THE EFFECTS OF EXPLICIT MATH INSTRUCTION BEFORE CHEMISTRY CONTENT INSTRUCTION AT THE HIGH SCHOOL LEVEL

by

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DEDICATION

This paper is dedicated to Andrew Latincsics whose life serves as a model for the gold standard of being a science teacher. Andrew was a mentor to many teachers including myself and his tragic departure from this world shook an entire community. It was my honor to take over his course load and help a school transition and heal. Andy's memory lives on in my science teaching and I have been blessed to grow with the MSSE program to strive to be the teacher that Andy was.

This paper is also dedicated to my wife Lianne Kulik who supported me through my academic journey. Lianne helped me stay focused on assignments when I wanted to give up and has been the single most positive influence in my life. I love you Lianne.

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ABSTRACT

Students struggle with the mathematical nature of chemistry coursework. This study looks to examine how the performance of high school students taking chemistry is affected by a curricular change to include mini math units between traditional chemistry units of study. Students were exposed to approximately a day and a half of explicit instruction on the mathematical concepts that would appear in the upcoming chemistry unit. Student confidence in mathematics, pre and post mathematics test scores, and chemistry unit test scores were analyzed to determine if the treatment improved student performance or not.

INTRODUCTION AND BACKGROUND

I have been teaching chemistry for seven years ranging from special education chemistry classes in a special education high school, inclusion classrooms, college preparatory chemistry and honors chemistry classes in traditional public high schools, and college preparatory and honors chemistry classes in a magnet vocational high school. Over my emerging career, I've seen students at all levels and with all different backgrounds struggle with the mathematical nature of chemistry.

My employment during the 2018-2019 school year was at a traditional, comprehensive high school in central New Jersey. Old Bridge High School had 2817 students from diverse backgrounds. Over fifty nationalities were represented during this school year. Students came from all walks of life but the community is largely blue collar located thirty five miles outside of New York City. I had an annual teaching load of four six-credit chemistry courses at both the honors and college preparatory level. Both courses required prerequisite grades from biology but no prerequisite grade was needed from a mathematics course. The math work concurrently completed by my students ranged from fundamentals of math enrichment classes to algebra I, geometry, algebra 2, and pre-calculus at both the college prep and honors levels.

My focus in completing this study was on a potential strategy to address math skills in the classroom to help students succeed in chemistry. My action research project focused on a treatment of supplemental math lessons before traditional units of study in chemistry to attempt to address the underlying mathematical reasoning behind chemical concepts. The attempt was to see if the supplemental math instruction increased student performance and student confidence in chemistry topics that had a math basis.

CONCEPTUAL FRAMEWORK

The 18th century mathematician Carl Friedrich Gauss said “mathematics is the queen of the sciences.” While mathematics has a hand in all forms of biological and physical science, this study looked at the connections between mathematics and chemistry. Specifically, this study focused on the abilities and success of high school students to answer chemistry questions with an underlying basis in mathematics. This framework will begin with a review of articles showing the current state of high school and undergraduate chemistry courses in order to provide an idea of how mathematics has been treated and perceived in the classroom. This framework will focus on evaluations at the college level of incoming students’ abilities, then an analysis of factors contributing to student success in the classroom, and last, will move to the current pedagogy in high school chemistry classrooms. The framework will then focus on strategies being employed at different levels of education to improve student abilities in mathematics and chemistry.

Fraser Scott (2012) asked the question “Is mathematics to blame?” while exploring the ability of students to answer mathematically based chemistry questions and pure mathematical questions. Scott based his research on a 1971 mathematics skill test for chemistry that identified ten fundamental mathematical skills high school students were expected to perform. These skills included computation, use of parentheses, signed number usage, use and manipulation of fractions, use of decimals, use of exponents, manipulation of numbers with exponents and logarithmic equivalence, use of percentages, manipulation of one-variable equations, use of ratios and proportions, and producing and interpreting graphs (Denny, 1971).

Scott (2012) set up two separate tests to be taken by students. The first set included eight chemistry questions including topics like the mole concept and chemical reactions.

> This set of chemistry questions was used to develop an analogous set of mathematical questions in which the numerical complexity was similar but the chemistry context had been replaced with that which could be found in a Standard Grade Mathematics setting (p. 331).

The second set included eight questions that were purely mathematics questions but used similar setups to the chemistry questions from the first set. Students correctly answered more mathematics questions than chemistry questions. On average, each analogous mathematical question had between five to ten percent higher correct answers than the chemistry question. The biggest contrast came in the seventh and eighth chemistry questions which corresponded with the fifth mathematical question. All focused on the topic of stoichiometry. The mathematical questions had 65% correct answers while the chemistry questions had 40% and 25% correct answers respectively for questions seven and eight (Scott, 2012). More students answered the harder math questions correctly but there was little evidence of any partial credit for students who answered these questions incorrectly. There was a large amount of partial credit on the harder chemistry questions for students who answered incorrectly. Scott points out “there is a tendency for the students to get the hard mathematics question either correct or incorrect; whereas, with the hard chemistry questions the students appear to be able to demonstrate some evidence of understanding" (Scott, 2012, p 335).

Scott attributed the algorithmic nature of the mathematics questions and the repetitious delivery of instruction to why students scored higher on the pure mathematics questions. While analyzing the chemistry questions Scott (2012) noted

> the ability of the first cohort of students to utilize a number of different strategies to obtain a solution to the chemistry questions but using only one method in solving the maths question suggests that a fuller grasp of the chemistry, rather than the mathematics, may be present (p 336).

In the United Kingdom a study was conducted to determine how well A-level mathematics courses prepared students for the demands of a chemistry degree (Darlington, & Bowyer, 2016). A-level mathematics courses are an advanced level for typical 18 year old students and allow the students to choose their own sequence of topics after completing four mandatory modules in mathematics. Students can chose from statistics, mechanics, and decision mathematics after completing the pure mathematics modules. Through a survey, the researchers found that over 60% of students reported that the pure mathematics was very useful preparation for chemistry coursework. The survey also found that 82.8% of students who had taken the mechanics modules reported it was either very useful or somewhat useful and 65.8% of students who had taken the statistics modules reported it was either very useful or somewhat useful in preparation for chemistry coursework (Darlington, & Bowyer, 2016). While the majority of students who completed A-level mathematics courses reported the coursework prepared them for the rigors of a chemistry program, not all universities require A-level mathematics as an entry requirement for undergraduate coursework. "However, the majority of the highest-performing institutions [required] an A or B grade in A-level mathematics, with some listing it as a 'preferred' rather than compulsory subject" (Darlington, & Bower, 2016, p 1192).

Villafane and Lewis (2016) explored the attitudes of undergraduates enrolled in introductory chemistry classes during the fall of 2010 by administering a survey using the Test of Science-Related Attitudes (TORSA). They looked at normality of science, attitudes toward inquiry, and career interest in science. After students completed the survey at the beginning of the semester, they then took the American Chemical Society (ACS) chemistry exam at the end of the semester. Students' prior SAT math scores were also included. Villafane and Lewis analyzed the TORSA results along with the ACS chemistry exam results and the reported SAT math scores. While trends could be shown such as women responding higher to the normality of science and the lifestyle of science careers, the students' TORSA scores proved insignificant in predicting the students success on the ACS exam. However prior math scores predicted the biggest achievement on the ACS exam, even when looking across all demographics including sex and race. (Villafane & Lewis, 2016).

In regards to the high school data, the National Education Longitudinal Study (NELS) analyzed connections between high school content in chemistry and the connection to success in college sciences (Tai, Sadler, & Loehr, 2005). One topic noted as correlating with higher levels of success at the college level was the topic of stoichiometry. The more exposed a student was to stoichiometry in high school the better that same student performed in college science classes. Not all topics saw this trend as topics like nuclear chemistry showed a negative correlation. Tai argued that a topic like nuclear chemistry might infer that a teacher rushed through topics to cover more breadth and didn't spend enough time practicing earlier material. Tai's interpretation of the NELS data also showed that while there was no significant correlation between the types of science classes students took in high school and their success in college, students who took calculus in high school scored higher in biology, chemistry, and physics courses at college level, which indicated that calculus may prepare students for more rigorous coursework in college (Tai, Sadler, & Loehr, 2005).

With mathematics abilities appearing as a predictor of student success in chemistry, it is important to look at ways in which schools and educators have attempted to improve the mathematical abilities of students in chemistry.

One potential method to improve mathematics ability is supplementing coursework. Several college physics programs include a mathematical methods course as part of their program and some chemistry departments have begun to add such a course. The idea behind offering a mathematical methods course is less focused on refreshing previously learned mathematical material and more focused on the mathematics involved in the chemistry topics (Arnaud, 2011). These courses exist at Cornell University, University of Southern California, University of Arizona, and Purdue University. A supplemental mathematical methods course is rare at the college level and research is lacking on this course's effectiveness (Arnaud, 2011).

A study was conducted during the 2014-2015 school year at the University of Queensland where students in an introductory chemistry course were offered an online math skills support class (Johnston, Watters, Brown, & Loughlin, 2016). The online math skills support class was supplemental and not required of students. The support class was developed by academic staff members and with input from math tutors to reflect math topics students consistently struggled with. The support class was broken in modules so students could access any part at their choosing. Students in the chemistry course were surveyed and the online data from the math skills support class was made available and analyzed. The website data showed that most students logged into the support class in the periods of time directly before a mid-term examination. The website data also showed that the majority of students who logged in, logged in five or fewer times over the course of the semester. A small portion of the students who identified as consistently logging into the support class logged in over 40 times during the semester. This group showed a higher final grade average, with a larger percentage of students receiving credit for the course when compared against the entire class (Johnston, Watters, Brown, & Loughlin, 2016).

Supplemental math material has been shown to improve student performance but hasn't been the only attempt to improve student performance in chemistry class work. Researchers have also looked at instructional strategies to see if student performance could be increased.

Srougi and Miller (2018) studied the effects of peer learning on math skills in introductory chemistry laboratories over the fall of 2015 and 2016. Ten sections of chemistry laboratories among four different professors at the same American university were selected. Half of the sections had students paired by math ability determined by a pre-test which focused on mathematical reasoning questions. The other half of the sections had students who picked their own partners. Students were given a follow-up post test on mathematical reasoning. Student mid-term and final scores were also analyzed. This study showed that the top students in either the paired or chosen sections still remained top students by the end of the semester but students who had been identified as a lower math student by the pre-test and were paired with a stronger student showed improvement on the post test. Midterm and final grades did not reflect a significant difference between whether a student was from a paired class or a class where students chose their own partner. A possible explanation was provided: “while students [in the paired sections] may be strengthening the math skills necessary to do well in chemistry, they are not yet adept at applying those skills” (Sroughi & Miller, 2018, p. 327).

Another instructional strategy that was examined in the classroom was the Thinking Aloud Pair Problem Solving (TAPPS) method while using a problem solving method in chemistry class (Jeon, Huffman, & Noh, 2005). The researchers analyzed data across three sets in a South Korean high school chemistry class. Previous records of mathematics and science performance was used to separate a group of South Korean students into three classes all with the same teacher. The purpose of separating the groups was to make the most homogeneous classes based on academic ability. One class would serve as the control and would be conducted the same way the teacher had always taught involving presentation of chemical concepts, laws, and principles using a textbook and then students working individually on practice problems. The second group was shown a four-stage strategy including analysis of the problem, transformation of the problem into a standard problem, execution of routine operations of the standard problem, checking the answer, and interpreting the results (Mettes, 2009). The second group still worked individually on practice problems like the first group did. The third group was shown the four-stage strategy like the second group, was taught the TAPPS method, and allowed to solve questions in groups. All groups were assessed with a post-test which was used for analysis. The control group performed the worse on the written post-test. Both the individual practice and TAPPS groups which were exposed to the four-stage strategy performed better at recalling the content and performing the mathematical equations. The post test revealed that the problem solving strategy did not improve conceptual knowledge amongst any of the groups. There was minimal evidence to suggest that the TAPPS group performed better than the individual group who was exposed to the problem solving strategy and it was concluded more research on TAPPS was needed. (Jeon, Huffman, & Noh, 2005)

Web-based software was used in a study conducted by Jennifer Ellis (2013) on the development of chemistry students' conceptual and visual understanding of dimensional analysis. Ellis compared two high schools in Tennessee where students enrolled in chemistry were learning the concept of dimensional analysis. One teach from each school used the web-based software "Conversionoes" as a treatment for a sample group of students. A control group was instructed using traditional lecture on dimensional analysis and performed individual practice on conversion problems. The study included quantitative analysis of students pre-test and post-test on dimensional analysis and qualitative analysis of interviews with students from both the test and control group. The students valued their experiences with the web software and were able to demonstrate dimensional analysis visually (Ellis, 2013).

The theme of mathematic abilities as a predictor of student success in chemistry appeared throughout the literature reviewed. Darlington and Bowyer (2016) showed that students in higher level math classes performed better in chemistry and Villafane and Lewis (2016) showed that math ability was the best predictor of success while Tai, Sadler, and Loehr (2005) concluded that the higher math a student took in high school translated to greater success in science classes in college. Unfortunately high school teachers cannot control which math classes a student will choose to take. Looking at the research focused on improvement illuminated two important pieces for my action research. First, Johnston, Watters, Brown, & Loughlin (2016) showed the ability of supplemental math to help students in chemistry class and Arnaud (2011) showed how some universities are structuring mathematics for chemist classes. The usage of supplemental math is important in bridging gaps in math abilities as a high school chemistry class will typically show diversity in the incoming academic experiences of students. Second, Ellis (2013) showed how instructional strategies such as introduction of problem strategy steps and inclusion of visual software seem the most efficient manner for a high school chemistry teacher to try to make improvements in student performance.

METHODOLOGY

Direct instruction of the underlying mathematic principles before typical units of study in chemistry was performed to attempt to improve student performance on typical chemistry exams. I used two College Preparatory Chemistry classes containing 28 and 30 students respectively. Of the 58 students, four had 504 accommodations and three had individualized education plans (IEP). The 58 students comprised of 25 sophomores, 31 juniors, and two seniors. The 58 students represented a diverse background in their current level of mathematics with 20 students taking geometry, 36 students taking Algebra II, one student taking pre-calculus, and one student taking college algebra during the course of this study. Of the 58 students, nine opted out of the study at the beginning of data collection and were not include in any of the data. The study began in early December 2018 and concluded in early April 2019. The research methodology for this project received an exemption by Montana State University's Institutional Review Board (Appendix A) and compliance for working with human subjects was maintained.

The students' unit test scores were tracked from pre-treatment through three units of study. Students took the Mathematics Diagnostic Test (Appendix B) and Confidence in Mathematics Survey (Appendix C) at the start of a unit on the mole concept. The mole concept served as the pre-treatment unit where no days were spent on supplemental math instruction. Students then received approximately one and a half days on supplemental math instruction focusing on specific skills needed in chemistry before learning the chemistry context for three separate units. Students had mathematics lessons on ratios and scaling before a unit of study on stoichiometry, manipulating algebraic equations before a unit of study on gas laws, and solving algebraic equations before a unit of study on thermochemistry. The Mole Concept Unit Test (Appendix E), Stoichiometry Unit Test

(Appendix F), Gas Laws Unit Test (Appendix G), and Energy and Calorimetry Unit Test (Appendix H) average scores were compiled and analyzed.

Approximately one and a half days of instruction were used for each mathematics lesson leading into a new unit of study in Chemistry. The mathematics lessons were focused on specific skills and included explicit demonstration at the board, guided practice, and independent practice for homework on mastering the skill in drills and in word problems with different context. The independent practice for homework was reviewed the following day as was a mathematics problem within the context of Chemistry. At the conclusion of the mathematics lesson, the chemistry instruction resumed with a typical hook lesson for the new unit.

At the conclusion of the four units of study, a sample of students were randomly selected from volunteers to participate in an interview where they responded one on one to the Mathematics Treatment Interview Questions (Appendix D). During the interviews, students shared their insight on the lessons presented, their satisfaction level with their grades before the treatment and during the treatment, and how their confidence in mathematics changed. Five students in total were interviewed at the conclusion of the treatment.

Results from the pre and post Mathematics Diagnostic Test were analyzed for normalized gains and a paired t-test was run. Student responses on the Confidence in Mathematics Survey were tallied and analyzed by a Wilcoxon Paired Test to determine if there was any significant change in student responses. Student responses from the Mathematics Treatment Interview Questions were analyzed to make sense of the student data. Scores on all four unit tests were analyzed to see how the class average changed and if any trends existed in student understanding. These instruments were all used to answer the focus questions listed in Table 1.

Table 1
Data Triangulation Matrix

Focus Question	Confidence Survey	Mathematics Post Test	Unit Test	Interview
Primary Question: 1. What is the impact of direct mathematics instruction on student test scores?	X	X	X	X
Sub Questions: 2. What is the impact of direct mathematics instruction on student confidence in answers?	X			X
3. Does early mathematics instruction help teacher provide more support during regular chemistry lessons?			X	X

DATA AND ANALYSIS

The Mathematics Diagnostic Test and Confidence in Mathematics Survey were administered pre treatment and post treatment (N = 49). After all data was collected, the Mathematics Diagnostic Test was analyzed for normalized gains and subject to a t test, while the Confidence in Mathematics Survey was subjected to a Wilcoxon Signed Rank test. Averages of the four unit exams spanning pre treatment through treatment were additionally compared, and five students were interviewed to make sense of the data.

The Mathematics Diagnostic Test had an average score of 33% pre-treatment and an average of 49% post treatment. The Mathematics Diagnostic Test saw low values of 0% on both pre-treatment and post-treatment. The highest score went from an 83% pre-treatment to a 100% post treatment. An average normalized gain of 0.29 was calculated.

Eight students had a normalized gain of zero and four students had a negative normalized gain. The normalized gains for the Mathematics Diagnostic Test can be seen in Figure 1 below.

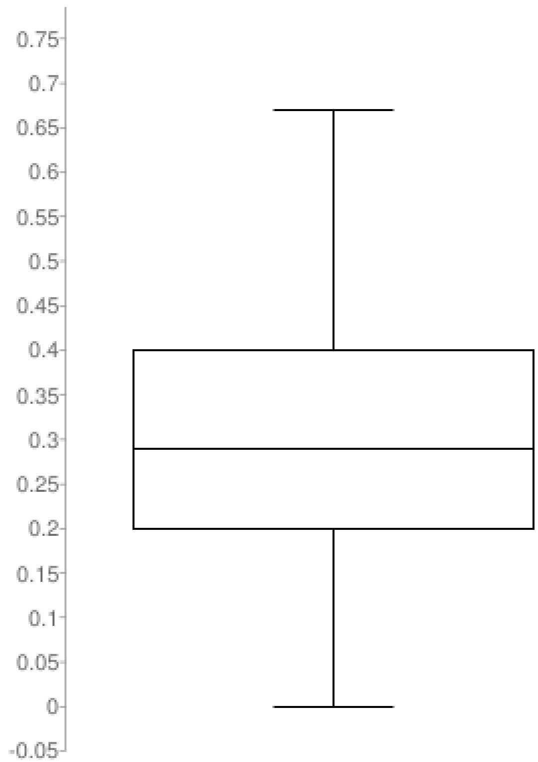

Figure 1. Mathematics diagnostic test pre/post test normalized gains, (*N*=49).

Student success of the individual questions can be seen question by question in Figures 2 and 3:

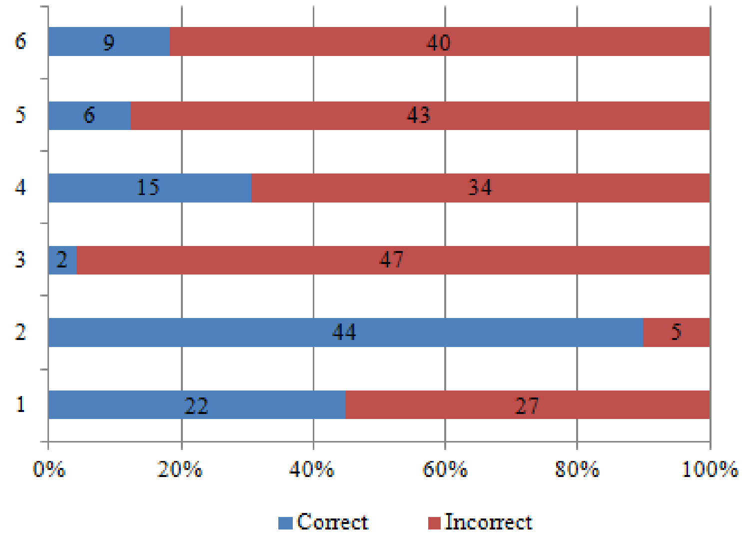

Figure 2. Pre-treatment mathematics diagnostic test question by question scores, (*N*=49).

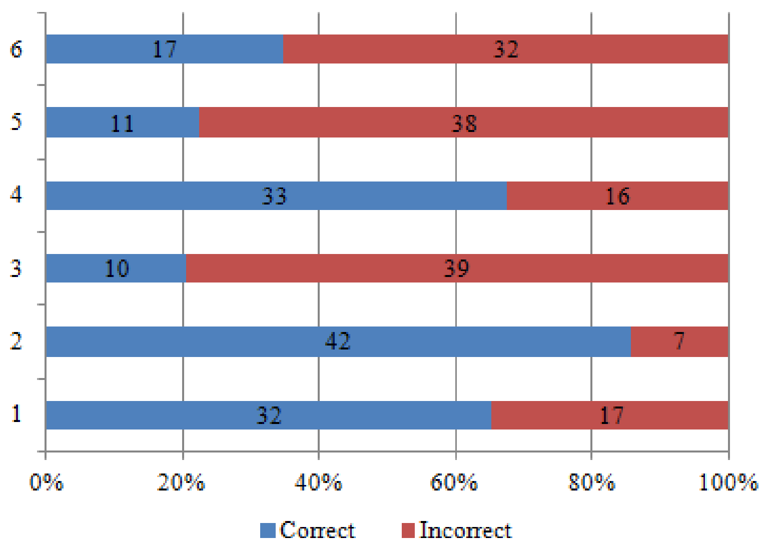

Figure 3. Post-treatment mathematics diagnostic test question by question scores, (*N*=49).

Question two was a simple algebra problem to solve for the numeric value of a variable and saw fewer students answer it correctly post-treatment. In both runs, this question had the highest percentage of students answering correctly. Question four focused on an algebraic manipulation to isolate a variable. This question had the largest improvement post-treatment with a 36% increase in correct answers. Question one focused on percentages and saw a 20% increase. Question three involved a metric conversion. This question was the most incorrectly answered question pre-treatment and post-treatment. Questions five and six focused on related rates and proportional scaling respectively and saw the smallest increases from pre to post-treatment. Overall, the majority of questions saw increases in correct answer post-treatment and when student scores were subjected to a paired t test a p value of 3.2e-8 was determined. The small p value supported the conclusion that the difference in means was significant. The Mathematics Diagnostic Test showed that the supplemental math instruction increased students' ability to answer mathematics questions.

The unit test on the mole concept was administered pre-treatment with an average score of 79.3%. The stoichiometry, gas laws, and thermochemistry units all included treatment supplemental mathematics instruction. The stoichiometry unit test average was 80.5%. The gas laws unit test average was 81.7% and the thermochemistry unit test average was 82.6%. All three post-treatment units had higher unit test averages with an increase observed from unit to unit. The largest increase was 3.3% points from the mole concept unit to the thermochemistry unit.

The Confidence in Mathematics Survey from pre-treatment and post-treatment were broken into two sections. The first five questions focused on positive statements about mathematics with Likert survey responses. Student responses to the first five question are listed in Figure 4 for the pre-treatment and in Figure 5 for the post-treatment.

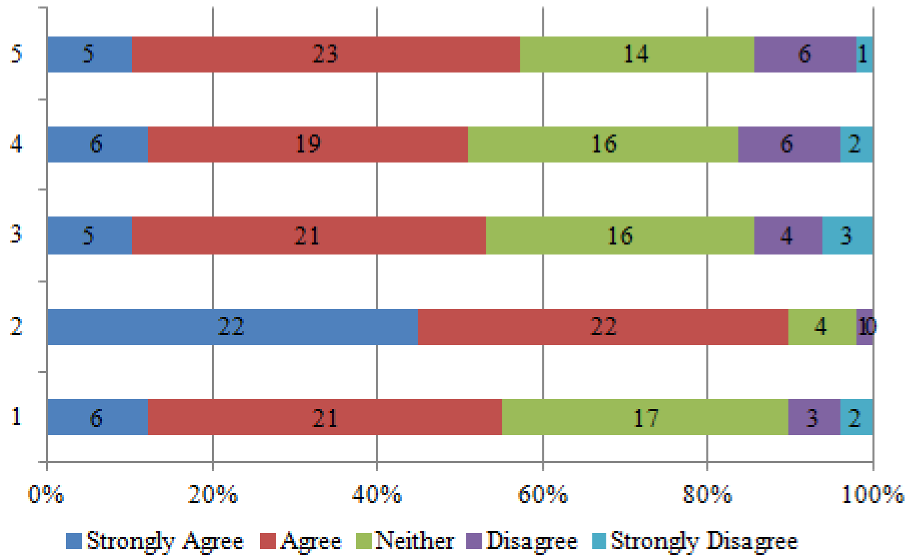

Figure 4. Pre-treatment confidence in mathematics survey results questions 6-10, (*N*=49).

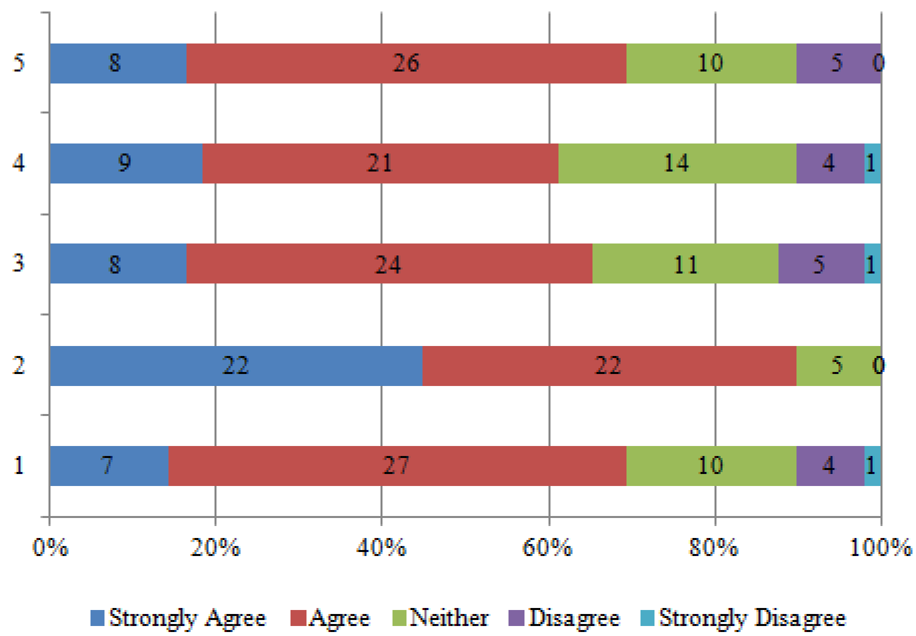

Figure 5. Post-treatment confidence in mathematics survey results questions, 1-5 (*N*=49).

The Confidence in Mathematics survey results for questions one through five were then subjected to the Wilcoxon rank pair test with the results listed below in Table 2.

Table 2
Confidence in Mathematics Questions 1-5 Wilcoxon Rank Paired Test

Number	Question	P value	Significant Change
1	I feel confident setting up a mathematical problem	0.1443	No
2	I feel confident using my calculator to solve a mathematical problem	0.8415	No
3	I feel confident that my answer makes sense when I've completed a mathematical problem	0.0854	No
4	I find mathematical questions in chemistry to be easy for me	0.0500	No
5	I think that math questions in chemistry class make sense	0.1164	No

In all five of the positive statement questions there was no observable change from pre-treatment to post-treatment. All five questions consistently had over 50% of agree or strongly agree responses with question two focusing on confidence using a calculator having over 80% agree or strongly agree responses in both sets.

The second set of questions from the Confidence in Mathematics Survey focused on negative statements about mathematics. Student responses to questions six through ten pre-treatment are listed in Figure 6 and post-treatment in Figure 7.

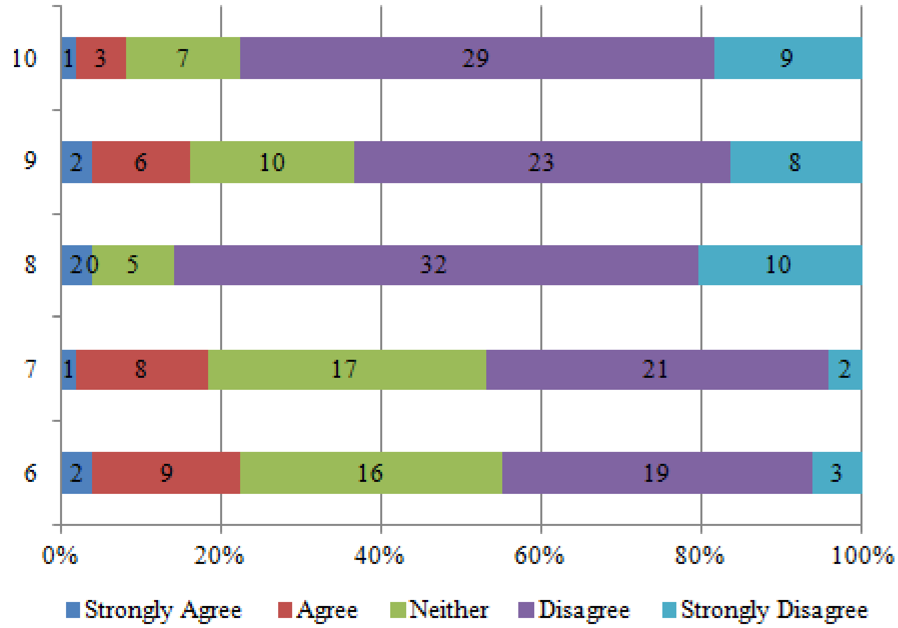

Figure 6. Pre-treatment confidence in mathematics survey results questions 6-10, (*N*=49).

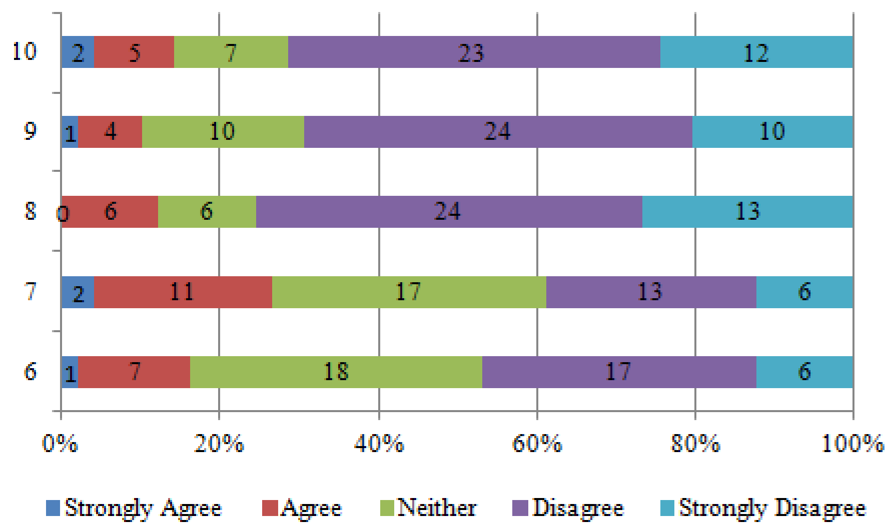

Figure 7. Post-treatment confidence in mathematics survey results questions 6-10, (*N*=49).

The second set of questions from the Confidence in Mathematics survey results was then subjected to the Wilcoxon rank pair test with the results listed in Table 3.

Table 3

Confidence in Mathematics Questions 6-10 Wilcoxon Rank Paired Test

Number	Question	P value	Significant Change
6	When I'm given a mathematical formula I get confused on where to start	0.2380	No
7	If a math question is worded differently I cannot solve the problem	0.4593	No
8	When the teacher works through a mathematical problem I cannot follow the explanation	0.5823	No
9	I feel weak in my ability to perform a mathematical calculation	0.1700	No
10	I do not see the connection between mathematics and chemistry	0.6672	No

In all five of the negative statement questions, there was no statistical change from pre to post-treatment responses. Generally, students consistently responded disagree or strongly disagree on the negative statements which connected to their agree and strongly agree responses to the first positive set of questions. Post-treatment more students agreed with question seven that if a math question was worded differently they could not solve the problem.

While the majority of students responded that they had confidence in their mathematical abilities as seen in the Confidence in Mathematics survey, there appeared to be a discrepancy between student confidence and the low scores on the Mathematics Diagnostic Test.

Five students were interviewed at the conclusion of the treatment. Student A had a unit test average of 98.5%. Student B had a unit test average of 87%. Student C had a unit test average of 69%. Student D had a unit test average of 63%. Student E had a unit test average of 56%. When asked how he or she was handling the mathematics portion of the class prior to the treatment students A, B, and C responded 'fine' while Student D and E said ‘not well’. Students A and B said that the math lessons helped but they didn’t feel they were necessary. Students C, D and E all said the mathematics lessons helped but Students D and E also identified that the lessons sometimes detracted from understanding the chemistry. All the students responded that they felt math was a big part of chemistry and that there should be a pre-requisite math. Student D expressed that they wished they knew more about how much math was involved when selecting courses the previous year.

Students were asked what type of mathematics help they would like to see in the future. Student A and B both expressed interest in seeing harder setups then what was presented during the supplemental math lessons. Student C expressed a pattern of second guessing themselves and would have liked instruction that may have prevented this second guessing. Students D and E both answered about setting up equations.

Students C, D, and E all responded that stoichiometry was the hardest unit. Students A and B both said that all units were equally easy. Interestingly, Students A and B had their highest unit test scores on the stoichiometry assessment while C, D and E all had their lowest unit test scores on this assessment. Students C and D said that the thermochemistry unit was the easiest which correlated with each student’s highest unit test score. Student E said that the gas laws unit was the easiest which also correlated with this student’s highest test score. Students C, D and E all expressed interest in not wanting to take further physical science coursework involving so much math.

The interview questions suggested that students who were already doing well in chemistry did not perceive that the supplemental instruction was necessary, which could explain the lack of significant change in the Confidence in Mathematics survey. The interview answers of Students C, D and E who had lower test averages indicated that the students perceived that math lessons at times did not help their learning and may have exposed their own math weaknesses. However there was no significant movement of students answering that they had less confidence in their mathematical abilities following the treatment units.

INTERPRETATION AND CONCLUSION

The data collected in this study showed that direct math instruction had at best minimal effect on student test scores. The unit test averages increased during the treatment but only to a max of 3.3%. Student performance was not negatively impacted by the supplemental math instruction but the allocation of instructional time on math lessons may not be justified by the modest increase in test averages. Additionally, this study can not address the subjective differences in the four topics assessed during the treatment. While each unit relied on math topics that were addressed, each skill was different and students may or may not have had an understanding of that particular skill.

The direct math instruction did not change student confidence in math as evidenced by the Wilcoxon rank test of the Confidence in Mathematics Survey. The pre and post data from this survey did not have a significant change in mean. Student interviews helped show that high scoring students perceived the supplemental instruction as unnecessary and low scoring students generally felt the instruction helped but did at times take away from their understanding of chemistry.

This study did not conclusively determine if the supplemental math lessons helped the teacher provide more instruction to students throughout the unit. This did not come up in student responses to the interview questions. In hindsight a teacher journal would have been another instrument to collect data to answer this sub question. While rankings of students could be determined with the diagnostic math test and from unit averages the treatment did not include a dimension of either pairing students based on ability or requiring groupings of students to attend further supplemental instruction. Less

While the use of math lessons did have some positive impacts in student test scores it is unclear from this study if such instruction should be conducted again when compared to more traditional chemistry instruction. The National Education Longitudinal Study analyzed by Tai, Sadler, and Loehr showed the correlation between student expose to stoichiometry and success in college. Due to Students C, D, and E identifying stoichiometry as the hardest topic, I think the supplemental math instruction before that particular unit of study should be repeated due to the importance of that particular topic. The supplemental instruction before gas laws and thermochemistry helped students achieve higher scores but might not be as necessary to students developing the most important chemical concepts.

This project highlighted a discrepancy about student confidence in mathematics versus performance. Considering the majority of students responded positively to questions like “I feel confident using my calculator to solve a mathematical problem” or “I feel confident that my answer makes sense when I’ve completed a mathematical problem” the same population of students struggled with the Mathematics Diagnostic

Test. Few students performed at a passing level. High school students have unsubstantiated confidence in their mathematics abilities that would be worthy of future study.

Considering all the students interviewed felt that there should be a pre-requisite mathematics course for chemistry, more work would need to be done to determine what that pre-requisite could look like. Currently, I believe a prerequisite of successful completion of geometry or concurrently enrolled in geometry honors would help benefit the chemistry department at my school. The prerequisite could help establish the significance of math work in the course so students might not be as caught off guard by the expectations. This prerequisite would ensure all students completed algebra I and most would currently be in an algebra II class while taking chemistry.

Overall, the data showed that while the treatment of supplemental math lessons slightly improved test averages it did not change student confidence about math. The clearest evidence for student improvement was the Mathematics Diagnostic Test which had an average of 49% post treatment. The lack of student responses on receiving more support indicated that the treatment did not inform the teacher to provide more support for struggling students. More data would need to be collected and analyzed to determine if supplemental math lessons would be an effective teaching strategy for high school chemistry classes.

VALUE

Upon completing this study, I’ve realized that I’ve used elements of action research my whole career. I’ve changed elements of my instruction from year to year because I wanted to make sure I provided my students with the best education possible. I was often nervous to deviate too much in case there was a negative impact on their learning. I was also nervous that I wouldn't be able to quantify the results of changing something about my classroom or my instruction. While trying my supplemental math lessons, I did not have the impact that I had hoped for, but my students were no worse off with my trying something different but still trying my best.

One approach I would consider in the future would be optional direct math instruction during blended lessons that provide set amounts of time for students to work independently. Students would have the choice to engage in a direct math lesson if they felt they needed help with the mathematical material and could opt into the lesson. Any student opting out of the supplemental math lesson would be working on a different prescribed task like a problem set or finishing the analysis of a lab. A potential treatment like this could collect data to see if students accurately self selected the need for supplemental instruction. A project like this would require more research into students identifying their own strengths and weaknesses.

The piece of this project that I did not employ throughout my teaching career was the background research. I found some interesting studies and conclusions in this project that will impact how I teach for a long time. I will certainly put more emphasis on stoichiometry year after year as it was identified in the literature to be one of the best predictors of student success in future coursework. I would want to continue researching topics in education that interest me to try to find best practices. After this experience, I think that I will adopt policies that data can support are best for student learning. While I used a lot of my own intuition in the past, I can see myself being stricter with sticking with instructional strategies and classroom procedures that can have the best impact on student learning.

While I looked to students for feedback in the past on my instruction, this project helped me see the value in focused questions to get feedback from students. I believe that student feedback is important, even if that data can be unreliable at times. As I become more experienced, I also move further away from my students in age and so I think their feedback is important with keeping a pulse on what the daily life is like for current high school students. While the core of teaching will probably endure, I think considerable changes will be needed to be made in the classroom to reflect and meet the needs of current generations. This ongoing change to daily life is why educators need to be using elements of the action research cycle to stay relevant in a changing world.

In conclusion of the action research cycle, I do not see myself utilizing supplemental math instruction as frequently as I did in this study. I do see the benefit of providing math instruction before stoichiometry since the math is more abstract in nature, but otherwise I think the math skills will be addressed as they come up and not front loaded like they were in my treatment. I plan to move on to looking into student abilities in eliciting information from word problems, as the context and when to use the math skills is another challenge to chemistry students.

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APPENDICES

APPENDIX A

MONTANA STATE UNIVERSITY INSTITUTIONAL REVIEW

MONTANA STATE UNIVERSITY

INSTITUTIONAL REVIEW BOARD

For the Protection of Human Subjects

FWA 00000165

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MEMORANDUM

TO: Timothy Lopreiato and Kathryn Solberg

FROM: Mark Quinn *Mark Quinn CJ*
Chair, Institutional Review Board for the Protection of Human Subjects

DATE: November 11, 2018

RE: *"The Effects of Explicit Math Instruction Before Chemistry Content Instruction at the High School Level" [MT121118-EX]*

The above research, described in your submission of November 10, 2018, is exempt from the requirement of review by the Institutional Review Board in accordance with the Code of Federal regulations, Part 46, section 101. The specific paragraph which applies to your research is:

_X_ (b) (1) Research conducted in established or commonly accepted educational settings, involving normal educational practices such as (i) research on regular and special education instructional strategies, or (ii) research on the effectiveness of or the comparison among instructional techniques, curricula, or classroom management methods.

_X_ (b) (2) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures or observation of public behavior, unless: (i) information obtained is recorded in such a manner that human subjects can be identified, directly or through identifiers linked to the subjects; and (ii) any disclosure of the human subjects' responses outside the research could reasonably place the subjects at risk of criminal or civil liability, or be damaging to the subjects' financial standing, employability, or reputation.

____ (b) (3) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures, or observation of public behavior that is not exempt under paragraph (b)(2) of this section, if: (i) the human subjects are elected or appointed public officials or candidates for public office; or (ii) federal statute(s) without exception that the confidentiality of the personally identifiable information will be maintained throughout the research and thereafter.

____ (b) (4) Research involving the collection or study of existing data, documents, records, pathological specimens, or diagnostic specimens, if these sources are publicly available, or if the information is recorded by the investigator in such a manner that the subjects cannot be identified, directly or through identifiers linked to the subjects.

____ (b) (5) Research and demonstration projects, which are conducted by or subject to the approval of department or agency heads, and which are designed to study, evaluate, or otherwise examine: (i) public benefit or service programs; (ii) procedures for obtaining benefits or services under those programs; (iii) possible changes in or alternatives to those programs or procedures; or (iv) possible changes in methods or levels of payment for benefits or services under those programs.

____ (b) (6) Taste and food quality evaluation and consumer acceptance studies, (i) if wholesome foods without additives are consumed, or (ii) if a food is consumed that contains a food ingredient at or below the level and for a use found to be safe, or agricultural chemical or environmental contaminant at or below the level found to be safe, by the FDA, or approved by the EPA, or the Food Safety and Inspection Service of the USDA.

Although review by the Institutional Review Board is not required for the above research, the Committee will be glad to review it. If you wish a review and committee approval, please submit 3 copies of the usual application form and it will be processed by expedited review.

APPENDIX B

MATHEMATICS DIAGNOSTIC TEST

Mathematics Test

Answer the following mathematical questions to the best of your ability.

Question 1
A cake that weighs 112 g in total has 5 g of sugar in it. What is the percent by mass of the sugar in the cake?

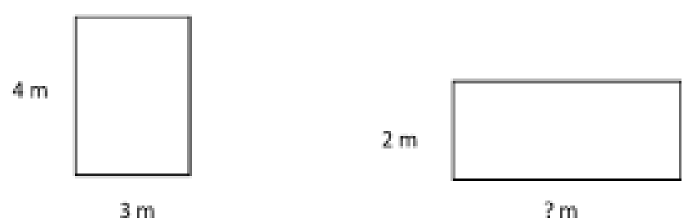
Question 2
If 6p – 3 = 8p – 9, then p =

Question 3
A plane travels 3000 m in 60 seconds. Calculate the speed of the plane in km/s

Question 4
If $a = \frac{b+2x}{z}$ solve for x.

Question 5
4 people can paint a fence in 3 hours. How long will it take 6 people to paint a fence?

Question 6
There are two different rectangles. The first rectangle has a length of 4 m and a width of 3 m. The second rectangle is twice as large and has a length of 2 m. Determine the width of the second rectangle.



APPENDIX C

CONFIDENCE IN MATHEMATICS SURVEY

Confidence in Mathematics Survey

Participation in this survey is optional

Question 1

I feel confident setting up a mathematical problem

5 Strongly Agree	4 Agree	3 Neither Or N/A	2 Disagree	1 Strongly Disagree

Question 2

I feel confident using my calculator to solve a mathematical problem

5 Strongly Agree	4 Agree	3 Neither Or N/A	2 Disagree	1 Strongly Disagree

Question 3

I feel confident that my answer makes sense when I've completed a mathematical problem

5 Strongly Agree	4 Agree	3 Neither Or N/A	2 Disagree	1 Strongly Disagree

Question 4

I find mathematical questions in chemistry to be easy for me

5 Strongly Agree	4 Agree	3 Neither Or N/A	2 Disagree	1 Strongly Disagree

Question 5

I think that math questions in chemistry class make sense

5 Strongly Agree	4 Agree	3 Neither Or N/A	2 Disagree	1 Strongly Disagree

Question 6

When I'm given a mathematical formula I get confused on where to start

5 Strongly Agree	4 Agree	3 Neither Or N/A	2 Disagree	1 Strongly Disagree

Question 7

If a math question is worded differently I cannot solve the problem

5 Strongly Agree	4 Agree	3 Neither Or N/A	2 Disagree	1 Strongly Disagree

Question 8

When the teacher works through a mathematical problem I cannot follow the explanation

5	4	3	2	1
Strongly Agree	Agree	Neither Or N/A	Disagree	Strongly Disagree

Question 9

I feel weak in my ability to perform a mathematical calculation

5	4	3	2	1
Strongly Agree	Agree	Neither Or N/A	Disagree	Strongly Disagree

Question 10

I do not see the connection between mathematics and chemistry

5	4	3	2	1
Strongly Agree	Agree	Neither Or N/A	Disagree	Strongly Disagree

APPENDIX D

MATHEMATICS TREATMENT INTERVIEW QUESTIONS

Interview Questions

1. How were you handling the math portion of chemistry before the treatment began?
2. Did the math lessons help you when it came time for the chemistry problems? Why or why not?
3. Did the math lessons detract from your chemistry understanding?
4. Were the math lessons understandable?
5. What role do you see mathematics having in chemistry class?
6. Did the math lessons help you interpret information from a word problem?
7. Do you think there should be a pre-requisite math class for chemistry?
8. What type of mathematics help would you have liked during the units?
9. Which unit of study (stoichiometry, gas laws, heat) did you find easiest? Hardest?
10. Did the math lessons help you make sense of the chemistry?
11. Do you think you would have been fine even without the math lessons?
12. Would you be interested in taking further physical science classes that contain mathematics?

APPENDIX E

MOLE CONCEPT UNIT TEST

Name: ______________________ **Class:** ___________________ **Date:** _________ **ID: A**

Moles

Multiple Choice
Identify the choice that best completes the statement or answers the question.

____ 1. How many atoms are in 3.5 moles of arsenic atoms?
a. 5.8×10^{-24} atoms
b. 7.5×10^{1} atoms
c. 2.1×10^{24} atoms
d. 1.7×10^{23} atoms

____ 2. What SI unit is used to measure the number of representative particles in a substance?
a. kilogram
b. ampere
c. kelvin
d. mole

____ 3. All of the following are equal to Avogadro's number EXCEPT ____.
a. the number of atoms of bromine in 1 mol Br_2
b. the number of atoms of gold in 1 mol Au
c. the number of molecules of nitrogen in 1 mol N_2
d. the number of molecules of carbon monoxide in 1 mol CO

____ 4. How many moles of tungsten atoms are in 4.8×10^{25} atoms of tungsten?
a. 8.0×10^{2} moles
b. 8.0×10^{1} moles
c. 1.3×10^{-1} moles
d. 1.3×10^{-2} moles

____ 5. What is the molar mass of $AuCl_3$?
a. 96 g
b. 130 g
c. 232.5 g
d. 303.6 g

____ 6. What is the molar mass of $(NH_4)_2CO_3$?
a. 144 g
b. 138 g
c. 96 g
d. 78 g

____ 7. What is the mass in grams of 5.90 mol C_8H_{18}?
a. 0.0512 g
b. 19.4 g
c. 389 g
d. 673 g

____ 8. What is the number of moles in 432 g $Ba(NO_3)_2$?
a. 0.237 mol
b. 0.605 mol
c. 1.65 mol
d. 3.66 mol

____ 9. How many moles of $CaBr_2$ are in 5.0 grams of $CaBr_2$?
a. 2.5×10^{-2} mol
b. 4.2×10^{-2} mol
c. 4.0×10^{1} mol
d. 1.0×10^{3} mol

Name: ________________________ **ID: A**

____ 10. What is the mass of oxygen in 250 g of sulfuric acid, H_2SO_4?

a. 0.65 g
b. 3.9 g
c. 16 g
d. 160 g

____ 11. What is the volume, in liters, of 0.500 mol of C_3H_8 gas at STP?

a. 0.0335 L
b. 11.2 L
c. 16.8 L
d. 22.4 L

____ 12. What is the percent composition of chromium in $BaCrO_4$?

a. 4.87%
b. 9.47%
c. 20.5%
d. 25.2%

____ 13. Which of the following is NOT an empirical formula?

a. $C_2N_2H_8$
b. C_3H_8O
c. $BeCr_2O_7$
d. Sb_2S_3

____ 14. What is the empirical formula of a compound that is 40% sulfur and 60% oxygen by weight?

a. SO
b. SO_2
c. SO_3
d. S_6O_4

____ 15. What is the empirical formula of a substance that is 53.5% C, 15.5% H, and 31.1% N by weight?

a. C_3HN_2
b. $C_4H_{14}N_2$
c. C_2H_8N
d. CH_4N_7

Short Answer

16. Find the mass in grams of 3.10×10^{23} molecules of F_2.

17. Find the number of moles of argon in 607 g of argon.

18. What is the percent composition of NiO, if a sample of NiO with a mass of 41.9 g contains 33.1 g Ni and 8.8 g O?

19. What is the percent by mass of hydrogen in aspirin, $C_9H_8O_4$?

APPENDIX F

STOICHIOMETRY UNIT TEST

Name: ______________________ **Class:** ________________ **Date:** _________ **ID: A**

Stoichiometry

Multiple Choice
Identify the choice that best completes the statement or answers the question.

____ 1. In the chemical equation $H_2O_2(aq) \rightarrow H_2O(l) + O_2(g)$, the O_2 is a ____.
   a. catalyst
   b. solid
   c. product
   d. reactant

____ 2. The reaction $2Fe + 3Cl_2 \rightarrow 2FeCl_3$ is an example of which type of reaction?
   a. combustion reaction
   b. single-replacement reaction
   c. combination reaction
   d. decomposition reaction

____ 3. The equation $2C_3H_7OH + 9O_2 \rightarrow 6CO_2 + 8H_2O$ is an example of which type of reaction?
   a. combustion reaction
   b. single-replacement reaction
   c. double-replacement reaction
   d. decomposition reaction

____ 4. What are the coefficients that will balance the skeleton equation below?
   $N_2 + H_2 \rightarrow NH_3$
   a. 1, 1, 2
   b. 1, 3, 3
   c. 3, 1, 2
   d. 1, 3, 2

____ 5. When the equation $KClO_3(s) \rightarrow KCl(s) + O_2(g)$ is balanced, the coefficient of $KClO_3$ is ____.
   a. 1
   b. 2
   c. 3
   d. 4

____ 6. What is conserved in the reaction shown below?
   $N_2(g) + 3F_2(g) \rightarrow 2NF_3(g)$
   a. atoms only
   b. mass only
   c. mass and atoms only
   d. moles only

____ 7. In the reaction $2CO(g) + O_2(g) \rightarrow 2CO_2(g)$, what is the ratio of moles of oxygen used to moles of CO_2 produced?
   a. 1:1
   b. 2:1
   c. 1:2
   d. 2:2

____ 8. Which of the following is true about the total number of reactants and the total number of products in the reaction shown below?
   $C_5H_{12}(l) + 8O_2(g) \rightarrow 5CO_2(g) + 6H_2O(g)$
   a. 9 moles of reactants chemically change into 11 moles of product.
   b. 9 grams of reactants chemically change into 11 grams of product.
   c. 9 liters of reactants chemically change into 11 liters of product.
   d. 9 atoms of reactants chemically change into 11 atoms of product.

Name: ______________________ ID: A

____ 9. How many moles of aluminum are needed to react completely with 1.2 mol of FeO?
$2Al(s) + 3FeO(s) \rightarrow 3Fe(s) + Al_2O_3(s)$

a. 1.2 mol
b. 0.8 mol
c. 1.6 mol
d. 2.4 mol

____ 10. Calculate the number of moles of Al_2O_3 that are produced when 0.60 mol of Fe is produced in the following reaction.
$2Al(s) + 3FeO(s) \rightarrow 3Fe(s) + Al_2O_3(s)$

a. 0.20 mol
b. 0.40 mol
c. 0.60 mol
d. 0.90 mol

____ 11. How many moles of glucose, $C_6H_{12}O_6$, can be "burned" biologically when 10.0 mol of oxygen is available?
$C_6H_{12}O_6(s) + 6O_2(g) \rightarrow 6CO_2(g) + 6H_2O(l)$

a. 0.938 mol
b. 1.67 mol
c. 53.3 mol
d. 60.0 mol

____ 12. Hydrogen gas can be produced by reacting aluminum with sulfuric acid. How many moles of sulfuric acid are needed to completely react with 15.0 mol of aluminum?
$2Al(s) + 3H_2SO_4(aq) \rightarrow Al_2(SO_4)_3(aq) + 3H_2(g)$

a. 0.100 mol
b. 10.0 mol
c. 15.0 mol
d. 22.5 mol

____ 13. How many moles of H_3PO_4 are produced when 71.0 g P_4O_{10} reacts completely to form H_3PO_4?
$P_4O_{10}(s) + 6H_2O(l) \rightarrow 4H_3PO_4(aq)$

a. 0.063 5 mol
b. 1.00 mol
c. 4.00 mol
d. 16.0 mol

____ 14. How many grams of H_3PO_4 are produced when 10.0 moles of water react with an excess of P_4O_{10}?
$P_4O_{10}(s) + 6H_2O(l) \rightarrow 4H_3PO_4(aq)$

a. 1.22 g
b. 6.7 g
c. 147 g
d. 653 g

____ 15. The equation below shows the decomposition of lead nitrate. How many grams of oxygen are produced when 11.5 g NO_2 is formed?
$2Pb(NO_3)_2(s) \rightarrow 2PbO(s) + 4NO_2(g) + O_2(g)$

a. 1.00 g
b. 2.00 g
c. 2.88 g
d. 32.0 g

Short Answer

16. Balance the following equation. Indicate whether combustion is complete or incomplete.
$C_3H_8 + O_2 \rightarrow CO + H_2O$

Name: ______________________ **ID: A**

17. If 8.00 mol of NH_3 reacted with 14.0 mol of O_2, how many moles of H_2O will be produced?
$4NH_3(g) + 7O_2(g) \rightarrow 4NO_2 + 6H_2O(g)$

18. How many grams of CO are needed to react with an excess of Fe_2O_3 to produce 209.7 g Fe?
$Fe_2O_3(s) + 3CO(g) \rightarrow 3CO_2(g) + 2Fe(s)$

19. If 5.0 g of H_2 are reacted with excess CO, how many grams of CH_3OH are produced, based on a yield of 86%?
$CO(g) + 2H_2(g) \rightarrow CH_3OH(l)$

APPENDIX G

GAS LAWS UNIT TEST

Name: ______________________ Class: __________________ Date: _________ ID: A

Gas Laws

Multiple Choice
Identify the choice that best completes the statement or answers the question.

____ 1. Which of the following statements is NOT true, according to the kinetic theory?
  a. There is no attraction between particles of a gas.
  b. Only particles of matter in the gaseous state are in constant motion.
  c. The particles of a gas collide with each other and with other objects.
  d. All of the statements are true.

____ 2. What is one standard atmosphere of pressure in kilopascals?
  a. 0 kPa
  b. 760 kPa
  c. 101.3 kPa
  d. 1 kPa

____ 3. Which of the following statements is NOT true about the movement of particles in a gas?
  a. Particles travel in straight-line paths until they collide with other objects.
  b. Particles usually travel uninterrupted indefinitely.
  c. Particles fill their containers regardless of the shape or volume of the container.
  d. The aimless path taken by particles is known as a random walk.

____ 4. If the volume of a container of gas is reduced, what will happen to the pressure inside the container?
  a. The pressure will increase.
  b. The pressure will not change.
  c. The pressure will decrease.
  d. The pressure depends on the type of gas.

____ 5. Why is a gas easier to compress than a liquid or a solid?
  a. Its volume increases more under pressure than an equal volume of liquid does.
  b. Its volume increases more under pressure than an equal volume of solid does.
  c. The space between gas particles is much less than the space between liquid or solid particles.
  d. The volume of a gas's particles is small compared to the overall volume of the gas.

____ 6. What happens to the pressure of a gas inside a container if the temperature of the gas decreases?
  a. The pressure increases.
  b. The pressure does not change.
  c. The pressure decreases.
  d. The pressure cannot be predicted.

____ 7. If 4 moles of gas are added to a container that already holds 1 mole of gas, how will the pressure change inside the container?
  a. The pressure will be five times higher.
  b. The pressure will double.
  c. The pressure will be four times higher.
  d. The pressure will not change.

Name: ____________________ ID: A

____ 8. Why does air escape from a tire when the tire valve is opened?
  a. The pressure outside the tire is lower than the pressure inside the tire.
  b. The pressure outside the tire is greater than the pressure inside the tire.
  c. The temperature is higher outside the tire than inside the tire.
  d. There are more particles of air outside the tire than inside the tire.

____ 9. When the Kelvin temperature of an enclosed gas doubles, the particles of the gas ____.
  a. move faster
  b. strike the walls of the container with less force
  c. decrease in average kinetic energy
  d. decrease in volume

____ 10. If a balloon is heated, what happens to the volume of the air in the balloon if the pressure is constant?
  a. It increases.
  b. It stays the same.
  c. It decreases.
  d. The change cannot be predicted.

____ 11. As the temperature of a fixed volume of a gas increases, the pressure will ____.
  a. vary inversely
  b. decrease
  c. not change
  d. increase

____ 12. A gas occupies a volume of 2.4 L at 14.1 kPa. What volume will the gas occupy at 84.6 kPa?
  a. 497 L
  b. 2.5 L
  c. 14 L
  d. 0.40 L

____ 13. A sample of gas occupies 17 mL at –112°C. What volume does the sample occupy at 70°C?
  a. 10.6 mL
  b. 27 mL
  c. 36mL
  d. 8.0mL

____ 14. How is the ideal gas law usually written?
  a. $\frac{PV}{nT} = R$
  b. $\frac{PV}{T} = nR$
  c. $PV = nRT$
  d. $P = \frac{nRT}{V}$

____ 15. A box with a volume of 22.4 L contains 1.0 mol of nitrogen and 2.0 mol of hydrogen at 0°C. Which of the following statements is true?
  a. The total pressure in the box is 101 kPa.
  b. The partial pressures of N_2 and H_2 are equal.
  c. The total pressure is 202 kPa
  d. The partial pressure of N_2 is 101 kPa.

Short Answer

16. The volume of a gas is 250 mL at 340.0 kPa pressure. What will the volume be when the pressure is reduced to 50.0 kPa, assuming the temperature remains constant?

Name: ______________________ **ID: A**

17. A balloon filled with helium has a volume of 30.0 L at a pressure of 100 kPa and a temperature of 15.0°C. What will the volume of the balloon be if the temperature is increased to 80.0°C and the pressure remains constant?

18. A gas has a volume of 590 mL at a temperature of –55.0°C. What volume will the gas occupy at 30.0°C?

19. How many moles of N_2 are in a flask with a volume of 250 mL at a pressure of 300.0 kPa and a temperature of 300.0 K?

APPENDIX H

THERMOCHEMISTRY UNIT TEST

Name: ______________________ Class: __________________ Date: __________ ID: A

Thermochemistry

Multiple Choice

Identify the choice that best completes the statement or answers the question.

____ 1. What happens to the average kinetic energy of the particles in a sample of matter as the temperature of the sample is increased?
- a. The average kinetic energy decreases.
- b. The average kinetic energy increases.
- c. The average kinetic energy does not change.
- d. The change in average kinetic energy cannot be determined.

____ 2. The average kinetic energy of water molecules is greatest in ____.
- a. steam at 100°C
- b. liquid water at 90°C
- c. liquid water at 373 K
- d. ice at 0°C

____ 3. Water could be made to boil at 105°C instead of 100°C by ____.
- a. adding a lot of energy to the water
- b. increasing the external pressure
- c. decreasing the external pressure
- d. taking the sample to a higher altitude

____ 4. A piece of metal is heated, then submerged in cool water. Which statement below describes what happens?
- a. The temperature of the metal will increase.
- b. The temperature of the water will increase.
- c. The temperature of the water will decrease.
- d. The temperature of the water will increase and the temperature of the metal will decrease.

____ 5. When energy is changed from one form to another, ____.
- a. some of the energy is lost entirely
- b. all of the energy can be accounted for
- c. a physical change occurs
- d. all of the energy is changed to a useful form

____ 6. What is the amount of heat required to raise the temperature of 200.0 g of aluminum by 10°C? (specific heat of aluminum = 0.21 $\frac{\text{cal}}{\text{g°C}}$)
- a. 420 cal
- b. 4200 cal
- c. 42,000 cal
- d. 420,000 cal

____ 7. What is the specific heat of a substance if 1560 cal are required to raise the temperature of a 312-g sample by 15°C?
- a. 0.033 $\frac{\text{cal}}{\text{g°C}}$
- b. 0.33 $\frac{\text{cal}}{\text{g°C}}$
- c. 0.99 $\frac{\text{cal}}{\text{g°C}}$
- d. 1.33 $\frac{\text{cal}}{\text{g°C}}$

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____ 8. How many kilocalories of heat are required to raise the temperature of 225 g of aluminum from 20°C to 100°C? (specific heat of aluminum = 0.21 $\frac{\text{cal}}{\text{g}°\text{C}}$)

a. 0.59 kcal
b. 3.8 kcal
c. 85 kcal
d. none of the above

____ 9. The specific heat of silver is 0.24 $\frac{\text{J}}{\text{g}°\text{C}}$. How many joules of energy are needed to warm 4.37 g of silver from 25.0°C to 27.5°C?

a. 2.62 J
b. 0.14 J
c. 45.5 J
d. 0.022 J

____ 10. Calculate the energy required to produce 7.00 mol Cl_2O_7 on the basis of the following balanced equation.
$2Cl_2(g) + 7O_2(g) + 130\text{ kcal} \rightarrow 2Cl_2O_7(g)$

a. 7.00 kcal
b. 65 kcal
c. 130 kcal
d. 455 kcal

____ 11. During a phase change, the temperature of a substance ____.

a. increases
b. decreases
c. remains constant
d. may increase or decrease

____ 12. The average kinetic energy of the particles of a substance ____.

a. is not affected by the temperature of the substance
b. increases as the temperature of the substance is lowered
c. is directly proportional to the temperature of the substance
d. is equal to the total energy absorbed by the substance

____ 13. Consider an iron cube and an aluminum cube. If the two cubes were at the same temperature, how would the average kinetic energy of the particles in iron compare with the average kinetic energy of the particles in aluminum?

a. The average kinetic energy of the iron particles would be greater.
b. The average kinetic energy of the aluminum particles would be greater.
c. There would be no difference in the average kinetic energies.
d. No determination can be made based on the information given.

____ 14. How can you describe the specific heat of olive oil if it takes approximately 420 J of heat to raise the temperature of 7 g of olive oil by 30°C?

a. greater than the specific heat of water
b. less than the specific heat of water
c. equal to the specific heat of water
d. Not enough information is given.

____ 15. A chunk of ice whose temperature is −20°C is added to an insulated cup filled with water at 0°C. What happens in the cup?

a. The ice melts until it reaches the temperature of the water.
b. The water cools until it reaches the temperature of the ice.
c. Some of the water freezes, so the chunk of ice gets larger.
d. none of the above

Name: ________________________ **ID: A**

Short Answer

16. The specific heat capacity of graphite is 0.71 $\frac{J}{g°C}$. Calculate the energy required to raise the temperature of 750 g of graphite by 160°C.

17. It takes 770 joules of energy to raise the temperature of 50.0 g of mercury by 110°C. What is the specific heat of mercury?

18. At what temperature do particles theoretically have no kinetic energy?

19. When 45 g of an alloy, at 25°C, are dropped into 100.0 g of water, the alloy absorbs 956 J of heat. If the final temperature of the alloy is 37°C, what is its specific heat?