Development of assessment to determine first term general chemistry mathematical fluency

by
Kiara Tomlinson

A THESIS

submitted to

Oregon State University

Honors College

in partial fulfillment of
the requirements for the
degree of

Honors Baccalaureate of Science in Chemistry
(Honors Scholar)

Presented June 1, 2020
Commencement June 2020

AN ABSTRACT OF THE THESIS OF

Kiara Tomlinson for the degree of Honors Baccalaureate of Science in Chemistry presented on June 1, 2020. Title: Development of assessment to determine first term general chemistry mathematical fluency.

Abstract approved:_____

Margie Haak

The purpose of this study was to analyze the scores of a mental math quiz taken by the CH 231 trailer course at Oregon State University and to determine courses of action to increase the success of students in general chemistry based on the results of the analysis. Students were given a mental math quiz at the beginning and end of the term. The average score of the pre-mental math quiz was 4.65 and the post-mental math quiz was 6.40. The average score increased slightly, but students generally kept the same score that they began the term with. Students are not entering general chemistry with the needed mathematical abilities and they are not learning them on their own during the term. Thus, I suggest implementing a mental math assessment at the beginning of each term to assess students' abilities. The results would show the mathematical abilities of students in the course, which can aid professors in providing the appropriate learning resources. Spending a small amount of effort on providing students with resources so they can understand and apply mathematical concepts, will save time in the long run both for students and professors and increase student success in general chemistry.

Key Words: Mental Math, General Chemistry Assessment, Mathematical Ability, Mathematical Fluency, Mathematical Transference

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APPROVED:

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Margie Haak, Mentor, representing Chemistry

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Toni Doolen, Dean, Oregon State University Honors College

I understand that my project will become part of the permanent collection of Oregon State University, Honors College. My signature below authorizes release of my project to any reader upon request.

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Kiara Tomlinson, Author

Development of assessment to determine first term general chemistry mathematical fluency

--- Background ---

Introduction

In this study, the relationship between an ability to complete simple mental math problems and success in general chemistry courses at Oregon State University was explored. Chemistry is a difficult subject for many to comprehend and as such, first year students often fail the course. With repeatedly failing students, it is important to look at what influences success or failure in general chemistry. Studies consistently show that the largest indicator of success in chemistry is mathematical ability.[1] Outside of mathematics being an integral part of chemistry, a student with mathematical fluency also has several advantages over those who do not. For one, an ability to perform simple mathematical operations frees up the student's mind to focus on the concept at hand as it is not occupied with calculations.[2] For another, the underlying thinking and analysis patterns that are used to be successful in mathematics are the same as those needed for chemistry.[3] Relationships between mathematical variables translate to relationships between chemical variables. Students who understand how mathematics expresses relationships in chemistry will have an easier time understanding the material. Given these reasons, an ability to do mathematics significantly aids students in their ability to do chemistry.

With this, though, it is important to look specifically at mental math as the particular mathematical skill among many, which most impacts success in general chemistry. Mental math is the ability to perform basic algebraic calculations in one's mind without the use of a calculator. Often, the ability to use a calculator is conflated with the ability to understand and perform complex mathematical operations. It is important to remember that being able to use a calculator does not necessarily mean that the student understands the reasoning behind the operations and thus they may not truly understand what they are doing, but rather can fall prey to

the plug-and-chug model.[3] Students who are able to perform basic mathematical operations without the use of a calculator show a true understanding of the mathematical concepts at hand and have the necessary mathematical skills to be successful in general chemistry.

High School Mathematical & Science Background

Understanding that mathematics is key to success in general chemistry, it is important to look at the mathematical background of the students taking general chemistry. General chemistry is typically a first-year course, and as such many of the students in the course have only taken high school mathematics up until this point. Thus, to understand the background that students are coming in with, we need to look at how students perform in high school At the time that data was pulled for this study, 55.6% of Oregon State University's population was enrolled as an Oregon Resident with 44.4% being Non-Resident and 11.0% being International students.[4] Given that over half of the students at Oregon State are in-state students, it is pertinent to evaluate the Oregon high school mathematical standards and proficiency.

The state of Oregon requires that high school seniors be able to demonstrate three essential skills before they can graduate with their diploma: 1) Read and comprehend a variety of texts, 2) Write clearly and accurately, and 3) Apply mathematics in a variety of settings.[5] To demonstrate fluency in these three areas, students take a Standardized Local Performance Assessment, which can be any of around a dozen different exams.[5] This vague requirement coupled with the fact that so many different exams, from the GED to the ACT, can be used to show proficiency means that graduating high school students have no guarantee of a base level of mathematical proficiency or fluency.

In addition to this, high school juniors have shown mathematical proficiency for the last several years. Only about 30% of Oregon high school juniors met the standard for being

proficient in mathematics.[6] Yet 80.0% of Oregon high school seniors graduated in 2018-2019.[7] While the issue of why these students are still being allowed to graduate is another subject, college educators in Oregon must take note of the fact that consistently Oregon high school students entering university level chemistry courses are not mathematically proficient even by the state's vague and loose standards. Along with this, only around 50 to 60% of Oregon juniors in high school are proficient in science by these vague standards.[6] Figure 1 below shows the mathematical and scientific proficiency of Oregon 11th graders from the 2014-15 school year to the 2017-18 school year. As noted earlier, science and math are interwoven, and science cannot be done without an understanding of mathematical concepts. Thus, it is important to note the mathematical and scientific background of students entering general chemistry.

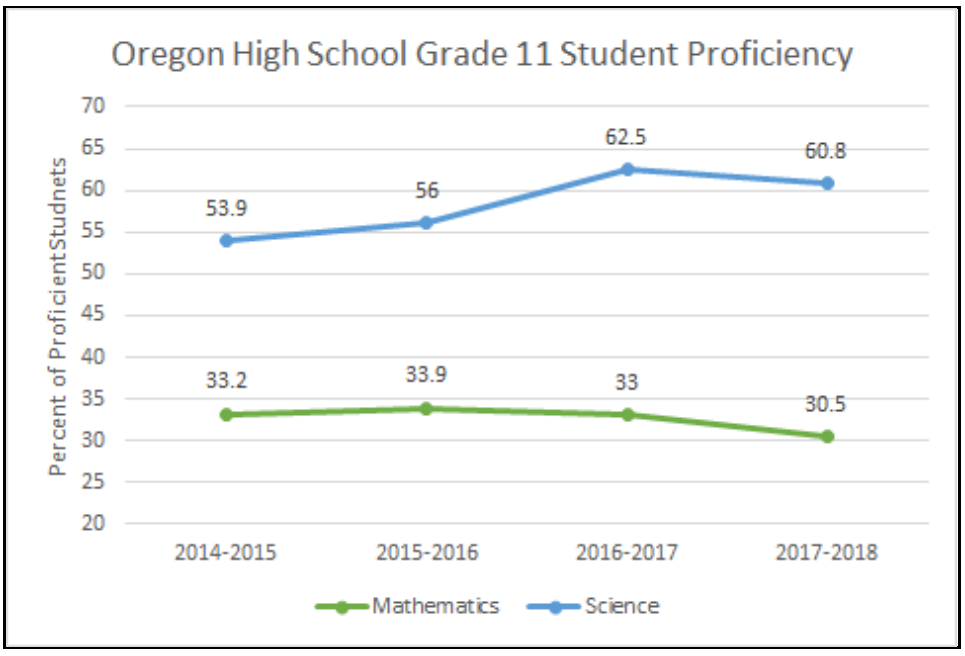

Figure 1. Oregon High School Grade 11 Student Proficiency

Needed Mathematical Skills for General Chemistry

With the understanding that many students are coming into general chemistry with low mathematical proficiency levels, it is important to determine what skills the students have and

what skills impact their success. Students need a good grasp on algebra in order to do well in chemistry, and this has shown to be an indicator for success.[8] Having simple mental algebra skills, often introduced in middle school will help students gain a better understanding of the answers that they are looking for when solving problems. Thus, these skills were explored in the mental math quiz used in this study. Following the Common Core Math Standards that Oregon high school students learn by, the mental math quiz primarily tested four basic skills: the ability to manipulate expressions with exponents, long multiplication skills, long division skills, and an ability to manipulate variable expressions. As general chemistry does not require understanding of calculus or statistics, studying these basic mathematical skills will ideally give an overview of how well students will understand and be able to solve chemistry problems and thus will indicate how well they will perform in the course.

--- Mental Math Quiz Study ---

Delivery of Mental Math Quiz

Students in both sections of the general chemistry CH 231trailer course were tested at the beginning and end of the term to determine their basic mathematical proficiency. A ten-question paper quiz was administered to students on an unannounced day in both the beginning and end of term so students were unable to prepare or study for the quiz. Students were unable to use calculators on the quiz, but were allowed to use free space in the quiz as scratch paper. These quizzes were then collected and graded on the basis of correctness. Students received one point per completely correct answer and zero points for a partial correct or incorrect answer. Students could score up to ten out of ten points on the quiz. Data was only kept for a quiz score if the student participated in both the first and the second quiz taking. Of the original pool of 324 students, only 214 sets of data were kept.

The ten-question quiz was designed to test student knowledge of basic algebraic concepts. When analyzing the questions, the algebraic skills were defined in terms of the standards presented by the Common Core Math Standards. Each question tested one primary skill and potentially also tested secondary math skills that supported the primary one. The questions and the primary skills they test are summarized in Table 1 below.

Table 1. Mental Math Quiz Questions and Corresponding Skills

Question Number	Question	Primary Skill Tested (Common Core Math Standard)
1	Change to scientific notation: 0.0074 =	8.EE.4: Expressions and Equations
2	$(3 \times 10^{2})(3 \times 10^{10}) =$	8.EE.1 + 8.EE.3: Expressions and Equations
3	$(7 \times 10^{-2})(6 \times 10^{15}) =$	8.EE.1 + 8.EE.3: Expressions and Equations
4	$\frac{6 \times 10^{-9}}{-3 \times 10^{6}} =$	8.EE.1 + 8.EE.3: Expressions and Equations
5	$\frac{10^{-16}}{2 \times 10^{-5}} =$	8.EE.1 + 8.EE.3: Expressions and Equations
6	$\frac{36 \times 10^{-12}}{(2)(2 \times 10^{-7})} =$	8.EE.1 + 8.EE.3: Expressions and Equations
7	Multiply 65 x 76 =	5.NBT: Number Operations in Base Ten
8	Divide 2,394/7 =	7.NS: The Number System
9	$\frac{56 \times 3 \times 12}{4 \times 7} =$	7.NS: The Number System
10	Solve for T_2: $\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$	HSN.A.CED: Creating Equations

Mental Math Quiz Score Overview

The Mental Math Quizzes taken at the beginning of the term (Pre) had a mean score of 4.65 with no outliers. Those taken at the end of the term (Post) had a mean score of 6.40 with no outliers. The distribution of each quiz's scores is outlined in the boxplots below. While the Pre

Quiz had a near perfect distribution of scores, the Post Quiz scores were slightly right skewed, indicating that students did minimally improve their scores at the end of the term. The Pre Quiz scores ranged from scores of zero to ten, while the Post Quiz Scores ranged from one to ten.

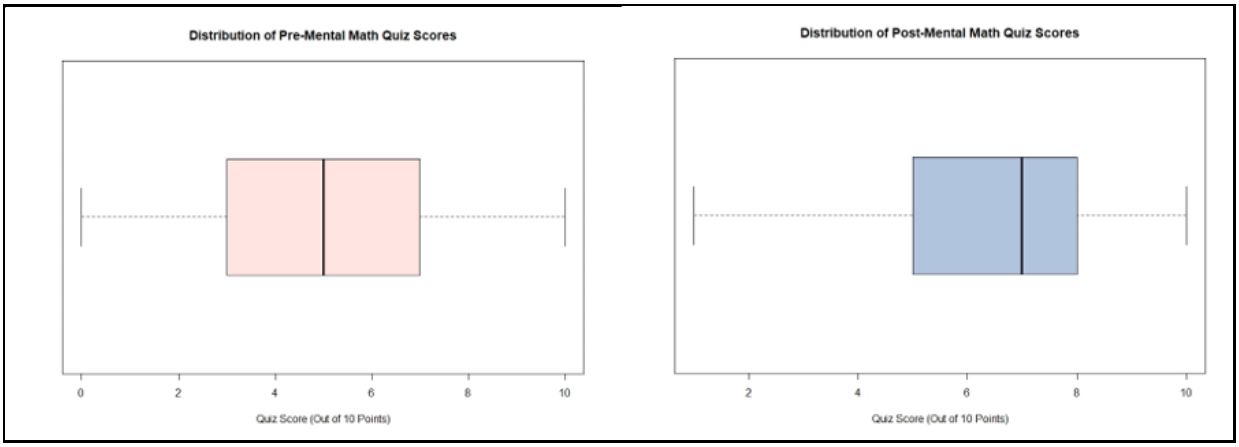

Figure 2. Distribution of Mental Math Quiz Scores

A correlation coefficient of 0.69 was found between the Pre and Post Mental Math Quiz Scores. This indicates a moderate to strong, positive linear relationship showing that students who performed well on the Pre Quiz, generally performed well on the Post Quiz. Students who scored a zero on the Pre Quiz achieved, at the highest, a score of six on the Post quiz. Although this is a significant jump, an ability to correctly answer only six of ten algebraic questions does not indicate a high level of proficiency. In addition to this, students who scored a ten on the Pre Quiz, achieved, at the lowest a nine on the Post Quiz. This roughly indicates that despite a term of using mathematical skills, students began and ended the first term of general chemistry with relatively the same mathematical proficiency.

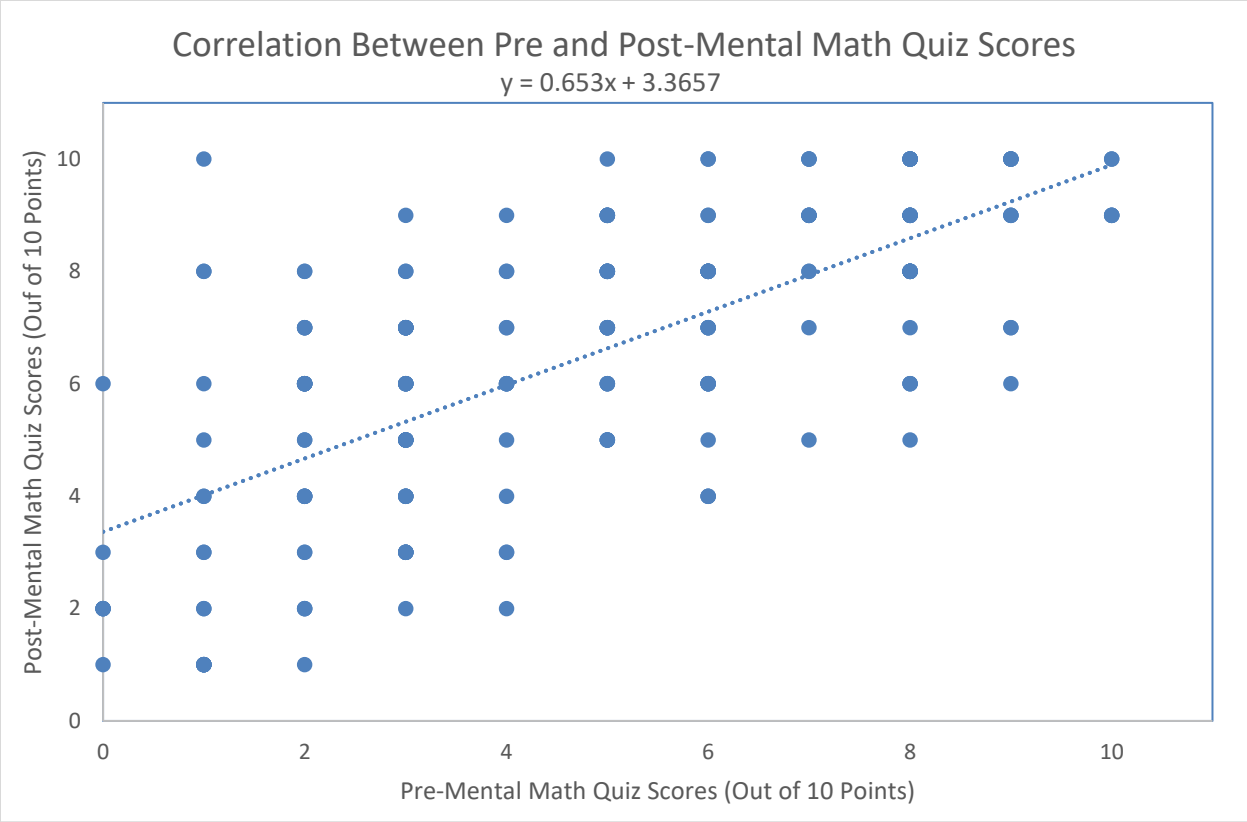

Figure 3. Correlation Between Pre and Post-Mental Math Quiz Scores

Figure 4 below, explores this relationship further. The figure shows the difference between pre and post mental math quiz scores for each student who took both quizzes. Ideally, since the average of the pre mental math quiz was 4.65, there would have been a minimum of a three point average increase in the post mental math quiz scores, to raise the average grade to around eight points, a mastery level. However, as shown by Figure 4, most students only increased their score by two points. Although 71% of the class increased their scores over the course of the term, 54% of these students - or 38% of the whole class - only increased their scores by one or two points, which raised the post mental math quiz average to 6.40. Thus, although about three-fourths of the students who took both quizzes increased their grades, this increase was not significant enough to show that students gained mastery over these topics.

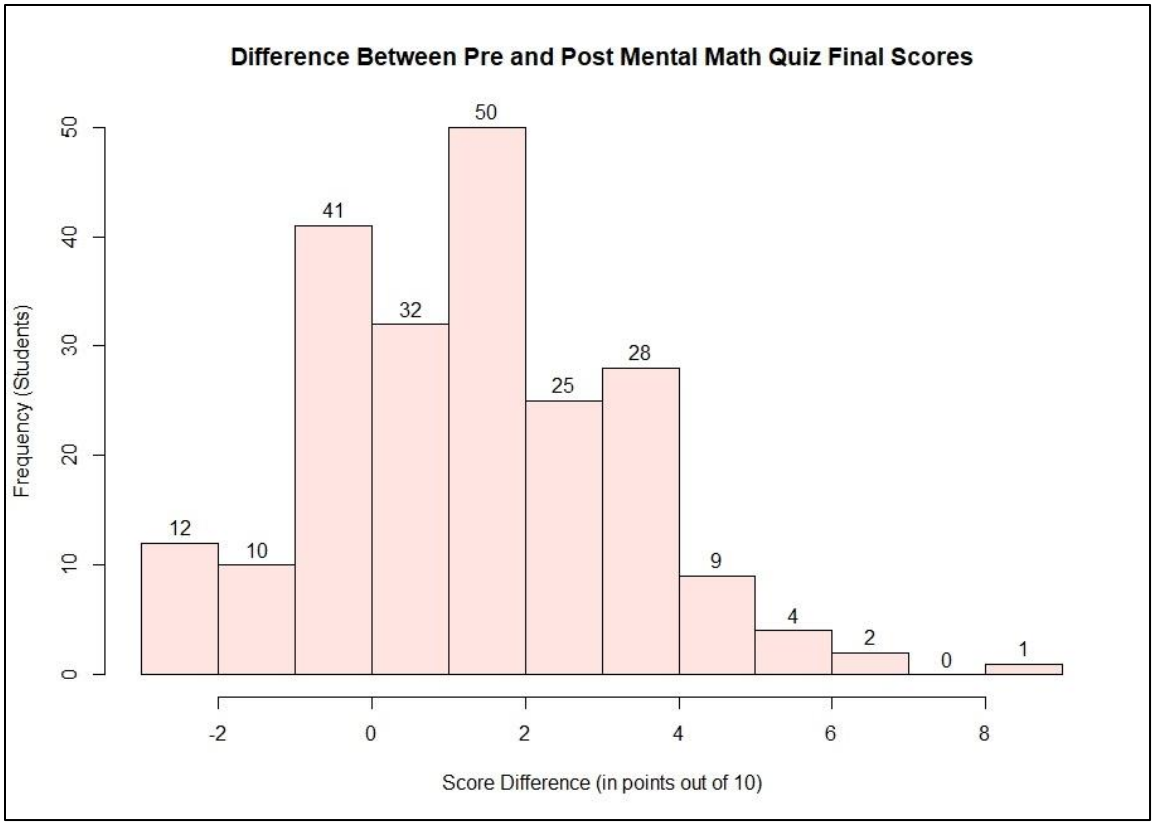

Figure 4. Difference Between Pre and Post Mental Math Quiz Final Scores

Mental Math Quiz Question Scores Analysis

Generally, students performed slightly better on the post quiz than the pre quiz as seen in the Figure 5 below. Students had the most significant difference in proficiency on Question 3 with a 57% change in proficiency. After that, Questions 2, 5, and 10 had a greater than 20% change in proficiency. Questions 1, 4, and 6 had a 10% or greater change in proficiency. Questions 7 and 9 had a less than 10% change while Question 8 actually went down 1% in the percentage of students who completed the question correctly.

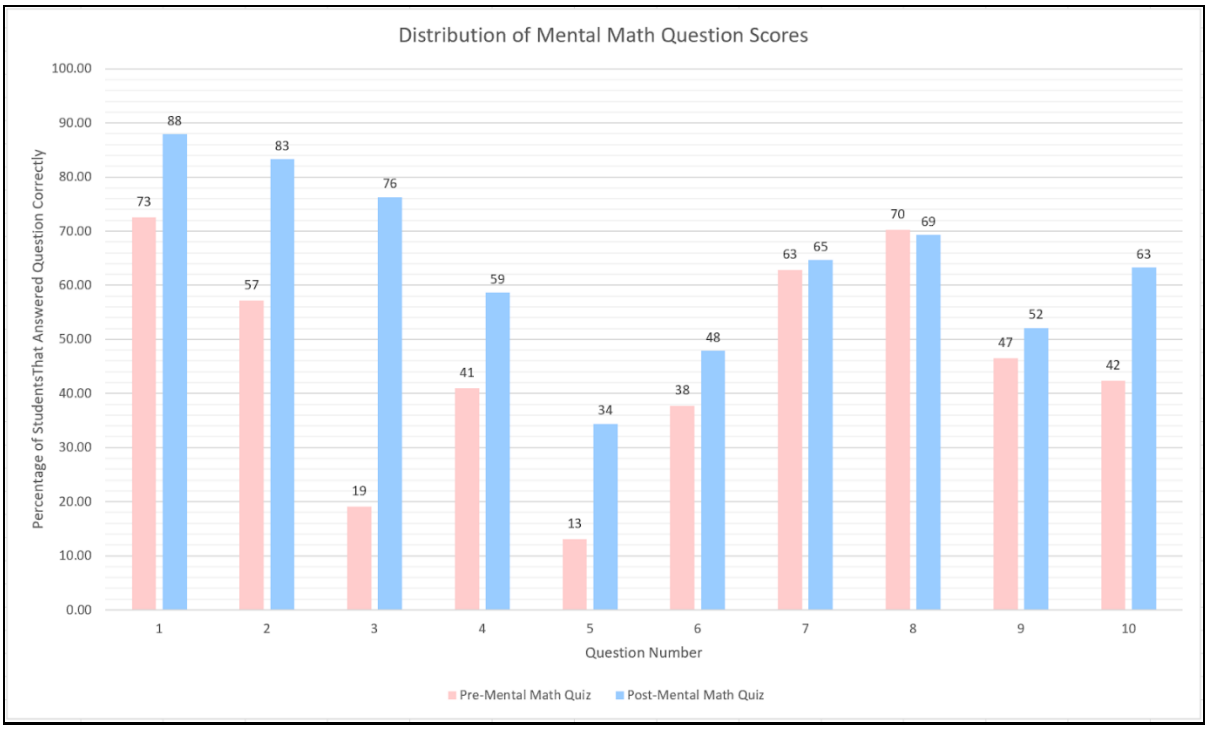

Figure 5. Distribution of Mental Math Question Scores

Question 1 tested the ability to convert decimals into scientific notation, which is covered by the Common Core Math Standard 8.EE.4 and thus is introduced in eighth grade. This standard specifically requires that students "Perform operations with numbers expressed in scientific notation, including problems where both decimal and scientific notation are used. Use scientific notation and choose units of appropriate size for measurements of very large or very small quantities … Interpret scientific notation that has been generated by technology".[9] This is a necessary skill in General Chemistry for problem-solving as chemists work with very large and very small numbers and many constants in chemistry are expressed in scientific notation. Students need to understand what scientific notation means in order to be successful. Looking at the Mental Math Quiz data, 77% of students were able to perform this simple operation coming into general chemistry and 88% could do this by the end of the first term. As this skill was already widely known by students and students learned it over the course of the term, it does not

appear to be a skill that needs to be largely focused on building in this course. However, it is important to note that by the end of a full ten weeks on doing chemistry, which relies on an understanding of this concept, 12% of the class was unable to answer this basic question correctly.

Questions 2 through 6 primarily tested students' abilities to manipulate exponents to simplify complex expressions, which mainly falls under eighth grade standards 8.EE.1 and 8.EE.3. Standard 8.EE.1. asks that students “Know and apply the properties of integer exponents to generate equivalent numerical expressions” while 8.EE.3 requires that students “Use numbers expressed in the form of a single digit times an integer power of 10 to estimate very large or very small quantities, and to express how many times as much one is than the other”.[9] In order for students to do this problem, they must also be able to perform Common Core Math Standard 6.EE.1, “Write and evaluate numerical expressions involving whole-number exponents”.[9] Thus these questions focus on skills that are built up over several years. In addition to these, high school standard N-RN.2 asks students to “Rewrite expressions involving radicals and rational exponents using the properties of exponents”, which is slight furthering of the primary skills described in 8.EE.1 and 8.EE.3.[9] The wide range of Common Core Math Standards that address this skill would ideally indicate that students are building proficiency over the course of many years and would thus mean that students entering general chemistry are adept in this. This is a particularly important algebraic skill as it is used so often to simplify expressions without the use of a calculator. These questions and skills are also important in chemistry as a furthering of question 1. To be successful in chemistry, students need not only to be able to understand exponents and scientific notation, but to be able to quickly simplify them. If students cannot get a quick general idea of the answer, they will be expending too much energy on the math and not

enough on the chemical concepts at hand. Specifically, students should be able to estimate the size of answer, or its order of magnitude, to evaluate the correctness of their approach and to determine if there was an error in their calculator output.[10]

Students' quiz scores indicate that they struggled the most with exponents. Looking more specifically at each question, Question 2 is a simple problem that asks students to multiply two large numbers - positive exponents - expressed in scientific notation. Of the questions testing standard 8.EE.1 and 8.EE.3, this question had the highest percentage correct at both the beginning and end of the term. When the course started, 57% of the students could answer this correctly and by the end 83%, showing a 26% increase. Half the students came into the course with a general understanding of exponents and some learned over the course of the term to how to use them.

Question 3 was the same as Question 2, but asked students to multiply a large number - positive exponent - and a small number - negative exponent - both expressed in scientific notation. Coming into the class, only 19% of students passed this question showing a general lack of understanding of the properties of rational exponents. By the end of the first term of general chemistry, there was a 57% increase in ability to solve this problem, however, this still meant that only 76% of students could solve a problem using the simple properties of rational exponents.

Questions 4, 5, and 6 all tested generally the same skill of dividing numbers expressed in scientific notation, but each tested different aspects of this skill. Question 4 involved students both applying a negative to the value and dividing a negative exponent by a positive one. Of the three division questions involving exponents, students scored the best on this both before and

after the term. Although students did the best on this question, by the end of the course, only 56% of students could solve the problem correctly.

Question 5 then asked students to solve a division problem where the numerator was just a number with a negative exponent and the denominator was a normal small number expressed using scientific notation. Students performed the worst on this question in both the pre and post mental math quizzes. By the end of the first term of general chemistry, only 34% of students could correctly answer this question.

Finally Question 6 tested students' ability to multiply the number expressed in scientific notation in the denominator by a single digit number and then divide the numerator, also expressed in scientific notation, by that number. Again, in this problem, both numbers expressed in scientific notation were small with negative exponents. Although this was the second question answered most correctly in this group of questions in the pre mental math quizzes, it was the fourth in the post quizzes, showing with this and its mere 10% increase in correctness that students did not generally learn this skill over the course of the term. By the end of the term, only 48% of students could answer this question correctly.

Question 7 then tested the basic skill of being able to multiply positive multi-digit whole numbers. This skill is introduced by the Common Core Math Standard 5.NBT.5, which requires students “fluently multiply multi-digit whole numbers using the standard algorithm”. [9] 63% of students answered this correctly on the pre quiz while 65% of students answered correctly on the post quiz. Thus, generally, students remained at the same skill level in this area throughout the course. Looking at these percentages, it is concerning that less than two-thirds of the students

could answer this question as in order to answer chemistry problems, students need an ability to multiply with multi-digit numbers.

Question 8 and 9 tested similar skills with division, which are outlined by Common Core Math Standard 7.NS.2, "apply and extend previous understandings of multiplication and division and of fractions to multiply and divide rational numbers". [9] Question 8 specifically looked at students' ability to perform the long division of a multidigit number by a single digit number. On the pre quiz, 70% of students answered this question correctly and 69% on the post quiz, showing like Question 7 that students generally stayed at the same ability level during the term.

Question 9 asked students to simplify a fraction with multiple numbers being multiplied in both the numerator and denominator. There were many ways to do this problem, but the simplest way is to understand that the numbers in the denominators are factors of numbers in the numerator so they can be cancelled out to create just a multiplication problem, as shown below. This is a skill that can be transferred over to working with numbers expressed in scientific notation in large equations with several variables, which are common in general chemistry. However, only 52% of students could solve this problem correctly by the end of the first term of general chemistry. It is difficult for students to perform well in chemistry if they cannot perform basic mathematical skills introduced in seventh grade.

If students are unable to use the mathematical skills tested in the first nine questions of the mental math quiz, then they will have difficulty solving chemistry problems without the use of the calculator. It is not enough to know how to use a calculator, students need to understand how the math works so that they can gain an idea of what is happening in chemistry.

The final question on the quiz, tested students' ability to manipulate variables in an equation without the use of numbers, which is a key skill in chemistry. This skill is introduced in standard HSN.A.CED, which requires that students be able to "rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations". [9] At the start of the term, only 42% of students could do this skill and by the end 63% of students answered correctly showing an increase in ability. This is a key skill for students as before they can even get to solving for the answer, they need to be able to create the correct equation. Thus, only 63% of a class being able to do variable rearrangement within an equation by the end of the term is concerning.

In general, students began the class with the least knowledge of how to multiply and divide numbers expressed in scientific notation or how to manipulate an equation to isolate a particular variable. While their scores in these areas did generally improve, by the end of the term, none of these questions had more than 80% of the class completing them correctly and these were still the worst scored questions. Thus, exponent manipulation would be an important area to explicitly work with students in. Although students did score the worst on these particular questions, none of the questions, except for the first two, had more than 80% of the students completing them correctly by the end of the term. Therefore, all of the skills tested in the mental math quizzes would be worth addressing explicitly in future course curriculums.

Summary of Mental Math Quiz Scores

With these limitations in mind, students in the CH 231 trailer course, began the term with an average score of 4.65 and ended with only a two point increase in the average score to 6.40 on the mental math quiz. 71% of the class either kept their initial grade or raised their scores by only one or two points. In addition to this, there was a 0.69, moderate to strong, correlation between

the pre and post mental math quiz scores. This combined with the low rate of score increases over the course of the term indicates that students generally began and ended the term with the same level of mathematical knowledge and thus did not pick up skills naturally. The quiz results indicate, in particular, that students struggle with multiplication and division of exponents and with variable manipulation.

Limitations of Mental Math Quiz Data

It is important to note some limitations of these data, and thus the subsequent conclusions drawn from it. The conclusions drawn from this study were based on the results from two sections in one class of general chemistry during Winter Term. Oregon State University offers six general chemistry courses during winter term and none of the other five courses were quizzed. Thus the results of this study are not necessarily representative of the entirety of general chemistry at Oregon State University. In addition to this, data was taken from only one year, rather than over time to determine an average, or to see if there is a change over time. Furthermore, each year Oregon State University has a unique population of students thus the results of this study could vary significantly from year to year. Finally, the course that data was pulled from is the trailer course for the CH 23x general chemistry series. As it is the trailer series, many of the students in the course have already failed general chemistry once before and thus might negatively skew the data in relation to the rest of the general chemistry courses. However, as the goal of this study was to determine the extent of mathematics knowledge of the students in general chemistry, understanding the students who perform the worst would be the most beneficial. Thus, this limitation potentially works towards the benefit of this particular study.

An additional limitation to consider is that these mental math quizzes solely tested mathematical proficiency. As noted in the question breakdown, it is key that students understand

basic algebra so that they can apply these skills to chemistry problems. Thus there are really two separate issues raised here. First, an ability to do algebra and, second, an ability to apply these skills to chemistry problems. As these mental math quizzes only addressed the ability to do algebra, they do not provide information on the second key issue raised.

Mathematical Transference to Chemistry

The second issue raised by this study is the ability to apply, or transfer, mathematical knowledge to chemistry problems. Students entering general chemistry often struggle to understand chemistry problems as they are not always clearly set up to show the arithmetic operations needed to solve the problem.[11] When this occurs, students attempt to "solve by analogy" by trying to match the problem at hand with one similar to something in the textbook or their notes.[11] Typically, when students do this they are comparing problems based on surface features, such as the unit of chemistry from which the problem is from, rather than the underlying mathematical features that determine the procedure for solving problems.[11] For example, students many not recognize that the mathematical skills needed to complete limiting reactant and solution stoichiometry problems are the same – dimensional analysis. This causes students to apply mathematical procedures based on similarity of problems within a learning unit, which leads to incorrect answers and confusion. Fluency in mathematics is meaningless in a chemistry course if students cannot use it to solve problems or interpret their results. Students must have an understanding of how and when to apply these skills or else they will waste time attempting to solve problems and have no true understanding of what is happening.

--- Courses of Action ---

Based on the results of this study, we cannot assume that students are entering general chemistry with the needed mathematical skills to be successful, or that most of them are learning these needed skills on their own over the course of the term. In an ideal world, students would have actually learned the skills that are required of them before entering general chemistry and professors would not need to explicitly address or teach these prerequisite skills. However, it is clear that this is not happening and thus in order to ensure the success of students in general chemistry a change needs to be made.

It would logically follow that if students are entering general chemistry without the needed mathematical skills then their course prerequisites should be reevaluated. To enter the CH 231 trailer course a student must be enrolled in MTH 111 (College Algebra) as a corequisite. Though, if a student has passed a higher-level math course that will meet this requirement. The minimum score in each course needed to enter CH 231 could be raised to help ensure students can perform the needed mathematical skills at a mastery level. However, this only addresses one of the problems raised in this study - an inability to do mathematics. Passing these courses does not mean that students will know how to apply their mathematical skills in chemistry problems as the courses are not hosted by the Department of Chemistry.

Following this line of reasoning, it could be helpful to offer a specific chemistry course that teaches students the mathematical skills needed for chemistry and how to apply them to scientific problems. The Department of Chemistry offers an optional course, CH 101 (Foundational Skills for General Chemistry), which teaches students mental math skills to prepare them for general chemistry. Mandating that all students take this course before entering general chemistry would ensure that all students have been exposed to the needed mathematical skills and know how to apply them to chemistry problems. However, several thousand students

take general chemistry each year and it would require significant time and resources to expand this into a prerequisite course. In addition to this, not all students need this additional help so it might not be helpful to force all students to take this course first.

There needs to be more flexibility in what is taught to students to meet the needs of the diverse student population entering Oregon State each year. Thus, I suggest that a more flexible route be taken that would allow professors to determine the mathematical demographics of the students in their courses and adjust their course as needed. A test similar to the mental math quiz given in this study can be used to test students incoming mathematics proficiency. The CH 23x trailer series in particular relies on students' ability to use and apply mathematics to chemistry on their own as it is structured as a flipped classroom. In flipped classrooms, students review the learning resources - lecture videos, readings, example calculations, etc. - on their own time before class and then during class students work in groups to complete problems about the learning resources. At the end of class, the most difficult concepts and problems are reviewed as a whole class. While some of these problems are written explanations of chemical theory, many of the problems are calculations. Thus, in order for students to get the most out of their class time they need to be able to actually apply mathematical skills to these problems and be able to contribute to the group.

With these considerations, it is necessary that the students have these skills, but as general chemistry is an introductory course, the students entering the course have a wide variety of backgrounds. In order to meet the needs of these students it would be useful to assess students' incoming mathematical abilities by implementing a mental math assessment similar to the mental math quiz used in this study. This assessment can be two parts to determine students' general ability in the two main areas - mathematical ability and ability to apply these skills to

chemistry problems. The results of the assessment will both help professors gain a better understanding of their students' abilities and could allow professors to adjust their learning resources and curriculum accordingly.

--- Development of Mathematical Skill Assessment ---

Mathematical Skill Assessment Creation

This assessment would draw from specific needs of the chemistry course and can be easily tailored to different courses. This assessment should be broken into two portions, the first testing mathematical ability separate from application and the second part evaluating students' ability to apply mathematics to chemistry problems.

I developed an example assessment for the CH 231 trailer course, shown in Figures 5 and 6. To determine which skills needed to be tested on the assessment, I first reviewed the learning objectives for the course on the whole. From these objectives, I chose the ones that explicitly dealt with calculations, a complete list of these objectives can be found in the Supplemental Information on page 33. From this list, I determined which mathematical skills were needed to complete the calculations in the learning objective. Below in Table 2 is a list of the primary mathematical skill needed to complete each learning objective in CH 231 and the corresponding objectives. Note that many of the objectives require the use of other mathematical skills, but only the primary skill is listed in this table. In addition, the learning objectives listed in Chapter 3 and Chapter 5 are not included as calculating Effective Nuclear Charge and formal charge require only simple addition.

Table 2. Needed Mathematical Skills for CH 231 Trailer Learning Objectives

Mathematical Skill	**Learning Objective (Chapter.Number)**
Dimensional Analysis	E.4, E.5, E.6, E.7, 4.13, 7.8, 7.10, 7.11, 8.18
Exponents	2.11
Long Multiplication and Division	2.9, 2.14, 2.17, 4.16, 4.18, 8.2, 8.9
Order of Operations	E.14, 2.12
Percentages	1.17, 1.18, 4.15, 4.17, 7.12
Scientific Notation	E.11
Significant Figures	E.11, E.12, E.13, E.14
SI Prefixes	E.3, E.5
Variable Rearrangement	2.7, 8.4

From this information, I created the first portion of the assessment by creating eight problems that solely addressed the mathematical skills needed for the learning objectives not in the context of chemistry. Figure 5 below shows the first portion of the assessment.

PART ONE:

1. Simplify the expression: $6\ unicorns \times \frac{2\ dragons}{3\ unicorns} \times \frac{5\ griffins}{1\ dragon} \times \frac{3\ mermaids}{10\ griffins} =$ 1. _____
2. Simplify the expression: $\frac{(45\times3)(2\times10^{3})}{(6+3)(5\times10^{-7})} =$ 2. _____
3. Multiply 72 x 46 = 3. _____
4. Divide 882 /42 = 4. _____
5. Determine 73% of 52 5. _____
6. Change to scientific notation: 0.0000678 6. _____
7. Report the answer with the correct number of significant figures: $\frac{(2.00+6.0)10.00}{5.0+0.5} =$ 7. _____
8. Solve for m: y = mx + b 8. _____

Figure 5. Part One of Mental Math Assessment

All the mathematical skills tested by the learning objectives, except for SI prefixes, are assessed in the first portion of the quiz. Some questions include multiple skills to determine if students are able to use several skills at once.

Question 1 tests students' basic skill with dimensional analysis. In order to complete this problem, students must understand that unit conversions allows for the cancelling of units to change the original units to new units. This skill is needed to do stoichiometry in chemistry, which is often a basis for more complex problems. Question 2 involves both order of operations and exponent manipulation. Students must understand in what order to multiple and add terms based on the order of operations to get the answer and they must also demonstrate an understanding of the properties of exponents. These two skills are often found together in chemistry problems such as when determining energy states of electrons or when looking at

emission spectra. Questions 3 and 4 test students' ability to perform long multiplication and division. Question 5 also tests the skill of long multiplication, but in the context of percentages. Question 6 looks at the ability to change numbers into scientific notation, which students need to do in order to properly note numbers produced by their calculators. Question 7 asks students to report the correct number of significant figures produced by the problem. In order to do this, students must understand both the order of operations and how this affects the final number of significant figures. Question 8 test students' ability to manipulate a variable equation that is familiar to most high school students – the slope-intercept equation. These are basic skills that students need to complete many of the chemistry problems in the first term of general chemistry. Table 3 below summarizes the mathematical skills tested by each question.

Table 3. Part One Questions and Corresponding Skills

Question Number	**Question**	**Mathematical Skill**
1	Simplify the expression: $6\ unicorns \times \frac{2\ dragons}{3\ unicorns} \times \frac{5\ griffins}{1\ dragon} \times \frac{3\ mermaids}{10\ griffins} =$	Dimensional Analysis
2	Simplify the expression: $\frac{(45\times3)(2\times10^{3})}{(6+3)(5\times10^{-7})} =$	Order of Operations, Exponents
3	Multiply 72 x 46 =	Long Multiplication
4	Divide 882 /42 =	Long Division
5	Determine 73% of 52	Percentages, Long Multiplication
6	Change to scientific notation: 0.0000678	Scientific Notation
7	Report the answer with the correct number of significant figures: $\frac{(2.00+6.0)10.00}{5.0+0.5} =$	Order of Operations, Significant Figures
8	Solve for m: y = mx + b	Variable Rearrangement

After determining the needed mathematical skills to be successful in the course and writing the first part, I reviewed the in-class problem sets for CH 231 to determine specifically how these mathematical skills will be applied in context. I pulled six example problems that encompassed the needed mathematical skills and simplified the numbers so that they could easily be completed as mental math problems, shown in Figure 6 below.

PART TWO:

1. How many grams of Helium gas are present in 179 liters assuming its molar mass is 4.00 g/mol and its density is 0.179 g/L?

2. How many significant figures should be present in the answer? _____

   $137.327\ g \times \frac{4.184\ J}{g\ °C} \times (53.6°C - 22.6°C) =$

3. The density of water is 1.0 g/mL at room temperature. What is the density of room temperature water in units of kg/dL?

4. Determine the frequency (ν) of orange-red radiation emitted by the krypton-86 atom using the equation $\lambda = \frac{c}{\nu}$ assuming that the speed of light (c) is 3.00 x 10^8 m/s and its wavelength (λ) is 6.0 x 10^{-7} m.

5. An element consists of 20% of an isotope with mass 10 amu, 30% of an isotope with 12 amu, and 50% of an isotope with mass 14 amu. Calculate the average atomic mass of the element from its three isotopes in units of amu.

6. Solve for T: $(8\ g)\left(\frac{10\ J}{g°C}\right)(100\ °C - T) = (5\ g)\left(\frac{4\ J}{g°C}\right)(T - 20\ °C)$

Figure 6. Part Two of Mental Math Assessment

Table 4 below denotes the mathematical skills tested by each question. The second portion of the assessment focuses on the application of mathematical skills to chemistry word problems. The first question tests the skill of dimensional analysis, or stoichiometry as it's called in chemistry. The problem requires not only that students understand the concept of unit conversion, but that they are able to set up a simple stoichiometric problem to find the answer.

This skill is very important as it is the basis for larger problems latter in the course. Question 2 determines students' understanding of the basic rules of significant figures in the context of the order of operations. Question 3 asks students to use dimensional analysis and unit conversion in the context of SI prefixes. Question 4 requires that students rearrange a simple variable equation to isolate a specific variable and then use the properties of exponents to determine the answer. The fifth question requires that student possess an understanding of percentages in order to determine an average. Finally, question 6 requires that students use the distributive property of multiplication to isolate a specific variable and find the answer. The skills tested in the second portion of the assessment are representative of common calculations in the first term of general chemistry.

Table 4. Part Two Questions and Corresponding Skills

Question Number	Question	Mathematical Skill
1	How many grams of Helium gas are present in 179 liters assuming its molar mass is 4.00 g/mol and its density is 0.179 g/L?	Dimensional Analysis, Long Multiplication and Division
2	How many significant figures should be present in the answer? $137.327\ g \times \frac{4.184\ J}{g\ °C} \times (53.6°C - 22.6°C) =$	Significant Figures
3	The density of water is 1.0 g/mL at room temperature. What is the density of room temperature water in units of kg/dL?	Dimensional Analysis, SI Prefixes
4	Determine the frequency (ν) of orange-red radiation emitted by the krypton-86 atom using the equation $\lambda = \frac{c}{\nu}$ assuming that the speed of light (c) is 3.00 x 10^8 m/s and its wavelength (λ) is 6.0 x 10^{-7} m.	Exponents, Variable Manipulation
5	An element consists of 20% of an isotope with mass 10 amu, 30% of an isotope with 12 amu, and 50% of an isotope with mass 14 amu. Calculate the average atomic mass of the element from its three isotopes in units of amu.	Percentages
6	Solve for T: $(8\ g)\left(\frac{10\ J}{g°C}\right)(100\ °C - T) = (5\ g)\left(\frac{4\ J}{g°C}\right)(T - 20\ °C)$	Order of Operations, Variable Manipulation, Long Multiplication and Division

Mathematical Skill Assessment Delivery & Analysis

This assessment should be delivered during the first class period and taken independently, without the use of a calculator. The quiz should then be scored, giving one point for each completely correct answer. Partial or partially correct answers should not be awarded points as only completely correct answers indicate a full understanding of the skill being assessed. Once each quiz has been graded, both the overall score and the specific question scores should be evaluated to determine the mathematical needs of the students in the course.

The overall quiz grade does provide a good overview of the mathematical level of the students, however, assessing the two parts of the quiz independently provides more detailed information about the skills of the class. The scores on the first portion of the quiz indicate students' ability to do mathematical skills on their own without adding in the extra difficulty of the context of chemistry. The second part of the quiz tests students' ability to apply these skills in the context of chemistry problems.

If students pass the first portion, but receive low scores on the second portion, they do not have the ability to apply their mathematical skills and will need explicit help in this area. However, if they fail both portions, they have neither the mathematical ability or the knowledge to apply it, indicating that the students will need resources for both using and applying mathematical skills.

Based on the students' difficulties in the assessment, different learning resources can be provided along with the typical chemistry resources that will help students understand the mathematical concepts and how to apply them. These resources can be made as optional reading to give students who need this help a resource without having to take class time to explain concepts to the whole class. For parts of the assessment that most of the class fails, though, time

can be allotted in class to explain these concepts and how they relate to the unit. If students cannot apply mathematical skills to chemistry, they will not be able to fully engage with the chemistry content. Thus, giving these assessments to determine the particular skills of a class can significantly help the professor tailor their curriculum and teaching methods to ensure the success of their students.

--- Future Research ---

Although this study provides some insight, there are several areas in which this study could be furthered to gain a better understanding of the mathematics ability of the students in general chemistry and what courses of action would be best in ensuring students' success in the course. First, as mentioned earlier, the CH 101 course potentially provides students with mathematics skills that will make them more successful in the CH 23x trailer series. It would be useful to follow the students who take CH 101 and study their exam scores and grades in the CH 23x trailer series afterwards to determine if the course significantly improves their scores and abilities compared to students who did not take the course. If students do perform significantly better after taking CH 101, then it could be pertinent to consider either incorporating material from CH 101 into the CH 23x series or possibly making it a mandatory course.

This study also only focuses on the CH 23x series, which is more difficult and mathematically heavy than the CH 12x series. Thus, it would be useful to determine the mathematical ability of students in the CH 12x series as well by conducting a similar study. Finally, the best way to determine the impact of students' mathematical ability on their chemistry abilities would be to compare their mental math quiz scores to students' overall exam and course grade scores.

--- Conclusion ---

The purpose of this study was to analyze a snapshot of the mental math abilities of students in general chemistry at Oregon State University and from this to determine courses of action to increase the success of students in general chemistry. To analyze these abilities, students in two sections of the CH 231 trailer course were given a ten question mental math quiz at the beginning and the end of the term. These quizzes were completed independently without the use of the calculator. 214 of the students in this course completed both the pre and post mental math quiz and their scores were analyzed to provide a look into the general mathematical abilities of students in general chemistry. As this study was based on the quiz scores from one term and one course of the six general chemistry courses offered at Oregon State University each term, these results do not necessarily provide a comprehensive overview of students' mathematical skills. Future research encompassing all of the classes over a period of several years would be helpful in gaining a better understanding of students' skills.

Despite this, the results of the mental math quiz do provide some insight into students abilities. The pre mental math quiz had an average score of 4.65 and the post mental math quiz had an average score of 6.40. Although the overall course average for the mental math quiz scores increased slightly, most students either kept their scores the same or increased by only one or two points. This indicates that despite assumptions that students will pick up needed mathematical skills over the course of the term if they do not know them coming in, students are generally keeping the same proficiency level that they began the term with.

Although in an ideal world, students would be entering general chemistry with the needed mathematical abilities, they are not and students are also not learning them on their own, thus a change needs to be made in order to increase the success of students in general chemistry. Stricter entrance requirements could be made or a chemistry mathematics course could be

mandated in order to ensure that students entering general chemistry are prepared, however, these changes would be time consuming and difficult to implement. I suggest instead implementing a mental math assessment at the beginning of each term to assess students abilities. This assessment would have two parts, the first to determine base mathematical skill and the second to determine if students can apply these skills to chemistry problems.

The results of this quiz would show the mathematical abilities and thus needs of the students in the course. Based on which questions students get incorrect, professors can provide additional learning resources about mathematical concepts or even explicitly teach concepts if the majority of students get a question wrong. Spending a small amount of time and effort on providing students with resources so they can understand mathematical concepts and how to apply them will save time in the long run both for students and professors and increase student success in general chemistry, as shown by previous studies. Thus the results of this study, as well as those of previous studies, indicate that in order for students to be successful in general chemistry, mathematical skills and their applications need to be explicitly taught during the course.

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--- Supplemental Information ---

Calculations

Outliers in Pre and Post Mental Math Quizzes occured if scores were < Q1 - 1.5(IQR) or > Q3 + 1.5(IQR).

Pre
Q1 = 3 → 3 - 1.5(4) = -3 → No outliers as there were no scores below zero
Q3 = 7 → 7 + 1.5(4) = 13 → No outliers as there were no scores above ten
IQR = 4

Post
Q1 = 5 → 5 - 1.5(3) = 0.5 → No outliers as there were no scores below one
Q3 = 8 → 8 + 1.5(3) = 12.5 → No outliers as there were no scores above ten
IQR = 3

RStudio Code

RStudio was used to generate several graphs and to determine the correlation coefficient between the pre and post mental math quiz scores.

Creation of Boxplot of Pre and Post Mental Math Quiz Scores

```
boxplot(CompleteMMQuizScores1$V4, main="Distribution of Pre-Mental Math Quiz Scores", xlab="Quiz Score (Out of 10 Points)", col="mistyrose", horizontal=TRUE)

boxplot(CompleteMMQuizScores1$V15, main="Distribution of Post-Mental Math Quiz Scores", xlab="Quiz Score (Out of 10 Points)", col="lightsteelblue", horizontal=TRUE)
```

Determination of Correlation Coefficient between Pre and Post Mental Math Quiz Scores

```
cor(PreMMScores1,PostMMScores1)
```

Creation of Histogram of Difference Between Pre and Post Mental Math Quiz Final Scores

```
hist(Full.Student.Data.V2$Difference, main="Difference Between Pre and Post Mental Math Quiz Final Scores", xlab="Score Difference (in points out of 10)", ylab="Frequency (Students)", col="mistyrose", labels = TRUE)
```

Complete List of Learning Objectives Involving Calculations for the CH 231 Trailer Course

Chapter E

3. Be able to use the SI Prefix multipliers to convert between different units with different prefixes (e.g. convert 52 cg to kg)

4. Be able to convert between different “American” units (e.g. convert 16 inches to miles)

5. Be able to convert between SI and “American” units (e.g. convert 16 inches to cm)

6. Be able to convert between volumes given in cubic terms, for example cm3, and standard terms, for example, liters (e.g. convert 25 cm3to liter)

7. Be able to convert units in squared or cubic terms into different squared or cubic terms (e.g. convert 32.4 cm3to mm3)

11. Be able to determine how many significant figures are in a given number, in both decimal and scientific notation

12. Be able to determine how many significant figures to report in the answer to calculations involving addition and/or subtraction

13. Be able to determine how many significant figures to report in the answer to calculations involving multiplication and/or division

14. Be able to determine how many significant figures to report in the answer to calculations involving multiple mathematical operations (a mix of addition/subtraction and multiplication/division)

16. Be able to give "order of magnitude" estimations for calculations you have laid out (very useful for detecting math errors made in calculations)

Chapter 1

17. Given information about the masses of isotopes and their abundance be able to calculate an average atomic mass for an element

18. Be able to determine which of several isotopes is found in the greatest abundance from the atomic mass of the element. Be able to justify your choice

Chapter 2

7. Be able to do calculations involving emission spectra

9. Be able to determine the binding energy, threshold frequency, or velocity of emitted electrons given data from a photoelectric effect experiment

11. Be able to calculate the allowed energy states for the electron in a hydrogen atom

12. Be able to determine the energy absorbed or released when an electron moves between any two allowed levels in a hydrogen atom, or determine the initial or final energy state of an electron in a hydrogen atom given data about the energy of light absorbed or emitted

14. Be able to calculate the DeBroglie wavelength of an object

17. Be able to use the Uncertainty Principle to determine the uncertainty in position or velocity of a particle of known mass

Chapter 3

9. Be able to explain what Effective Nuclear Charge is, how it is calculated, and how it affects atomic size

Chapter 4

13. Be able to do calculations which interconvert mass, moles, and number of particles

15. Be able to calculate the empirical formula of a chemical given the percent by mass data

16. Be able to determine the molecular formula of a chemical from its empirical formula and information about the approximate molar mass of the chemical

17. Be able to calculate the mass percent of an element in a compound given the chemical formula of the compound

18. Be able to determine the mass of a given element in a sample of a compound of known mass

Chapter 5

10. Be able to calculate formal charge for each atom in a molecule or ion

Chapter 7

8. Be able to do stoichiometric calculations as shown in the book and discussed in the videos.

10. Be able to determine which reactant is the limiting reactant in a problem

11. Be able to work limiting reactant problems

12. Be able to calculate theoretical and percent yields

Complete Pre Mental Math Quiz Scores

*Blank boxes indicate that the student did not take the quiz.

Student Number	Quiz Score	Question 1	Question 2	Question 3	Question 4	Question 5	Question 6	Question 7	Question 8	Question 9	Question 10
1	1	0	0	0	0	0	0	0	0	1	0
2	4	1	1	0	0	0	1	0	1	0	0
3	6	0	0	0	1	1	1	1	1	0	1
4	8	1	1	0	1	0	1	1	1	1	1
5	4	1	0	0	0	0	0	1	1	1	0
6	3	0	0	0	0	0	0	1	1	0	1
7	4	1	0	0	0	0	0	1	1	0	1
8	5	1	1	0	0	0	0	1	1	0	0
9	2	0	0	0	0	0	0	1	0	1	0

10	8	1	1	0	1	0	1	1	1	1	1
11	1	1	0	0	0	0	0	0	0	0	0
12											
13	2	1	0	0	0	0	0	0	0	0	1
14	6	1	1	0	0	0	0	1	1	1	1
15											
16	6	1	0	1	0	0	0	1	1	1	1
17	3	1	0	0	0	0	0	1	1	0	0
18	2	0	1	0	1	0	0	0	0	0	0
19	6	1	1	1	0	1	1	0	0	1	0
20	2	1	1	0	0	0	0	0	0	0	0
21	4	0	0	1	0	0	0	1	1	1	0
22	5	1	0	0	0	0	0	1	1	1	1
23	7	1	1	1	1	1	0	1	1	0	0
24	6	1	0	0	0	0	1	1	1	1	1
25	5	1	1	0	0	0	0	1	1	1	0
26	6	1	1	0	0	0	0	1	1	1	1
27	6	0	1	0	1	0	1	0	1	1	1
28	3	1	1	0	1	0	0	0	0	0	0
29	3	1	0	0	0	0	0	0	1	0	1
30	7	1	1	0	1	0	1	1	1	1	0
31	2	0	1	0	1	0	0	0	0	0	0
32	3	1	0	0	0	0	0	1	1	0	0
33	1	0	1	0	0	0	0	0	0	0	0
34	4	0	1	0	1	1	1	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0
36	3	1	1	0	0	0	0	1	0	0	0
37	5	1	1	0	0	0	0	1	1	1	0
38	9	1	1	1	1	0	1	1	1	1	1
39	8	1	1	0	1	1	1	0	1	1	1
40	1	1	0	0	0	0	0	0	0	0	0
41	8	1	1	0	1	0	1	1	1	1	1
42	5	1	0	0	0	0	0	1	1	1	1
43	1	1	0	0	0	0	0	0	0	0	0
44	2	1	0	0	0	0	0	0	1	0	0
45	7	1	1	0	0	0	1	1	1	1	1
46	4	1	0	0	0	0	0	1	1	0	1
47	2	0	0	0	0	0	0	1	1	0	0
48	2	1	0	0	0	0	0	1	0	0	0
49	3	1	0	0	0	0	0	1	1	0	0
50	5	1	0	0	0	0	1	1	1	1	0
51	3	1	0	0	0	0	0	0	0	1	1
52	3	1	1	0	0	0	0	0	1	0	0

53	0	0	0	0	0	0	0	0	0	0	0
54	7	0	1	0	1	0	1	1	1	1	1
55	6	1	1	1	0	0	1	1	1	0	0
56	7	1	1	1	1	1	1	0	1	0	0
57	8	1	1	1	1	1	1	1	1	0	0
58	6	0	1	1	0	0	1	1	1	1	0
59	3	1	0	0	1	0	0	0	1	0	0
60	5	1	1	0	1	0	0	1	1	0	0
61	3	1	1	0	0	0	0	0	0	0	1
62	4	1	0	0	0	0	1	0	1	0	1
63	8	1	1	1	1	1	1	0	1	1	0
64	0	0	0	0	0	0	0	0	0	0	0
65	1	1	0	0	0	0	0	0	0	0	0
66	4	1	1	0	0	0	0	0	1	0	1
67	3	0	1	0	0	0	0	0	1	1	0
68	6	0	1	0	1	0	1	1	1	0	0
69	4	1	1	0	0	0	0	1	1	0	0
70	6	1	0	0	1	0	1	1	1	0	1
71	2	1	0	0	0	0	0	0	1	0	0
72	2	1	0	0	0	0	0	1	0	0	0
73	3	1	0	0	0	0	0	1	1	0	0
74	3	1	1	0	0	0	0	1	0	0	0
75	4	1	0	0	0	0	0	0	1	1	1
76	3	1	0	0	0	0	0	1	1	0	0
77	4	1	0	1	0	0	1	0	1	0	0
78	4	1	0	0	0	0	0	1	1	1	0
79	2	1	0	0	0	0	0	0	0	0	1
80	4	1	1	0	0	0	0	1	1	0	0
81	1	0	0	0	0	0	0	1	0	0	0
82	1	0	1	0	0	0	0	0	0	0	0
83	1	0	0	0	0	0	0	0	1	0	0
84	5	1	0	0	1	0	0	1	1	1	0
85	6	1	1	0	1	0	0	1	1	1	0
86	8	1	1	0	1	1	1	0	1	1	1
87	0	0	0	0	0	0	0	0	0	0	0
88	6	1	1	0	0	0	0	1	1	1	1
89	7	1	1	1	0	0	0	1	1	1	1
90	2										
91	3	0	0	0	0	0	0	1	1	1	0
92											
93	8	1	1	0	0	1	1	1	1	1	1
94											
95	7	1	1	0	1	1	1	1	1	0	0

96	6	1	0	0	1	0	1	1	1	0	1
97											
98	1	0	0	0	1	0	0	0	0	0	0
99	8	1	1	1	1	0	0	1	1	1	1
100	9	1	1	1	0	1	1	1	1	1	1
101	8	1	1	0	1	1	1	1	1	1	0
102	9	1	1	0	1	1	1	1	1	1	1
103	9	1	1	1	1	0	1	1	1	1	1
104	5	0	1	0	0	0	0	1	1	1	1
105	10	1	1	1	1	1	1	1	1	1	1
106	6	0	1	0	1	0	0	1	1	1	1
107	5	1	1	0	1	0	1	0	0	0	1
108											
109	2	1	0	0	0	0	0	1	0	0	0
110	5	1	1	0	1	0	1	0	0	0	1
111	7	1	1	0	1	0	0	1	1	1	1
112	3	1	1	0	0	0	0	0	1	0	0
113	5	1	1	0	1	0	1	1	0	0	0
114	8	1	1	0	1	0	1	1	1	1	1
115	5	1	1	0	1	0	0	1	0	1	0
116											
117	5	1	1	0	0	0	0	0	1	1	1
118	5	1	1	1	0	0	0	1	1	0	0
119	3	1	1	0	0	0	0	0	0	1	0
120	2	0	1	0	0	0	0	0	1	0	0
121	5	1	1	0	1	0	1	0	0	0	1
122	2	1	0	0	0	0	0	0	0	0	1
123	3	1	0	0	0	0	0	0	1	1	0
124	8	1	1	0	1	1	1	1	1	1	0
125	3	0	1	0	1	0	1	0	0	0	0
126	10	1	1	1	1	1	1	1	1	1	1
127	2	0	0	0	0	0	0	1	0	0	1
128	10	1	1	1	1	1	1	1	1	1	1
129	1	0	0	0	0	0	0	1	0	0	0
130	4	1	1	1	1	0	0	0	0	0	0
131	8	1	1	0	1	0	1	1	1	1	1
132	2	1	0	0	0	0	0	0	1	0	0
133	3	1	0	0	0	0	0	0	1	1	0
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136	9	1	1	1	1	0	1	1	1	1	1
137	9	1	1	1	1	0	1	1	1	1	1
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139	7	1	1	0	1	1	1	1	1	0	0
140	0	0	0	0	0	0	0	0	0	0	0
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143	10	1	1	1	1	1	1	1	1	1	1
144	7	1	1	0	1	0	0	1	1	1	1
145	6	1	1	0	1	1	0	0	1	1	0
146	2	1	0	0	0	0	0	0	1	0	0
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154	7	1	1	0	0	0	1	1	1	1	1
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157	3	1	0	0	1	0	0	1	0	0	0
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173	4	1	1	0	1	0	1	0	0	0	0
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177	4	1	0	0	0	0	0	0	1	1	1
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282	7	1	0	0	0	1	1	1	1	1	1
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289											
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321	9	0	1	1	1	1	1	1	1	1	1
322	4	0	0	0	0	0	0	1	1	1	1
323	0	0	0	0	0	0	0	0	0	0	0
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325	4	1	1	0	0	0	0	1	1	0	0

Complete Post Mental Math Quiz Scores

*Blank boxes indicate that the student did not take the quiz.

Student Number	Quiz Score	Question 1	Question 2	Question 3	Question 4	Question 5	Question 6	Question 7	Question 8	Question 9	Question 10
1	5	1	1	1	0	0	0	1	1	0	0
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3	8	0	1	1	1	0	1	1	1	1	1
4	3	1	0	0	0	0	0	1	1	0	0
5	7	1	1	1	1	0	0	1	1	0	1
6	6	1	1	1	0	0	0	1	1	0	1
7	7	1	1	1	1	0	0	1	1	0	1
8	5	0	1	1	1	0	1	0	0	1	0
9	10	1	1	1	1	1	1	1	1	1	1
10	8	1	1	1	1	0	1	0	1	1	1
11	10	1	1	1	1	1	1	1	1	1	1
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13	8	1	1	1	1	0	0	1	1	1	1
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15	6	1	1	1	0	0	0	1	0	1	1
16											
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18	6	1	1	1	1	1	1	0	0	0	0
19	2	0	1	0	0	0	0	1	0	0	0
20											
21	9	1	1	1	1	0	1	1	1	1	1
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24	8	1	1	1	0	1	1	1	0	1	1
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30	4	1	0	0	1	1	0	0	0	0	1
31	5	1	1	1	0	0	0	1	1	0	0
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110											
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172											
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176											
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178											
179											
180	9	1	1	1	1	0	1	1	1	1	1
181	6	1	1	1	0	0	0	0	1	1	1
182	6	1	1	1	0	0	0	1	1	0	1
183											
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185											
186	5	1	1	1	1	0	1	0	0	0	0
187	6	1	1	1	1	0	1	0	1	0	0
188	9	1	1	1	1	1	1	1	1	1	0
189											
190											
191											
192											
193											
194	1	0	0	0	0	0	0	0	1	0	0
195											

196											
197	7	1	1	0	1	0	1	1	0	1	1
198											
199											
200	6	1	1	1	1	0	1	1	0	0	0
201	4	1	0	0	1	0	0	1	0	0	1
202	8	1	1	1	1	1	0	1	0	1	1
203											
204	2	1	0	0	0	0	0	0	1	0	0
205											
206											
207	2	1	1	0	0	0	0	0	0	0	0
208	6	1	1	1	1	0	1	0	0	0	1
209	10	1	1	1	1	1	1	1	1	1	1
210	3	1	1	1	0	0	0	0	0	0	0
211	9	1	1	1	1	1	0	1	1	1	1
212											
213	8	1	1	1	1	1	1	0	1	0	1
214	9	1	1	1	1	1	1	1	0	1	1
215	8	1	1	1	1	0	0	1	1	1	1
216	6	1	1	1	0	0	0	1	1	1	0
217											
218	2	1	0	0	0	0	0	0	0	0	1
219	1	1	0	0	0	0	0	0	0	0	0
220											
221	1	1	0	0	0	0	0	0	0	0	0
222	10	1	1	1	1	1	1	1	1	1	1
223											
224											
225	7	1	1	1	0	1	1	1	0	1	0
226	7	1	1	1	1	0	0	0	1	1	1
227											
228											
229	1	1	0	0	0	0	0	0	0	0	0
230											
231	6	1	1	1	0	0	0	1	1	1	0
232	6	1	0	0	1	1	1	0	1	1	0
233	10	1	1	1	1	1	1	1	1	1	1
234	9	1	1	1	1	1	1	1	1	0	1
235											
236	4	1	1	1	0	0	0	1	0	0	0
237	6	0	1	1	0	0	1	1	1	1	0
238											

239											
240	4	0	1	1	0	0	0	1	1	0	0
241	8	1	1	1	1	0	1	0	1	1	1
242											
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244	6	1	1	1	1	0	0	1	1	0	0
245	7	1	1	1	1	0	0	1	1	0	1
246	7	1	1	1	0	0	0	1	1	1	1
247	9	1	1	1	1	1	1	1	1	1	0
248											
249											
250	10	1	1	1	1	1	1	1	1	1	1
251	F										
252											
253	9	1	1	1	1	0	1	1	1	1	1
254	5	0	1	1	0	0	0	1	1	1	0
255	6	1	1	1	0	0	0	1	1	1	0
256											
257	6	1	0	0	0	0	1	1	1	1	1
258											
259	7	1	1	1	1	1	1	0	0	0	1
260	8	1	1	1	0	1	1	0	1	1	1
261	7	1	1	1	1	0	0	0	1	1	1
262											
263	10	1	1	1	1	1	1	1	1	1	1
264											
265											
266											
267	8	1	1	1	1	0	0	1	1	1	1
268	7	1	1	1	1	0	0	1	1	1	0
269	4	1	1	1	1	0	0	0	0	0	0
270	9	1	1	1	1	1	1	1	1	1	0
271	9	1	1	1	1	1	1	1	1	0	1
272	6	1	1	1	1	0	0	1	1	0	0
273											
274	4	1	0	0	1	0	0	0	1	1	0
275											
276	8	0	1	1	1	1	1	1	1	0	1
277	9	1	1	1	1	0	1	1	1	1	1
278											
279	1	0	1	0	0	0	0	0	0	0	0
280	7	1	1	0	1	0	1	1	1	0	1
281											

282											
283	9	1	1	1	1	0	1	1	1	1	1
284											
285	7	1	1	1	0	0	1	1	1	0	1
286	6	1	0	1	1	1	1	0	0	0	1
287	4	1	1	1	0	0	0	0	1	0	0
288											
289	8	0	1	1	1	0	1	1	1	1	1
290											
291	3	1	1	0	0	0	0	1	0	0	0
292	9	1	1	1	1	1	1	0	1	1	1
293	8	1	1	1	1	0	0	1	1	1	1
294	8	1	1	1	1	1	0	1	0	1	1
295											
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297	10	1	1	1	1	1	1	1	1	1	1
298	7	1	1	0	0	1	1	1	1	1	0
299	5	1	1	0	0	0	0	1	1	1	0
300											
301	5	0	1	1	1	0	1	0	0	0	1
302	8	1	1	1	1	1	0	0	1	1	1
303											
304	1	0	0	0	0	0	0	0	1	0	0
305	8	1	1	1	1	0	0	1	1	1	1
306	7	1	0	1	0	1	1	1	1	1	0
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308	9	1	1	1	1	0	1	1	1	1	1
309	8	0	1	1	1	0	1	1	1	1	1
310	10	1	1	1	1	1	1	1	1	1	1
311	8	1	1	1	0	1	1	1	1	0	1
312	8	1	1	1	1	1	1	1	1	0	0
313	3	1	1	1	0	0	0	0	0	0	0
314	10	1	1	1	1	1	1	1	1	1	1
315	10	1	1	1	1	1	1	1	1	1	1
316											
317											
318	4	1	1	1	0	0	0	0	1	0	0
319	8	1	1	1	1	0	1	1	1	0	1
320											
321											
322	1	1	0	0	0	0	0	0	0	0	0
323	8	1	1	1	1	1	1	1	0	0	1
324	4	1	1	0	0	0	0	0	1	1	0