curriculum.

During the project, I also learned valuable lessons about time management, both of student time and my own. For instance, both the students and I quickly became overwhelmed when faced with multiple portions of a long term project at once either to complete or to grade. It ended up working best to distribute and collect a single portion of the project without moving on to the next. It was also too hard to have multiple large assignments out at once, so I ended up using a strategy where I alternated lab reports with portions of the Proportions Project.

I feel that this study has helped me to improve my focus as a teacher and my ability to correlate what I am teaching the students with what I actually want them to know and what I am testing them on. Some things I still need to work on are time management for large projects and being sure not to focus on one area of study to the point where students perceive less importance attached to others.

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APPENDICES

APPENDIX A

INTERVIEW QUESTIONS

Interview Questions – Pre-Treatment Interviews

1. Do you like science class?
2. Do you like chemistry more, less, or the same amount as the sciences you have taken in the past?
    a. Why?
3. Do you think that you are good at science?
    a. At chemistry?
4. What do you think is the hardest part of chemistry?
5. What do you think is the easiest part?
6. Do you like math class?
7. What math class are you currently in?
8. Do you think you are good at math?
9. Do you think the parts of chemistry which use math are harder, easier, or the same as the other parts of the class?
    a. Why?
10. How much of the math we have done in chemistry class have you recognized from your math classes in the past?
    a. Can you give any specific examples?
11. What math class do you remember learning things that we have used this year in chemistry?
    a. Can you give any specific examples?
12. Is there anything I could do that would help you feel more comfortable with the math we use in class?
13. Is there anything else you would like to tell me?

Interview Questions – Post-Treatment Interviews

1. Do you like science class?
2. Do you like chemistry more, less, or the same amount as the sciences you have taken in the past?
    a. Why?
3. Do you think that you are good at science?
    a. At chemistry?
4. What do you think is the hardest part of chemistry?
5. What do you think is the easiest part?
6. Do you like math class?
7. What math class are you currently in?
8. Do you think you are good at math?
9. Do you think the parts of chemistry which use math are harder, easier, or the same as the other parts of the class?
    a. Why?
10. How much of the math we have done in chemistry class have you recognized from your math classes in the past?
    a. Can you give any specific examples?
11. What math class do you remember learning things that we have used this year in chemistry?
    a. Can you give any specific examples?
12. Did you find the work you did with your math teacher on the proportions project helped you connect math and chemistry better?
13. Is there anything else you would like to tell me?

APPENDIX B

COLORADO LEARNING ATTITUDES ABOUT SCIENCE SURVEY-CHEMISTRY

Name:______________________ (This will be used to compare this survey to other results and to give you extra credit points, but this survey will have NO EFFECT on your grade.)

Introduction

Here are a number of statements that may or may not describe your beliefs about learning chemistry.

You are asked to rate each statement by circling a number between 1 and 5 where the numbers mean the following:

1. Strongly Disagree
2. Disagree
3. Neutral
4. Agree
5. Strongly Agree

Choose one of the above five choices that best expresses your feeling about the statement. If you don't understand a statement, leave it blank. If you understand, but have no strong opinion, choose 3.

Survey

1. A significant problem in learning chemistry is being able to memorize all the information I need to know. Strongly Disagree 1 2 3 4 5 Strongly Agree

2. To understand a chemical reaction, I think about the interactions between atoms and molecules. Strongly Disagree 1 2 3 4 5 Strongly Agree

3. When I am solving a chemistry problem, I try to decide what would be a reasonable value for the answer. Strongly Disagree 1 2 3 4 5 Strongly Agree

4. I think about the chemistry I experience in everyday life.
Strongly Disagree 1 2 3 4 5 Strongly Agree

5. It is useful for me to do lots and lots of problems when learning chemistry.
Strongly Disagree 1 2 3 4 5 Strongly Agree

6. After I study a topic in chemistry and feel that I understand it, I have difficulty solving problems on the same topic. Strongly Disagree 1 2 3 4 5 Strongly Agree

7. Knowledge in chemistry consists of many disconnected topics.
Strongly Disagree 1 2 3 4 5 Strongly Agree

8. As chemists learn more, most chemistry ideas we use today are likely to be proven wrong.
Strongly Disagree 1 2 3 4 5 Strongly Agree

9. When I solve a chemistry problem, I locate an equation that uses the variables given in the problem and plug in the values.
Strongly Disagree 1 2 3 4 5 Strongly Agree

10. I find that reading the text in detail is a good way for me to learn chemistry.
Strongly Disagree 1 2 3 4 5 Strongly Agree

11. I think about how the atoms are arranged in a molecule to help my understanding of its behavior in chemical reactions.
Strongly Disagree 1 2 3 4 5 Strongly Agree

12. If I have not memorized the chemical behavior needed to answer a question on an exam, there's nothing much I can do (legally!) to figure out the behavior.
Strongly Disagree 1 2 3 4 5 Strongly Agree

13. I am not satisfied until I understand why something works the way it does.
Strongly Disagree 1 2 3 4 5 Strongly Agree

14. I cannot learn chemistry if the teacher does not explain things well in class.
Strongly Disagree 1 2 3 4 5 Strongly Agree

15. I do not expect equations to help my understanding of the ideas in chemistry; they are just for doing calculations. Strongly Disagree 1 2 3 4 5 Strongly Agree

16. I study chemistry to learn knowledge that will be useful in my life outside of school.
Strongly Disagree 1 2 3 4 5 Strongly Agree

17. I can usually make sense of how two chemicals react with one another.
Strongly Disagree 1 2 3 4 5 Strongly Agree

18. If I get stuck on a chemistry problem on my first try, I usually try to figure out a different way that works. Strongly Disagree 1 2 3 4 5 Strongly Agree

19. Nearly everyone is capable of understanding chemistry if they work at it.
Strongly Disagree 1 2 3 4 5 Strongly Agree

20. Understanding chemistry basically means being able to recall something you've read or been shown. Strongly Disagree 1 2 3 4 5 Strongly Agree

21. Why chemicals react the way they do does not usually make sense to me; I just memorize what happens. Strongly Disagree 1 2 3 4 5 Strongly Agree

22. To understand chemistry I discuss it with friends and other students.
Strongly Disagree 1 2 3 4 5 Strongly Agree

23. I do not spend more than five minutes stuck on a chemistry problem before giving up or seeking help from someone else.
Strongly Disagree 1 2 3 4 5 Strongly Agree

24. If I don't remember a particular equation needed to solve a problem on an exam, there's nothing much I can do (legally!) to come up with it.
Strongly Disagree 1 2 3 4 5 Strongly Agree

25. If I want to apply a method used for solving one chemistry problem to another problem, the problems must involve very similar situations.
Strongly Disagree 1 2 3 4 5 Strongly Agree

26. In doing a chemistry problem, if my calculation gives a result very different from what I'd expect, I'd trust the calculation rather than going back through the problem.
Strongly Disagree 1 2 3 4 5 Strongly Agree

27. In chemistry, it is important for me to make sense out of formulas before I can use them correctly. Strongly Disagree 1 2 3 4 5 Strongly Agree

28. I enjoy solving chemistry problems.
Strongly Disagree 1 2 3 4 5 Strongly Agree

29. When I see a chemical formula, I try to picture how the atoms are arranged and connected.
Strongly Disagree 1 2 3 4 5 Strongly Agree

30. In chemistry, mathematical formulas express meaningful relationships among measurable quantities. Strongly Disagree 1 2 3 4 5 Strongly Agree

31. We use this statement to discard the survey of people who are not reading the questions. Please select agree (not strongly agree) for this question.
Strongly Disagree 1 2 3 4 5 Strongly Agree

32. It is important for the government to approve new scientific ideas before they can be widely accepted. Strongly Disagree 1 2 3 4 5 Strongly Agree

33. The arrangement of the atoms in a molecule determines its behavior in chemical reactions. Strongly Disagree 1 2 3 4 5 Strongly Agree

34. Learning chemistry changes my ideas about how the world works.
Strongly Disagree 1 2 3 4 5 Strongly Agree

35. To learn chemistry, I only need to memorize how to solve sample problems.
Strongly Disagree 1 2 3 4 5 Strongly Agree

36. Reasoning skills used to understand chemistry can be helpful to me in my everyday life. Strongly Disagree 1 2 3 4 5 Strongly Agree

37. In learning chemistry, I usually memorize reactions rather than make sense of the underlying physical concepts. Strongly Disagree 1 2 3 4 5 Strongly Agree

38. Spending a lot of time understanding where mathematical formulas come from is a waste of time. Strongly Disagree 1 2 3 4 5 Strongly Agree

39. I find carefully analyzing only a few problems in detail is a good way for me to learn chemistry. Strongly Disagree 1 2 3 4 5 Strongly Agree

40. I can usually figure out a way to solve chemistry problems.
Strongly Disagree 1 2 3 4 5 Strongly Agree

41. The subject of chemistry has little relation to what I experience in the real world.
Strongly Disagree 1 2 3 4 5 Strongly Agree

42. There are times I solve a chemistry problem more than one way to help my understanding.
Strongly Disagree 1 2 3 4 5 Strongly Agree

43. To understand chemistry, I sometimes think about my personal experiences and relate them to the topic being analyzed. Strongly Disagree 1 2 3 4 5 Strongly Agree

44. Thinking about a molecule's three-dimensional structure is important for learning chemistry. Strongly Disagree 1 2 3 4 5 Strongly Agree

45. It is possible to explain chemistry ideas without mathematical formulas.
Strongly Disagree 1 2 3 4 5 Strongly Agree

46. When I solve a chemistry problem, I explicitly think about which chemistry ideas apply to the problem. Strongly Disagree 1 2 3 4 5 Strongly Agree

47. If I get stuck on a chemistry problem, there is no chance I'll figure it out on my own.
Strongly Disagree 1 2 3 4 5 Strongly Agree

48. Spending a lot of time understanding why chemicals behave and react the way they do is a waste of time. Strongly Disagree 1 2 3 4 5 Strongly Agree

49. When studying chemistry, I relate the important information to what I already know rather than just memorizing it the way it is presented.
Strongly Disagree 1 2 3 4 5 Strongly Agree

50. When I'm solving chemistry problems, I often don't really understand what I am doing. Strongly Disagree 1 2 3 4 5 Strongly Agree

APPENDIX C

PURE MATH ASSESSMENT

Pure Math Assessment

Solve the problems below to the best of your ability. Please show work wherever possible.

1. (6+5)7 =

2. $24/2^3$ =

3. $7^3/2^4$ =

4. 4(3/2)+10 =

5. Using the formula F = (9/5)C+32, convert 35 degrees C to degrees F

6. Describe the rule for the order of operations.

Solve for x:

7. 5x+2 = 22

8. (18+x)/3 =5

9. 24/x = 6

10. Y = 12, z = 3, 6x+2z = y/4

11. Describe the basic procedure involved in solving for x:

Using the equation AB = CDE, solve for the missing variable:

12. A = 5, B = 7, C = 3, E = 4

13. B = -3, C = 1/3, D = 2, E = 5

Solve the problems below

14. Bob is twice as old as Cynthia, who is 4 years younger than Alice. Alice just turned 10. How old is Bob?

15. Apples cost three times as much as pears and pears are half the price of bananas. If you can afford 10 bananas, how many apples could you afford if you chose to buy those instead?

16. If a formula reads q*r = s and the units for q are liters and the units for s are minutes, what are the units for r?

17. If a/b = c, a = 4.5g, and c = 9 g/mL, what is b? Make sure to include units.

18. 4 blobs = 3 cubes. 1 cube = 2 triangles. How many blobs are equal to 12 triangles?

19. There are 24 hours in a day and 28 days in a lunar cycle. How many lunar cycles will have passed in 2048 hours?

20. Put the following numbers in scientific notation.

    0.00763

    43200

    29.41

21. Define the following terms in your own words:

    Equation:

    Variable:

    Coefficient:

    Logarithm:

    Constant:

APPENDIX D

MATHEMATICS IN CONTEXT ASSESSMENT

Math in Context Assessment

Solve the problems below to the best of your ability. Please show work wherever possible.

1. (6+5)7 =

2. $24/2^3$ =

3. $7^3/2^4$ =

4. 4(3/2)+10 =

5. Using the formula F = (9/5)C+32, convert 35 degrees C to degrees F

Solve for x:

6. 5x+2 = 22

7. (18+x)/3 =5

8. 24/x = 6

9. Y = 12, z = 3, 6x+2z = y/4

10. Describe the basic procedure involved in solving for x:

Using the equation PV = nRT, solve for the missing variable:

11. P = .87atm, V = ?, n = 1.24 mol, R = .0821Latm/molK, T = 302K

12. P = 1.5 atm, V = 2.5 L, n = ?, R + .0821Latm/molK, T = 298K

Solve the problems below

13. If one box contains three moles of aluminum atoms (mass ~27amu), and another box contains two moles of manganese atoms (mass ~55amu), which box is heavier?

14. The amount of TV you watch and the amount of power you use are directly proportional. If you watch 3 hours of TV, you use 60kW. How much power does it use to watch 5 hours of TV?

15. If a formula reads q*r = s and the units for q are liters and the units for s are minutes, what are the units for r?

16. If a/b = c, a = 4.5g, and c = 9 g/mL, what is b? Make sure to include units.

17. 1 mole of sodium chloride weighs 58.44 grams. There are 6.02*10^23 units in a mole. How many sodium chloride units are in 10.0g?

18. There are 24 hours in a day and 28 days in a lunar cycle. How many lunar cycles will have passed in 2048 hours?

APPENDIX E

PROPORTIONS PROJECT

Chemistry/Math Proportions Project

Part One: Direct Proportions

For this part of the project, you will need to come up with two relationships in your daily life that are directly proportional. Some examples:

The number of stairs in a flight is proportional to the height of the staircase

The number of pages in a book is proportional to the thickness of the book

You need to come up with two examples that you can measure directly.

Collect 10 data points for each of your two examples. Use these points to create a graph.

Is your graph a straight line? If not, why? How can you collect new data so the graph will be a straight line?

From the graph, what is the constant of proportionality of each sample? What does this represent in the real world? (For example, in a rain gauge, the proportionality constant represents the area)

Construct an equation for each of your proportional relationships, and create a "math triangle" to help others use each of your relationships.

Part Two: Direct and Inverse Variation Name: ________________________

Inverse and Direct Variation

Tell whether *x* and *y* show direct variation, inverse variation, or neither.

1. $y = 2x + 3$
2. $y = \frac{x}{3}$
3. $x = \frac{3}{y}$
4. $xy = 2$

Determine whether *x* and *y* show *direct variation, inverse variation,* or *neither*. Graph the points from the t-charts and tell whether your graphs agree with your conclusion from the t-charts.

5.

x	**1**	**2**	**3**	**4**
y	**1**	**4**	**9**	**16**

6.

x	**2**	**5**	**8**	**15**
y	**60**	**24**	**15**	**8**

7.

x	**1**	**4**	**7**	**10**
y	**7.5**	**30**	**52.5**	**75**

Boyle's Law states that for a constant temperature, the pressure *p* of a gas varies inversely with its volume *V.* A sample of oxygen gas has a volume of 50.25 cubic milliliters at a pressure of 20.6 atmospheres.

8. Write an equation that relates *p* and *V*.

9. Find the constant of variation *k*.

10. Find the volume of the oxygen gas if the pressure changes to 15.2 atmospheres.

Chemistry/Math Project Part Three: Proportions and the Ideal Gas Law

You will be using the method described on the sheet "Measuring the Ideal Gas Constant" to determine a value for R. Copy your data from that sheet to your project. Also copy down the ideal gas law and the combined gas law. Make sure to show ALL of your work for the steps below.

1. Convert all of the data you collected into appropriate units. (atm, K, L, and mol). You will need to calculate the molar mass of butane to do this. Look up the formula for butane, then use the periodic table to calculate the mass of one mole. Use this number to convert grams to moles.

2. Correct your pressure data for the water vapor in the graduated cylinder (subtract the vapor pressure of water, found on the table on the reverse, from the atmospheric pressure)

3. Use the combined gas law to correct your volume data to standard temperature and pressure (1 atm and 273 K)

4. Use the corrected data to calculate a value for 'R"

5. The accepted value for R is 0.0821 L*atm/K*mol. Calculate your percent error, including the sign. (Was your value too big or too small?)

6. If you had forgotten to correct for the water vapor in the graduated cylinder, would your calculated R value be too large or too small? Explain in terms of proportional relationships.

7. If you had not corrected your temperature to STP using the combined gas law, would your value for R be too large or too small? Explain in terms of proportional relationships.

8. List at least two experimental errors that could have caused your calculated value of R to differ from the accepted value. Be sure to pay attention to how each error would cause your value to be either too small or too large.

Temperature	Vapor Pressure
oC	of Water (atm)
10	0.012
11	0.013
12	0.014
13	0.015
14	0.016
15	0.017
16	0.018
17	0.019
18	0.020
19	0.022
20	0.023
21	0.025
22	0.026
23	0.028
24	0.029
25	0.031
26	0.033
27	0.035
28	0.037
29	0.040
30	0.042
31	0.044
32	0.047
33	0.050
34	0.052
35	0.055
36	0.059
37	0.062
38	0.065
39	0.069
40	0.073
41	0.077

Part 4: Unit Conversion Problems

Level 1 problems
Convert 14.7 inches to feet

Convert 32.91 feet to inches

Convert $43.50 to yuan (look this one up)

Convert 225 miles to km

Convert 23,200 nm to dm

Convert 24.3 g to oz

Convert 400m to ft

Level 2 Problems

Convert 59.5 km to feet

Convert 1 week to seconds

Convert 2.3 gallons to fluid ounces

Convert 350 grams to pounds

Convert 62.5 kJ to calories (look this one up)

Convert 8800 ft. to furlongs

Convert 6 cups to mL

Level 3 Problems

Convert 45 mph to meters/sec

Convert 4.2 L/min to quarts/hour

Convert 45 in^2 to m^2

Convert 2.5 L to m^3

Convert 6.5 m^2/min to $miles^2$/day

US/IMPERIAL

Length	**Area**	**Capacity**	**Weight**
1 mile = 5280 feet 1 mile = 1760 yards 1 mile = 8 furlong 1 furlong = 10 chains 1 chain = 4 rods 1 rod = 5 1/2 yards 1 yard = 3 feet 1 foot = 12 inches	1 sq. mile = 640 acres 1 acre = 4840 sq. yards 1 sq. yard = 9 sq. feet 1 sq. foot = 144 sq. inches	1 gallon = 4 quarts 1 quart = 2 pints 1 pint = 2 cups 1 pint = 16 fl. oz. 1 cup = 8 fl. oz. 1 yard^3 = 27 feet^3 1 foot^3 = 1728 inches^3	1 US ton = 2000 lb. 1 stone = 14 lb. 1 lb. = 16 oz. 1 oz. = 16 drams 1 oz. = 437.5 grains *1 UK ton = 2240 lb.* *1 UK ton = 1.12 US ton*

US/IMPERIAL to METRIC

Length	**Area**	**Capacity**	**Weight**
1 mile = 1.609 km 1 yard = 0.9144 m 1 foot = 0.3048 m 1 inch = 25.4 mm	1 sq. mile = 2.59 km^2 1 acre = 0.4047 hectares 1 acre = 4046.86 m^2 1 sq. yard = 0.8361 m^2 1 sq. foot = 0.0929 m^2 1 sq. inch = 645.16 mm^2	1 gallon = 3.7854 litres 1 pint = 0.4732 litres 1 cu. inch = 16.3871 cm^3	1 US ton = 0.9072 metric tonnes 1 lb. = 0.4536 kg 1 oz. = 28.3495 g *1 UK ton = 1.016 metric tonnes*

METRIC PREFIXES

tera	T	10^{12} = 1,000,000,000,000
giga	G	10^{9} = 1,000,000,000
mega	M	10^{6} = 1,000,000
kilo	k	10^{3} = 1,000
hecto	h	10^{2} = 100
deka	da	10^{1} = 10
deci	d	10^{-1} = 0.1
centi	c	10^{-2} = 0.01
milli	m	10^{-3} = 0.001
micro	µ	10^{-6} = 0.000,001
nano	n	10^{-9} = 0.000,000,001

Part Five: Molar Unit Conversions and Stoichiometry

You and your partner will be assigned an insoluble compound. You will be provided with a variety of molarities of solutions of several soluble compounds. Your mission is to create EXACTLY 2 grams of your target compound.
On a separate sheet:

1. Choose which soluble compounds you will combine

2. Write a balanced equation for the formation of your target compound

3. Calculate how much of each solution you will need to combine to create EXACTLY 2 grams of target compound. Show your work (hint: This will require several conversion factors as well as the balanced equation).

4. Once the teacher has approved your calculations, you may measure out your amounts, mix them, and put your compound in a pre-weighed container to be dried.

5. Return and mass your compound after it has dried. Calculate a percent yield for your experiment.

6. Write a paragraph explaining any errors that might have occurred in this lab that could prevent your percent yield from being 100%. Be sure to include discussion of the direction of each possible error.