An Interdisciplinary Math and Science Curriculum for Middle School

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An Interdisciplinary Math and Science Curriculum for Middle School

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A Thesis in the Field of Mathematics for Teaching
For the Degree of Master of Liberal Arts in Extension Studies

Harvard University
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Abstract

Mathematics and science are often taught separately, rendering students with a fragmented knowledge base unable to naturally integrate math and science into a coherent whole. Movements have arisen to offer solutions to this problem, basing their approaches, in large part, on the principles set forth by the National Council of Teachers of Mathematics (NCTM, 2000). In their document, *Principles and Standards for School Mathematics*, the NCTM calls for a reform to mathematics education, encouraging change that would allow students to discover their knowledge based on conceptual thinking and the exploration of mathematics in real world contexts (NCTM, 2000).

This thesis examines one such avenue of change, interdisciplinary education. Pedagogical literature is replete with articles and books on interdisciplinary curricula, and research shows that courses in which multiple disciplines are integrated, when compared to single-discipline courses, either benefit students equivalently or to a greater degree (Russo, 2011). Despite this, however, few first-hand accounts from the teachers who have implemented interdisciplinary curricula or created sample lessons can be found. This thesis is, therefore, motivated by the need for such concrete examples, offering an original sample curriculum for a course in which math and science, specifically pre-algebra and basic chemistry, are fully integrated. The ultimate goal of this curriculum is to teach students the beauty of math and science in a way that allows them to discover both the mathematics and scientific worlds.
This project begins by examining current interdisciplinary approaches to education in order to offer a context by which to view my original curriculum. My curriculum consists of a scope of sequence with nine units outlined, including topics covered, areas of integration, and the California Next Generation Science Standards and Common Core Math Standards applicable to each unit. For one of these units specifically, a unit on rates, proportions, and stoichiometry, I offer a more in depth view, providing lesson plans, labs, and assessments to serve as an example of what an interdisciplinary curriculum could look like in a Middle School environment and to provide a guideline and a vision for how it might be implemented. I implemented this unit in my own pre-Algebra class, and I offer a reflection on its creation and implementation, and examine its execution and efficacy in my classroom. In discussing my own experiences, I hope to offer other educators a personal view of the creation of an interdisciplinary curriculum, providing a “how to” guide, helpful tips, and both personal and student feedback, in the hopes that educators may draw from this work and extend upon it when considering implementing interdisciplinary curricula in their own classrooms.
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I am also eternally grateful to the schools I have taught at and the students I have worked with. I often feel as though I am still new to the teaching profession, and I am so appreciative that these schools have helped me to grow as an educator. I am able to do what I love due to the support of my colleagues, mentors, and students.

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Chapter 1: Introduction

A common concern of students is the irrelevance of their course work in their lives out of school. They find it difficult to understand why they need math when most of their instruction is based on a textbook used in isolation from its applications…We get up in the morning and confront the whole of our lives. It is here that relevancy comes into play. It is not that schools should avoid dealing with specific disciplines; rather, they also need to create learning experiences that periodically demonstrate the relationship of the disciplines, thus heightening their relevancy. There is a need to actively show students how different subject areas influence their lives, and it is critical that students see the strength of each discipline perspective in a connected way. (Jacobs, 1989, p. 4)

The Need for Interdisciplinary Education

At one point or another, every math teacher has been asked, “When are we ever going to use this in life?” To many students, math is an abstract concept, a series of rules and formulas to be practiced only within the confines of the math classroom, and then never to be utilized again. Traditionally, schooling is designed such that each subject is taught in isolation, subconsciously imbuing students with the mentality that math is only relevant for one hour a day, five days a week, and that external disciplines, from science to reading to sports, are unrelated. This method of education, however, does not provide students with the necessary opportunities to build connections between that which they are learning in school and their daily lives. To this end, many schools and institutions are moving towards a method of education known as interdisciplinary education, a methodology which provides students with “the capacity to integrate knowledge and
modes of thinking drawn from two or more disciplines to produce a cognitive advancement – for example, explaining a phenomenon, solving a problem, creating a product, or raising a question – in ways that would have been unlikely through single disciplinary means” (Mansilla, 2005, p. 16).

The field of education has noticed a marked shift in recent years, as many advanced degree programs have instituted mandatory interdisciplinary requirements. For example, many medical schools now have philosophers-in-residence, in order to train doctors to deal with the philosophical questions that surround their treatments (Sullivan, 1982). Similarly, business schools now require their students to take ethics courses. Some PhD programs, like The University of Notre Dame, are offering Masters degrees in Interdisciplinary Mathematics, acknowledging the ubiquity of math in the doctoral studies of other disciplines (UND, 2015). These professional degree programs are designed to train adults for their role in the real world, with the belief that interdisciplinary education might be the best training for an interdisciplinary society.

Just as these graduate programs acknowledge their purpose in training their students for an interdisciplinary reality, grade schools and high schools alike must do the same. While schools across the nation have already instituted various types of interdisciplinary studies programs, the most notable example of interdisciplinary education has been the rise of STEM programs, curricula which incorporate science, technology, engineering, and math. Currently, “STEM schools are cropping up across the country, and parents are rushing to get their kids into these schools” (Chen, 2012), while the US Department of Education has recently created a committee on STEM education, CoSTEM, to promote STEM across the country and they have increased
federal investments in developing STEM programs (USDE, 2016). Programs such as these give hope to the fact that “attention to the integrative theme fosters a level of abstraction in students’ thinking that they are otherwise not likely to reach. For example, to address the dynamics of change, juxtaposing cases from literature and from mathematics is to push students’ thinking toward a pane of generalization where remarkably fundamental and universal patterns may appear” (Jacobs, 1989, p. 75).

Definitions of Interdisciplinary Education

As it currently stands, there is no universally agreed upon definition of interdisciplinary education. For example, Heidi Hayes Jacobs, author of Interdisciplinary Curriculum: Design and Implementation, defines interdisciplinary education as “a knowledge view and curriculum approach that consciously applies methodology and language from more than one discipline to examine a central theme, issue, problem, topic, or experience,” (Jacobs, 1989, p. 8). The executive director of the Association for Integrated Studies, a program at Miami University dedicated to interdisciplinary education and led by interdisciplinary scholar William Newell, defines interdisciplinary education as, “inquiries which critically draw upon two or more disciplines and which lead to an integration of disciplinary insights” (Haynes, 2002, p. 17). While various scholars and institutions have chosen to define interdisciplinary education in their own way, the intention of the education is similar – to imbue students with the knowledge and tools necessary to approach a single topic through multiple frameworks and disciplines,
so that they will, one day, be able to approach any issue with the wisdom that a variety of perspectives provides.

In creating this curriculum, I have chosen to abide by a more stringent definition of interdisciplinary education. I believe that for a curriculum to be interdisciplinary, a single curriculum must be created in such a way that each discipline comprises a critical part of its infrastructure. That is to say that the inclusion of both disciplines are required in order for each discipline to be understood and appreciated in its entirety.

While interdisciplinary curricula are beneficial across numerous disciplines, as a math teacher, my primary goal (and passion) is to teach students the utility of the math that they are learning and to help them recognize its relevance. Hence, this thesis focuses specifically on an interdisciplinary math and science curriculum. My 7th grade students take pre-Algebra as their math course and basic chemistry as their science course. Thus, I have created and field-tested a curriculum that integrates these two disciplines in accordance with my definition of interdisciplinary, such that the math being learned is essential to a complete understanding of the chemistry, and the chemistry is the most natural application of the mathematics.

**Thesis Overview**

This thesis is structured as follows – it begins with a section entitled “An Overview of Current Interdisciplinary Approaches to Education,” which presents a brief history of interdisciplinary education and a discussion of a sample of the current literature in existence. This provides readers with a context by which to examine the
interdisciplinary curriculum I have created and a lens through which to view my original unit plan, so that this work might be evaluated as a part of a larger philosophy and movement.

The next section, “Design and Implementation,” discusses the design of the original curriculum, including a scope and sequence for the entire curriculum, and lesson plans, homework assignments, labs, and assessments for the sample unit specifically. This section also examines the implementation of this unit in the classroom. Having tested these lessons in my own classroom, I evaluate the perceived benefits or drawbacks of an interdisciplinary curriculum from both a student perspective and that of an educator. By “beta testing” such a project, I hope to offer some first-hand insight into the creation of such a curriculum, so that the other educators might better understand both the potential benefits and drawbacks of such an endeavor.

The following section, “Execution and Efficacy,” explores the actual execution of these lesson plans in a more detailed manner, and offers a discussion of their efficacy based both on student feedback and assessment scores. I believe it to be essential for any educator, regardless of the curriculum, to assess their work, as a teacher’s success is measured only by the efficacy of the lessons. My aim was to specifically examine whether my students achieved proficiency in the material, and whether such a project ultimately enhanced the learning process for them.

In the last section of this thesis, “Interdisciplinary Curriculum Sample,” there is a detailed discussion of my original scope and sequence in order to give the reader a thorough description of what such a curriculum would look like in its entirety. Additionally, there are sample lessons plans, homework assignments, and assessments for
one of the units, specifically the unit on proportions and stoichiometry, to help the reader take the abstract concept of an interdisciplinary math-science curriculum, and actually witness concrete examples of how such lessons would appear and be taught.

Generally, research on the effects of interdisciplinary curricula indicates that students in integrated classrooms are more likely to master the concepts and engage in classroom activities (Russo, 2011). Personally, this project has served to enhance my belief that, “when students can connect mathematical ideas, their understanding is deeper and more lasting. They can see mathematical connections in the rich interplay among mathematical topics, in contexts that relate mathematics to other subjects, and in their own interest and experience” (NCTM, 2000, p. 64). It is my hope that through such a body of work, educators might draw from my experiences, whether using the work and methodology directly or improving upon it, to test interdisciplinary approaches to education in their own classrooms.
Chapter 2: An Overview of Current Interdisciplinary Approaches to Education

The British philosopher Lionel Elvin once said, “when you are out walking, nature does not confront you for three quarters of an hour only with flowers and in the next only with animals” (Jacobs, 1989, p. 2). It is out of simple recognition of the interdisciplinary nature of our world that the idea for interdisciplinary curricula is born.

The Roots of Interdisciplinary Education: The Progressive Education Movement

For over a century, the idea of combining multiple disciplines in education has existed. The creation of the Progressive Education Movement in the late 19th century combated the traditional view of education in which secondary school was merely utilized to prepare the upper class for University, and offered a view of education rooted in experiential instruction, thematic units, and lifelong learning. Philosopher John Locke believed that, “truth and knowledge… arise out of observation and experience rather than manipulation of accepted or given ideas,” (Hayes, 2006, p. 2) while John Dewey, the father of the Progressive Education movement in the United States, advocated that school curricula should reflect daily life, and that the disciplines should be taught in conjunction with practical applications (Parker, 2010). Thus, the notion of adapting education to account for a multidisciplinary society arose.
Recent Calls for Interdisciplinary Education

Despite the Progressive Education Movement and others similar to it, the traditional methodology of schooling continues to revolve around short time blocks in which separate disciplines are taught in succession. However, over the past few decades, there has been a growing interest in and recognition of the need for interdisciplinary curricula. A poll conducted by the Association for Supervision and Curriculum Development suggests that interest in interdisciplinary curricula has intensified recently due to a few key factors among which are the growth of knowledge and the relevance of curriculum to daily life (Jacobs, 1989). As scientific discoveries progress, literature is written, history is made, students are being asked to learn more and more. The poll cites that as the breadth of knowledge students are expected to learn increases, curricula must be whittled down based on importance and relevance. Interdisciplinary curricula are, therefore, significant as they not only have the potential to pair abstract concepts with practical applications, but to efficiently teach multiple concepts.

Moreover, studies suggest that the chief complaint among students who drop out of school is its irrelevance in their daily lives (Jacobs, 1989, p. 4), indicating that educators must help students to see the significance of that which they are learning and to view their subjects not as isolated disciplines, but as interconnected fields. The complexity of a globalized workplace and the growing need for contextual thinking have been the driving force for interdisciplinary studies, a methodology that is “an innovative and purposeful way that shows relationships between what happens within and outside of school” (Wood, 2010, p. 3).
Cross-Disciplinary vs. Multi-Disciplinary vs. Interdisciplinary Curricula

The desire to make curricula both relevant and efficient has bred various forms of analyses used to integrate multiple disciplines. The Science Education Resource Center (SERC) at Carleton College defined the three forms most often used: cross-disciplinary analysis, multi-disciplinary analysis, and interdisciplinary analysis. Cross-disciplinary analysis is defined as an analysis which, “examines an issue typically germane to one discipline through the lens of another discipline” (SERC, 2010). For example, many schools align their curricula such that American history and American literature are taught in the same year, allowing the teacher to draw on the historical context of a novel when discussing literature and to examine a historical era by the art and literature produced in its time when learning history. While this form of analysis indicates a certain level of integration, it continues to isolate the disciplines, teaching them as separate subjects while merely illustrating a connection between them.

A second form of analysis, multi-disciplinary analysis “examines an issue from multiple perspectives, without making a concerted effort to systematically integrate disciplinary perspectives” (SERC, 2010). Essentially, a single thematic topic is examined through various discipline. At my school, for example, we chose to do an “interdisciplinary” unit on water, where the students learned a bit on the history of aqueducts, some of the math associated with water flow, the science behind water conservation efforts, and so forth. In taking a central theme, and analyzing it through multiple disciplines, the students were afforded the opportunity to examine a single topic through multiple lenses and to perform a simple multi-disciplinary analysis of water. A
thematically driven multi-disciplinary approach emphasizes connecting a single theme to multiple disciplines, thereby allowing the students to able to discuss a single topic in depth. However, the constraints of this approach prohibit students from delving deeply into any single discipline or explore connections between the disciplines beyond the scope of the theme. The concern with such an approach is that whether water or ancient Greece is being taught, students are shown how multiple disciplines can be connected to a single topic, but not how multiple disciplines connect with one another.

The third form of analysis as outlined by the SERC is interdisciplinary analysis, which “examines an issue from multiple perspectives, leading to a systematic effort to integrate the alternative perspectives into a unified or coherent framework of analysis” (SERC, 2010). This form of analysis most closely mirrors my definition of an interdisciplinary curriculum. Hence, when creating my curriculum, I opted for this form of analysis, in which a math and science curriculum would be taught as one in the hopes that the students will not only organically learn multiple disciplines, but they will also learn how to think and process information through multiple lenses. I chose to study, create a sample curriculum on, and examine the effects of such a curriculum because I believe in the ideals it purports and its ability to imbue students with the essential skill of integrative thinking. According to Repko, “a defining characteristic of interdisciplinary learning, is the ability to knit together information from different sources to produce a more comprehensive understanding or create new meaning” (Repko, 2014, p. 16).
Levels of Integration in Interdisciplinary Education

The enthusiasm for interdisciplinary education has bred several approaches, classified by level of integration. Researcher Marlene Hurley categorized the various approaches to interdisciplinary curricula being implemented across the country over the last century and studied their effects, examining their implementation and efficacy. Hurley categorized the various approaches by level of integration, noting five distinct possibilities:

1. Sequenced: taught sequentially, with one preceding the other.
2. Parallel. Science and mathematics are planned and taught simultaneously through parallel concepts.
3. Partial. Science and mathematics are taught partially together and partially as separate disciplines in the same classes.
4. Enhanced. Either science or mathematics is the major discipline of instruction, with the other discipline apparent throughout the instruction.
5. Total. Science and mathematics are taught together in intended equality.

(Hurley, 2001, p. 263)

Hurley analyzed these levels of integration, including statistical analyses on their efficacy and anecdotal evidence on their success, and concluded that sequenced integration and total integration were the two approaches that provided the greatest positive effects on student comprehension, proficiency, and attitudes towards math and science (Hurley, 2001, p. 264). In my curriculum, I opted for Hurley’s method of total integration, as it most closely mirrored my own definition of interdisciplinary education. In the following section, I will discuss the design and implementation of my original curriculum.
Chapter 3: Design and Implementation

The development of mathematical ideas and the use of mathematics in other disciplines are intertwined. At times, new ideas develop in a purely mathematical context and are applied to other situations. At other times, new mathematics arises out of situations in other disciplines or in real-world contexts… The use of mathematics within different contexts gives students an appreciation of the power of mathematics and its generality. (NCTM, 2000, p. 202)

This project originated out of a desire for my students to see natural connections between math and other disciplines, and between math and their world. As the National Council of Teachers of Mathematics states, mathematical ideas can develop within a purely math context and be applied to other disciplines, or they can arise out of other contexts and enhance its own discipline. Thus, I embarked on a project of creating a curriculum in which math was integrated with another discipline in the hopes of revealing to students the ubiquity of math. Researchers Svetlana Nikitina and Veronica Mansilla, in an article entitled “Three Strategies for Interdisciplinary Math and Science Teaching: A case of the Illinois Mathematics and Science Academy,” outline three strategies for an interdisciplinary curriculum: essentializing, problem-centering, and contextualizing.

Essentializing: Creating a Scope and Sequence

As Nikitina and Mansilla explain, “essentializing is an integrative strategy designed to take students’ thinking beyond the facts and tools of science and mathematics to the level of the underlying ideas that expose their relatedness… Thinking conceptually
about science and mathematics means thinking in terms of unifying scientific ideas or mathematical constructs that have the potential to produce sharable tools and understandings” (Nikitina and Mansilla, 2006, p. 8). Essentializing serves to create the foundation of an interdisciplinary curriculum where the primary goal is revealing the relatedness of the disciplines and unifying their ideas into a single construct with shared concepts and methodologies. Essentializing is, therefore, a natural first step when creating an interdisciplinary curriculum as it serves to unify the disciplines and provide structure and direction for the curriculum as a whole, thereby ameliorating the criticism that interdisciplinary curricula often lack in focus and that, “unlike the disciplines that have an inherent scope and sequence used by curriculum planners, there is no general structure in interdisciplinary work. Curriculum developers themselves must design a content scope and sequence for any interdisciplinary unit or course” (Jacobs 1989, p. 2). It is for this reason that the initial step in creating an “essentialized” interdisciplinary curriculum was to create a scope and sequence for the course, in order to ensure that my curriculum was taught with focus and purpose, and with the explicit goal of using the disciplines to support one another, such that the math being learned was imperative to understanding the science, and the science seemed to be an authentic application of the math being taught. I operated with the mentality purported by scientist Leonardo Frid, 

Science, like other mythologies, attempts to retell this story in its own vocabularies: in numbers and formulas, in the documentation of pattern and repetition in Mathematics, Physics, Chemistry, and Biology; these are the dialects with which we retell our own existence; these are the links with which we write our scripts. But each discipline alone tells only one fraction of the story; harnessed together they give rise to depth, and tone, and color.  

(Nikitina and Mansilla, 2006, p. 8)
Creating a scope and sequence was, therefore, not only a natural but imperative first step. I began by listing all of the topics imperative to a pre-algebra course, and consulted with the 7th grade science teacher at my school to get a list of the topics covered throughout the year in basic chemistry. I then attempted to group the math and science topics in a way that seemed both coherent and cohesive. Having taught pre-Algebra for many years prior, I had designed my math curriculum in such a way that each new concept relied on and built upon those taught before it. I, therefore, used this as my basis and grouped each math concept with a chemistry topic that utilized and required the same basic skills, with the recognition that chemistry also builds upon itself throughout the year. Due to deliberate effort and the frequent natural pairing of math and science, the curriculum came together in such a way that the topics from each discipline intertwined time and time again, integrally relying on one another for a complete understanding, thereby creating an interdisciplinary curriculum. Ultimately, I found true Nikitina and Mansilla’s claim that, “essentializing, when applied to math and science, is not just the training ground for wider and bolder external connections. It is a rigorous, integrative activity in and of itself…conceptual links even within the scientific and mathematical disciplines demand an effort on the part of the teacher and the student” (Nikitina and Mansilla, 2006, p. 10).

While I created a cohesive scope and sequence, it was not an easy task. Certain topics do not easily lend themselves to a combined pre-algebra/basic chemistry curriculum. For example, in chemistry, when discussing opaque and transparent metals, while it is possible that some mathematical connection could be made in isolation, a natural application of pre-algebra was challenging to find. Likewise, my 7th grade pre-
algebra course traditionally includes a unit the probability of independent events. While advanced chemistry may model independent situations, this basic 7th grade chemistry course stressed the relatedness of molecules, kinetic energy, and their dependence upon one another. Pairing the concepts was an intricate process due to the fact that, “the connections in this model occur at the level of discipline-grounded concepts and practices rather than general philosophical ideas, they involve a deliberate and often non-intuitive effort of coordination. They are produced ‘by design’ and not by happenstance” (Nikitina and Mansilla, 2006, p. 10). Hence, due to the lack of authentic connections, some non-essential chemistry and math topics, that may have otherwise been taught in individual curricula, were excluded in the creation of my interdisciplinary curriculum.

Additionally, regardless of discipline, when planning a curriculum an educator must choose which topics to focus on throughout the year, which skills are essential for their students to learn, and which topics there may simply not be time to cover throughout the course of the year. Creating an interdisciplinary curriculum is no different; ultimately, sacrifices to both curricula were certainly made. Whereas in a traditional curriculum, sacrifices may be made due to time constraints, the preferences of the teacher or school, the abilities of the students, and so on, in an interdisciplinary curriculum, sacrifices are made in order to allow the units to be intertwined as closely as possible. Ultimately, however, these sacrifices presented an opportunity to prioritize some of the skills that occur as a benefit of an interdisciplinary curriculum, chief among them being the ability for students to see the application of that which they are learning, and to learn how to think, infer, and deduct across disciplines and subject matters, which can only occur by discussing the underlying unity of these concepts.
Problem-Centering: Creating a Unit

After creating a scope and sequence, I then chose a unit on proportions and stoichiometry, and set out to create sample lessons, labs, and assessments. Each lesson incorporates basic components catering to various styles of learning. For example, there is a handout for each lesson, which provides a visual aid for those students who are visual learners, guides auditory learners as we go through it together in class, and provides kinesthetic learners a way to organize their notes. Reviewing the handout as a class provides the students with an opportunity to learn the material all together, ideally teaching it to the students through their preferred learning method while reinforcing the concepts in multiple ways. While reviewing the handout, the students also have the opportunity to ask questions, attempt problems individually, in peer groups, and with the support of their teacher. This allows the students to see the implementation of the various concepts, while providing them with an opportunity to practice their application with the support of peers and teacher.

While such components may be applied to any lesson, interdisciplinary lessons are unique in that they not only teach students content, but they aim to teach a strategic way of thinking, imbuing them with the ability to consider topics from multiple perspectives. When considering this, I applied Nikitina and Mansilla’s second strategy of interdisciplinary curriculums – problem-centering. As Nikitina and Mansilla describe, a problem-centering approach to curriculum design focuses on tangible problem solving. An interdisciplinary curriculum forces students to view the material from both a math and a science perspective, to see the applications of math in science, and to see the necessity
for math in science. In this way, each discipline is enhanced by the inclusion of the other, and to lack either discipline would be lacking a complete understanding and appreciation of the material. It is precisely this that I bore in mind as I created my lessons. While essentializing created the foundation of the curriculum, ensuring that the math and science were conceptually integrated throughout, problem-centering provided a concrete strategy to implement the integration of math and science. Within each lesson, a scientific theme was presented, along with practice problems. The math necessary to solve those problems was woven into the lesson, such that, by the end of the lesson, the students had learned a new topic in both basic chemistry and pre-algebra. As Nikitina and Mansilla describe,

> the advantage of this pragmatic orientation toward interdisciplinary interaction is that it brings together a wide range of disciplines. Also, the disciplinary content and tools of these disciplines are used with precision and rigor rather than in a generalized and abstract way… When mastery of disciplinary tools serves a compelling problem, significant and highly motivated learning of mathematical and scientific theories can occur. (Nikitina and Mansilla, 2006, p. 15)

Each lesson is accompanied by a homework assignment in order to allow the students to further practice the material at home, and to serve as miniature individual assessments. This provides the students with an opportunity to gauge how well they are understanding the material, and allows a teacher, to gain a better understanding of how the lessons are being received and how they might further tailor or differentiate them for an enhanced understanding.

In addition to the class notes and homework assignments, this unit also contains a test and two labs. The test is a very formal assessment of the students’ grasp of the concepts and their recollection of the key ideas. It tests their understanding of both stoichiometry and proportions by giving them problems rooted in chemical science,
which must be solved using stoichiometric proportions. The labs are a rather unique
form of both instruction and assessment, as they provide the students with an opportunity
to witness the scientific principles that we have discussed. The opportunity to see the
lessons in action is a remarkable one for the students, as they were performing
experiments and analyzing data directly related to proportions and stoichiometry, thereby
embodying the principles of a problem-centered approach.

The class notes, homework, test, and labs were designed with a specific purpose.
Throughout this process, my aim was that,

students should be developing the important processes needed for scientific
inquiry and for mathematical problem solving – inferring, measuring,
communicating, classifying, and predicting. The kinds of investigations that
enable students to build these processes often include significant mathematics as
well as science. It is important that teachers stimulate discussion about both the
mathematics and the science ideas that emerge from the investigations.

(NCTM, 2000, p. 201)

Of course, as in any curriculum, these materials are used to impart knowledge and skills
to students, and to assess their comprehension. Interdisciplinary education, however, has
an additional goal – to teach students how to think and interpret beyond a single
discipline, using multiple lenses through which to view and tackle various information.
Ultimately, “it should also lead students to connect and integrate the different parts of
their overall education, to connect learning with the world beyond the academy, and
above all, to translate their education to new contexts, new problems, new
responsibilities” (Schneider, 2004, p. 1). These lessons took the basic concepts of
stoichiometry, and taught the students that without the use of pre-Algebra and
proportions, chemical reactions and stoichiometric proportions would be essentially
unsolvable. The lessons were woven together in such a way that proportions were both
necessary to the understanding of stoichiometry, and stoichiometry was a natural
application of the math.

**Contextualizing: Future Curricular Goals**

It is worth noting that Nikitina and Mansilla promote a third strategy in the design
of an interdisciplinary curriculum – contextualizing. Contextualizing, as they describe,

> Contextualizing is an external integrative strategy that places scientific and
> mathematical knowledge in the context of cultural history and the history of ideas.
> Science and mathematics are represented not so much by their separate theories
> and practices but by their common philosophical foundations and historical roots.
> Historical, philosophical, or epistemological foundations of a particular scientific
> theory can all serve as contexts, or as the “organizing centers of the integrative
> curriculum.” (Nikitina and Mansilla, 2006, p. 12)

While this idea seems worthwhile, it, in essence, adds yet another layer to the creation of
an interdisciplinary curriculum, not only fully integrating the two disciplines, but
contextualizing the reason for integration. In the creation of this sample unit, I chose to
prioritize essentializing and problem-centering, as they most clearly supported my goal of
creating an interdisciplinary curriculum inextricably linking math and science with one
another. Contextualizing the curriculum, however, provides an opportunity for continued
growth, as offering context to the math and science can only serve to connect the
disciplines and enhance an understanding of them.
Chapter 4: Execution and Efficacy

In reading about interdisciplinary curricula and their implementations in classrooms, the research on its effects inspired me to attempt it in my own classroom. While some studies have shown that students in an integrated course score equally well to those in non-integrated courses (Russo, 2011), studies have also shown that, “integrated students were more likely to maintain a mastery orientation to learning and were engaged in more productive task talk and less off-task than students in the control (segregated) courses… [and] the achievement of the students in the experimental group was significantly higher than that achieved by students not involved in the integrated activities” (Russo, 2011, p. 115). While more research must still be done on the classroom and student effects of integrated curricula, the research and results encouraged me to test my curriculum in my own classroom. In this chapter I will discuss the results of this experiment, examining specifically the execution and efficacy of my unit based on both formal feedback, through graded work, and informal feedback, through student feedback.

Classroom Demographics

Given the highly experimental nature of such a course, I was allowed by the administration one week’s worth of classes – five 45-minute class periods – in which to test this curriculum. I teach at a small Kindergarten – 12th grade private school in Southern California, where many of the students have either attended the school since
Kindergarten or join the school from similar private elementary schools in the area. I am, therefore, familiar with the students’ previous exposure to mathematical and scientific concepts. My students, 7th graders, have had limited exposure to chemistry concepts, and minimal exposure to algebraic concepts. They are not tracked in school, so all of the 7th graders take pre-Algebra regardless of individual aptitude, cognitive development, or capability for abstract thinking. Thus, in creating this unit, it was imperative that the topics, while new, were accessible to all of the students in order to provide a unique experience to them all. Given this, and given the progress of my 7th grade pre-Algebra curriculum at the time, I chose to focus on Unit 4 from my scope and sequence, specifically a unit on rates, proportions, and stoichiometry. As previously discussed, I created lessons in which the students learned about rates and proportions, while simultaneously learning about basic chemical reactions, reaction rates, and stoichiometry. Each lesson was accompanied by a homework assignment, and the unit ended with two labs, which focused specifically creating chemical reactions utilizing stoichiometric proportions, and a final assessment on the unit as a whole.

Execution and Efficacy

In comparison to the math units taught earlier in the year, the lessons and homework of this unit were equally successful by multiple formal and informal measures. The students participated equivalently in class, both in asking and answering questions, and problem-solving in groups and at the board. Additionally, their homework was done as thoughtfully and thoroughly as any of their previous single-discipline assignments.
Every homework problem provided the students with an opportunity to practice the new science and math material learned in class that day, and to reflect on that which we learned in each lesson, specifically asking the students to write a sentence explaining the scientific concept from that lesson, a sentence discussing the math performed on that homework, and a sentence naming one practical application of the information in this lesson. This, in essence, compelled the students to reflect on the fact that, not only had they learned a significant amount of new material, but that in a single class, they had learned something scientific, something mathematical, and, most importantly, something practical. Before creating an interdisciplinary unit, I had never thought to include such a question on any homework. However, in class each day, while reviewing the previous night’s homework assignment, the students would informally comment that, prior to completing these questions, they, themselves, didn’t realize how much they had learned! A few students even remarked on the fact that they appreciated having to recognize and note the practical applications of their work. Whereas they often felt as though math problems were very contrived, connecting the math with chemistry allowed them to more readily recognize the real-world applications of their work. Given this positive feedback, I am currently contemplating ways to include questions connecting math to its practical applications, on a regular basis in my math classroom, whether on student homework or perhaps through the use of a math journal.

The labs in the math class provided the students a unique opportunity to do a hands-on activity applying that which they have learned. To be able to create and witness chemical reactions taking place, and to measure and calculate reaction rates was significant for the students, as it allowed for both the math and the science to be a product
of their own creation. While labs are a regular practice in a science class, they are rarely a part of a math classroom. This interdisciplinary unit allowed not only for the integration of the two subject matters, but also for the integration of teaching methodologies, such that the opportunities for concrete applications, so common in a science classroom, could now also be utilized in a math classroom. While implementing this unit in my classroom, my observations were consistent with those of other pilot interdisciplinary program, as I found that, students take what they learn and, rather than drill their lessons in a textbook and workbook, the application of their knowledge becomes of the upmost importance, and their skills are repeatedly used in different contexts and across different disciplines. This allows students not only to witness a direct application of their learning, but to deepen their conceptual understanding, and to experience the joy of learning. (Jacobs, 1989, p. 50)

Finally, the unit test demonstrated the students’ retention of the class material, and assessed their ability to apply both their math and science knowledge. The test average was an 89% with a standard deviation of 6%, which is consistent with their average on units throughout the year. This test revealed that the students were not only able to competently answer scientific questions and proficiently perform mathematical operations, but that they were able to do both in conjunction with one another. It is evident that solving math problems phrased in a scientific context did not confuse them or impede their ability to do the math, and that they were able to understand what significance their solutions had in a scientific context.

Due to administrative restrictions, I could not formally survey my students following this interdisciplinary unit, but I was able to informally seek their feedback, and the reviews were mainly positive. While admittedly they were initially apprehensive, overall they enjoyed the unit and they seemed to feel as though they grasped both the
scientific and mathematical concepts well, and they reiterated that teaching the two
disciplines together allowed them to, ultimately, have a better understanding of both.
This is consistent with the research on interdisciplinary curricula which purports that,
“the teachers of interdisciplinary pilot programs have noticed that their students ‘seem to
remember more, believe that what they have to contribute is important, and participate
more fully in class activities’” (Jacobs, 1989, p. 50).
Chapter 5: Reflections on Creation and Implementation

The stages of this project – researching current approaches to interdisciplinary education, creating an interdisciplinary curriculum, and implementing an interdisciplinary unit in my classroom – have all been equally elucidating. In researching interdisciplinary education, it became evident that while theories, literature, and statistics on interdisciplinary education exist, concrete examples of such curricula and first-hand accounts by teachers who have implemented them were challenging to find. Thus, in this section, I aim to share my reflections on the creation and implementation of this project in the hopes that it may prove insightful to educators interested in implementing interdisciplinary education in their classrooms.

Creating an Interdisciplinary Curriculum

I was aware that designing an interdisciplinary curriculum would be daunting, however I was unprepared for how arduous a task it was. As previously discussed, many schools correlate their subject matters, teaching American history and literature in the same year or similar math and science concepts within the same time frame, thereby abiding by Hurley’s definition of parallel integration and allowing students to contextualize their work. While this kind of correlation undoubtedly requires effort and coordination among teachers and across disciplines, creating an interdisciplinary curriculum is significantly more challenging in nature. As Nikitina and Mansilla
describe, creating an interdisciplinary curriculum, “requires massive coordination, resequencing, and restructuring of the material around unifying concepts rather than disciplinary lines. Links are built one plank of solid proof at a time, and therefore the process is more laborious and time-consuming” (Nikitina and Mansilla, 2006, p. 10).

To use a math analogy, a parallel curriculum is analogous to parallel lines, as an interdisciplinary curriculum is to coinciding lines. The goal of my interdisciplinary curriculum is not to teach math and science in parallel fashion, but rather to have them coincide with one another. My sample curriculum is created with the intention that students will not have separate math and science courses, where minimal connections can be made, but rather they will be taught mathematical and scientific concepts simultaneously through a single course, in such a way that each discipline is necessary to a true appreciation of the other.

Given that the subjects are taught hand-in-hand, rather than side-by-side, the concepts of a “math teacher” and a “science teacher” no longer exist. While such a curriculum could be taught by two or more teachers proficient in single subjects, the autonomy that a single teacher might generally have over their classroom and curriculum cannot exist in an interdisciplinary curriculum, as each lesson must be the creation of both teachers. As previously noted, this endeavor can become rather challenging, and hence, an interdisciplinary curriculum better lends itself to a single teacher well versed in multiple disciplines. This means, however, that for this instructor, the time necessary to create an interdisciplinary curriculum is a significant factor. Planning lessons for two separate curricula is daunting enough. However, the time needed to integrate the lessons in a cohesive and coherent manner is essentially worthy of being considered a third
“prep,” as teachers call it. While each teacher plans lessons with different time-spent and rigor, in my experience, the time spent planning an interdisciplinary unit was nearly twice that of planning two single discipline units. While such rigor may seem like a deterrent (particularly, as teaching is already a rather time-intensive career), after having implemented the lessons in my own classroom and witnessed their effect on my students, I feel as though the time spent is worthwhile given the possibilities of increased learning and connections for students.

**Implementing an Interdisciplinary Curriculum**

The opportunity to implement an interdisciplinary curriculum, if only for a week, was an illuminating experience. Teaching an interdisciplinary curriculum requires not only the proficiency to anticipate and answer student questions on multiple subjects, but the mastery to forge deep and meaningful connections between multiple disciplines. Additionally, I found that an unintentional and unexpected benefit of this interdisciplinary curriculum was the creation of a spiraling curriculum as well. Not only were meaningful connections formed between the disciplines, but skills and concepts were reinforced between sequential units. The science and the math curricula were specifically selected to integrate well with one another, but I found that by integrating the curriculum in this manner, “the acquisition of vital learning skills would be enhanced, perhaps significantly, by reinforcement and refinement through a range of applications” (Jacobs, 1989, pg. 81), as opportunities continually presented themselves to practice and reinforce previously taught concepts and even to foreshadow upcoming concepts.
From this experience, I also learned that an interdisciplinary educator must be able to occupy multiple roles simultaneously. My role as a math teacher is, in the subtlest of ways, very different than that of a science teacher. Aside from the unfamiliarity of running a lab and overseeing meticulous procedural work, as a math teacher, I generally teach students new, abstract concepts, primarily focusing on theory and understanding, and making (perhaps, at times, forcing) connections between these concepts and the real world. As a “science teacher,” however, I was able to take concepts that students were already intrinsically aware of – energy, heat, atoms – and elucidate these real world concepts for them, focusing mainly on utility and application. While there is merit in studying both theory and application, studying the two together may ultimately enhance both approaches to knowledge, as “in its broadest sense curriculum integration embraces not just the interweaving of subjects…but of any curriculum elements (e.g. skills and content) that might be taught more effectively in relation to each other than separately” (Jacobs, 1989, pg. 79).

Before attempting the creation of another unit or revising this one, however, I believe that I would benefit from observing, assisting, or co-teaching in a science classroom, so that I might better possess the nuanced distinctions that being an interdisciplinary educator demands. Despite this, I found the implementation of an interdisciplinary curriculum to be a unique experience for the students, one that was worthwhile, if only for a single unit, as it allowed them to see both the applicability and necessity of math in science, and to bear this in mind as we continued our math curriculum throughout the year.
Chapter 6: Interdisciplinary Curriculum Sample

Curriculum Introduction

The following section contains my proposal for a 7th grade pre-algebra and basic chemistry interdisciplinary curriculum. This proposal includes a scope and sequence with nine units, as well as examples of content of each unit, and corresponding standards. A sample unit on rates, proportions, and stoichiometry is included in the first appendix.

The scope and sequence is the core of my interdisciplinary curriculum, as it intricately pairs the two subjects and offers a plan for how such a unique curriculum might flow throughout a school year, not only teaching the students two subjects simultaneously, but, ideally, enhancing the teaching of each subject. The scope and sequence offers a brief discussion of the lessons covered in each proposed unit, so that the reader might sense the connection between the various math and science topics, and gain an understanding of how the unit topics were paired to create an integrated curriculum.

Additionally, the corresponding California Math Common Core Standards (CSBE, 2015) and California Next Generation Science Standards (CSBE, 2013) have been included in order to highlight the connection between an interdisciplinary curriculum and the most current math and science standards widely adopted across the nation. It is imperative to note that while the Math Common Core Standards and Science Next Generation Standards are drawn from the lower, middle, and high school levels, my curriculum is tailored specifically for the 7th graders based on their prior education and
knowledge. I chose the standards that I felt were most applicable to each unit, however, the elementary school standards are meant to be reviewed at a more advanced level, while the fundamental ideas of the high school level standards will be foreshadowed, though not fully addressed at this level.

Provided in Appendix 1 is a sample unit, specifically Unit 4 on rates and proportions from the mathematics curriculum, and reaction rates and stoichiometry from the chemistry curriculum. Included are sample lessons, homework assignments, labs, an assessment, and answer keys so that teachers interested in the idea of an interdisciplinary curriculum may have a concrete example of one.
Scope and Sequence

Unit 1:
Science Concept: Introduction to Atoms, Ions, and the Periodic Table
Math Concept: Operations with Positive and Negative Numbers

Unit 2:
Science Concept: Atoms, Elements, Isotopes – Moles and Molecular Weight
Math Concept: Powers of 10 and Scientific Notation

Unit 3:
Science Concept: Solutions
Math Concept: Fractions, Decimals, and Percents

Unit 4:
Science Concept: Reaction Rates and Stoichiometry
Math Concept: Rates, Ratios, and Proportions

Unit 5:
Science Concept: Chemical Equilibrium
Math Concept: Solving single variable algebraic equations

Unit 6:
Science Concept: Thermodynamics
Math Concept: Functions and function notation

Unit 7:
Science Concept: States of Matter
Math Concept: Linear equations

Unit 8:
Science Concept: Limiting Reagents and Catalysts
Math Concept: Graphing Linear Equations

Unit 9:
Science Concept: Bonding and Orbitals
Math Concept: Geometric Figures
Discussion of Scope and Sequence

Unit 1:
Science Concept: Introduction to Atoms, Ions, and the Periodic Table
Math Concept: Operations with Positive and Negative Numbers

Abstract: This unit serves as an introductory unit, teaching students about integer operations, atoms, ions, and the periodic table. This unit serves to integrate the subjects by focusing on subatomic particles, specifically protons and electrons, and relating this to the study of operations with negative numbers. Proton and electron counters will be used study these operations and to gain a further understanding of ionic charge.

Traditionally, my pre-Algebra curriculum begins with a unit on integer operations, as this not only helps to build on concepts that the students have learned in younger grades, but it also helps to ensure that all 7th graders will begin pre-Algebra with a similar knowledge base, as 7th grade is a common entry point for new students. For 7th graders, negative numbers are a very abstract concept, and beginning the year with an abstract concept not only teaches the students something new, but helps them to learn how to think abstractly and visualize negative values. Students will begin by drawing number lines, but will quickly move to visualizing them without drawing until these operations become second nature for them.

This level of abstract thinking will prove useful in an introductory unit on the periodic table, atoms, and ions as students are asked to understand subatomic particles. Not only are operations with negative numbers and the periodic table both good introductory units for their respective subjects, but the topics themselves integrate naturally. Many teachers often teach addition and subtraction of negative numbers with counters (red and black chips), so that the students might have a visual. In this unit,
instead of red and black chips, we will be using nature’s counters – protons and electrons. Students will be able to use $p^+$ (protons) and $e^-$ (electrons) to stand for positive and negative values respectively, and add and subtract these values to both practice their operations with negative numbers and to gain a more complete understanding of how ionic charge relates to an atom’s composition.

Students will learn that ionic charge can be calculated by subtracting the number of electrons from the number of protons. For example, an Oxygen molecule has 8 protons and 8 electrons, while a Hydrogen molecule has 1 proton and 1 electron. However, when Oxygen binds with two Hydrogen atoms to form a water molecule, it essentially “adopts” the electron from each of the Hydrogens. Therefore, the ionic charge of Oxygen becomes $8 - 10 = -2$. Likewise, because the Hydrogens “donated” their electrons when bonding to Oxygen, the ionic charge of each Hydrogen becomes $1 - 0 = +1$. For the purposes of 7th grade basic chemistry, we will not officially learn about covalent bonding and ionic pull – simply that some atoms “adopt” or “donate” their electrons when bonding. Using similar examples, students will practice working with integers and gain a better understanding of subatomic particles.

This unit integrates these two disciplines on both a conceptual and applicable level. Conceptually, these young students are being asked to begin to think abstractly, and to understand negative numbers and subatomic particles. On a more applicable level, a lesson on protons, electrons, and ions provides a venue with which to practice operations with negative numbers using real-world examples, thereby reinforcing both the scientific concepts and the mathematical operations.
While protons and electrons provide a substantive introduction to positives and negatives, it will be essential in this unit to elucidate other significant math and science concepts for the students. For example, it is imperative for the students to recognize and understand real-world contexts pertaining to positive and negative numbers other than atomic number. Additionally, while the periodic table is, in large part, arranged by ionic charge, there also exist other defining characteristics within each group of elements, and learning about the periodic table will allow for a discussion of these properties. The overarching concept behind this unit is one that lies at the core of both pre-Algebra and basic chemistry, and an understanding of this unifying concept, particularly as it relates to both disciplines, ultimately serves to enhance related math and chemistry concepts.

Unit 1 begins the year by allowing to students to practice and build upon math concepts that they have learned in previous years. It also provides them with a solid foundation for us to build upon in both pre-Algebra and in Chemistry. In this unit, operations with negative numbers are practiced using their new found knowledge of the composition of atoms and ions, and their knowledge of the periodic table is enhanced by their understanding of operations with integers.
California Math Common Core Standards

6.NS.5: Understand that positive and negative numbers are used together to describe quantities having opposite directions or values; use positive and negative numbers to represent quantities in real-world contexts, explaining the meaning of 0 in each situation.

7.NS.1: Apply and extend previous understandings of addition and subtraction to add and subtract rational numbers; represent addition and subtraction on a horizontal or vertical number line diagram.
   a. Describe situations in which opposite quantities combine to make 0. For example, a hydrogen atom has 0 charge because its two constituents are oppositely charged.
   b. Understand $p + q$ as the number located a distance $|q|$ from $p$, in the positive or negative direction depending on whether $q$ is positive or negative. Show that a number and its opposite have a sum of 0 (are additive inverses). Interpret sums of rational numbers by describing real-world contexts.
   c. Understand subtraction of rational numbers as adding the additive inverse, $p – q = p + (–q)$. Show that the distance between two rational numbers on the number line is the absolute value of their difference, and apply this principle in real-world contexts.
   d. Apply properties of operations as strategies to add and subtract rational numbers.

7.NS.3: Solve real-world and mathematical problems involving the four operations with rational numbers.

California Next Generation Science Standards

HS-PS1-1: Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms.

HS-PS1-2: Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties.

HS-PS1-3: The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms.

Table 1 – California Math Common Core and Next Generation Science Standards as Applicable to Unit 1
Unit 2:
Science Concept: Atoms, Elements, Compounds – Moles and Molecular Weight
Math Concept: Powers of 10 and Scientific Notation

Abstract: This unit integrates the concepts of powers of 10 and scientific notation with that of moles and molecular weight. In this unit students will work with very small and very large numbers, and they will learn how to express these numbers efficiently and how this relates to our base 10 number system.

The chemistry covered in this unit focuses on the concept of moles and molecular weight. Students will learn how small a single atom is, and how an atom’s mass is related to its atomic mass on the periodic table. This unit teaches the students that one mole is equivalent to $6.02 \times 10^{23}$ atoms, and through various problems, analogies, and labs they will come to understand the magnitude of such a number. For example, I will have my students measure out 58.44 grams (1 mole) of the compound salt, and lead a discussion on how this is $6.02 \times 10^{23}$ molecules. Ultimately, demonstrations such as these will serve to enhance their understanding of how small subatomic particles are and the necessity for scientific notation.

Using this knowledge, students will be able to manipulate the numbers to understand just how little a single atom weighs. Given that an atom’s weight is largely comprised of the weight of its protons and neutrons, this provides an opportunity to discuss neutrons and isotopes with the students, essential topics in basic chemistry. This unit naturally follows an introduction on the periodic table, as it allows the students to delve deeper into subatomic particles and basic chemistry. In Unit 1, the students learned about elements in general, their arrangement in the periodic table, and the difference between atoms and ions. Unit 2 provides the students a closer look at the composition of atoms, and demonstrates to them how chemists study and measure atoms.
The mathematical concepts in this unit are powers of 10 and scientific notation. These two topics complement one another, because whether discussing a mole of atoms, a very large number, or the weight of a single atom, a very small number, the students will be using scientific notation and powers of 10. In this unit the students will learn both how to represent very small and very large numbers, and how to perform operations with these numbers, specifically performing operations with numbers in scientific notation. Ultimately, this will not only give them a better understanding of our base-10 number system, but will ultimately allow them to do more with the chemistry that they are learning, providing them with the tools to study and analyze the smallest or largest of quantities.

Within this unit, it will be essential to highlight a few key differences between the languages of math and chemistry. While the overarching concept of working with exponents and very large or very small numbers is stressed, it will be imperative to discuss the difference of the use of exponents in math and science. Whereas, in basic chemistry, exponents are used to indicate ionic charge, in pre-Algebra, exponents indicate the multiplicity of a number. For example, in pre-Algebra, $e^2$ is equivalent to $e \cdot e$, while in chemistry, $e^{2+}$ means that element, $e$, has an ionic charge of $+2$, indicating that it has two fewer electrons than it does protons. While highlighting such differences might seem as though it may cause confusion, teaching the disciplines though an interdisciplinary curriculum allows these nuances to be readily compared and contrasted, and compels the students to understand the material on a deeper level as they must evaluate everything through the lenses and languages of multiple disciplines in order to achieve complete comprehension.
This unit is integrated on both a conceptual level, as students are growing to understand very small and very large quantities both mathematically and chemically, and an applicable level, as students will practice scientific notation and learn to better understand powers of 10 through problems directly related to chemistry concepts. This unit is also a natural follow-up from the previous unit as the students build on their understanding of atomic numbers, protons, electrons, to neutrons and atomic mass. Together, these two introductory units build a solid foundation for the students as they progress to more advanced math and chemistry. Teaching students about the powers of 10 and scientific notation allows the students to work with numbers that they essentially could not fathom before.
California Math Common Core Standards

5.NBT.1: Recognize that in a multi-digit number, a digit in one place represents 10 times as much as it represents in the place to its right and $\frac{1}{10}$ of what it represents in the place to its left.

5.NBT.2: Explain patterns in the number of zeros of the product when multiplying a number by powers of 10, and explain patterns in the placement of the decimal point when a decimal is multiplied or divided by a power of 10. Use whole-number exponents to denote powers of 10.

5.NBT.3: Read, write, and compare decimals to thousandths.

   a. Read and write decimals to thousandths using base-ten numerals, number names, and expanded form, e.g., 347.392 = $3 \times 100 + 4 \times 10 + 7 \times 1 + 3 \times \left(\frac{1}{10}\right) + 9 \times \left(\frac{1}{100}\right) + 2 \times \left(\frac{1}{1000}\right)$.

   b. Compare two decimals to thousandths based on meanings of the digits in each place, using $>$, $=$, and $<$ symbols to record the results of comparisons.

5.NBT.4: Use place value understanding to round decimals to any place.

8.EE.3: 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. For example, estimate the population of the United States as $3 \times 10^8$ and the population of the world as $7 \times 10^9$, and determine that the world population is more than 20 times larger.

8.EE.4: 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 (e.g., use millimeters per year for seafloor spreading). Interpret scientific notation that has been generated by technology.

California Next Generation Science Standards

5-PS1-1: Develop a model to describe that matter is made of particles too small to be seen.

MS-PS1-1: Develop models to describe the atomic composition of simple molecules and extended structures.

Table 2 – California Math Common Core and Next Generation Science Standards as Applicable to Unit 2
Unit 3:
Science Concept: Solutions
Math Concept: Fractions, Decimals, and Percents

Abstract: In this unit students will learn about fraction, decimal, and percent equivalence, and they will examine it in the context of chemical solutions. Students will do a number of critical-thinking problems that enhance their understanding of solutes, solvents, and saturation and compel them to practice using fractions, decimals, and percents, and converting between them.

Now that the students have a basic understanding of elements and the periodic table, they can start to learn about solutions, mixtures in which a substance (a solute) is dissolved in another (a solvent). This is an opportunity for students to learn about solutes and solvents, and saturated, unsaturated, and supersaturated solutions. Solutions are most often classified in two ways – either, they are classified by their percent composition of different elements, or they are classified by their saturation which examines the ratio of solute to solvent within the solution. A solution is considered saturated if as much solute as possible has been dissolved. For example, to be considered saturated, 37% of a salt water mixture must be salt. That is to say, that for every 100 grams of salt water, 37 of those must be salt. Salt water mixtures with a lower percentage of salt than this are considered unsaturated, while mixtures that have more salt are considered supersaturated. This unit provides the opportunity to teach students about these basic chemistry topics, and allows the students to practice working with fractions, decimals, and percents as they discuss solubility.

Mathematically, this unit begins with a focus on percents, as solutions and solubility are often discussed in those terms. Percents are often taught in conjunction with decimals and fractions, so this unit provides students with the opportunity to learn the relationship between all three representations. As a class, we will examine the
composition of solutions as percents, fractions, and decimals, so that students might have
the opportunity to practice these various forms.

This unit, in particular, allows for creative problem solving. One type of problem
that I often use with my 7th graders is to provide the students with measuring cups of
different fractional measurements, and to ask them how they might use those measuring
cups to make a solution of a specific composition. I also often use problems that utilize
fractions, decimals, and percents, and compel the students to convert between the three.
For example, in one such problem, I might provide the students with the aforementioned
information – in order to be considered saturated, a salt water solution must be 37% salt.
I would then tell them that they currently have three beakers: beaker 1) 100 grams of salt
water that has a salt to salt-water ratio of 0.2, beaker 2) 100 grams of salt, and beaker 3)
100 grams of water. I would then ask the students what fraction of beaker 2 and what
fraction of beaker 3 they must add to beaker 1 to create a saturated salt water mixture.

These types of problems serve three main purposes. First, they allow students to
practice operations with fractions and decimals. Second, they serve as logic and critical
thinking problems, which is essential for 7th graders as they learn to think abstractly.
Third, and perhaps most importantly, they integrate math and science concepts, and
students are able to witness the real world applications of that which they are learning.
Often times fractions, decimals, and percents are taught through the use of contrived
problems. However, by teaching these mathematical concepts in conjunction with
solutions, students will be able to experience through discussions, problems, and labs,
how fractions, decimals, and percents can represent the chemical composition of
solutions, and they will witness the genuine utility of the math.
While this allows for a very applicable integration of math and chemistry, it also serves a spring board to discuss more advanced topics with the students, at an age-appropriate level. A natural extension of this lesson is a discussion on the other factors, such as pressure and temperature, that affect solubility. This topic will reemerge as the students progress mathematically, and they will be able to solve some more complex solubility equations once they learn to solve basic algebraic equations for different variables, but this unit provides a framework in which to introduce these concepts.

This unit is one in which students are learning a lot of the core chemistry and pre-Algebra concepts that will set them up for the rest of the curriculum. Learning about solutions prepares chemistry students to learn about chemical and ionic bonding, chemical reactions and stoichiometry, and limiting reagents and catalysts. Likewise, learning about fraction, decimal, and percent equivalence prepares students not simply for the remainder of the pre-Algebra curriculum, but for the math they will use most commonly in their daily lives.
California Math Common Core Standards

6.RP.3: Use ratio and rate reasoning to solve real-world and mathematical problems, e.g., by reasoning about tables of equivalent ratios, tape diagrams, double number line diagrams, or equations.

   c. Find a percent of a quantity as a rate per 100 (e.g., 30% of a quantity means $\frac{30}{100}$ times the quantity); solve problems involving finding the whole, given a part and the percent.

7.NS.2: Apply and extend previous understandings of multiplication and division and of fractions to multiply and divide rational numbers.

   d. Convert a rational number to a decimal using long division; know that the decimal form of a rational number terminates in 0s or eventually repeats

7.EE.3: Solve multi-step real-life and mathematical problems posed with positive and negative rational numbers in any form (whole numbers, fractions, and decimals), using tools strategically. Apply properties of operations to calculate with numbers in any form; convert between forms as appropriate; and assess the reasonableness of answers using mental computation and estimation strategies. For example: If a woman making $25 an hour gets a 10% raise, she will make an additional $\frac{1}{10}$ of her salary an hour, or $2.50, for a new salary of $27.50. If you want to place a towel bar 9 ¼ inches long in the center of a door that is 27 ½ inches wide, you will need to place the bar about 9 inches from each edge; this estimate can be used as a check on the exact computation.

California Next Generation Science Standards

5-PS1-4: Conduct an investigation to determine whether the mixing of two or more substances results in new substances.

Table 3 – California Math Common Core and Next Generation Science Standards as Applicable to Unit 3
Unit 4:
    Science Concept: Reaction Rates and Stoichiometry
    Math Concept: Rates, Ratios, and Proportions

Abstract: This unit teaches students how to solve stoichiometric problems using rates, ratios, and proportions. It also teaches students how to solve for reaction rates given lab data, practicing their use of ratios and exponents. Sample lessons for this unit are provided in Appendix 1.

This unit is on reaction rates and stoichiometry, primarily examining the different factors that affect reactions. Students will learn how to calculate reaction rates given sample lab data. By examining the occurrence of different reactions, students can create rate laws. This unit begins by teaching students using basic rates, and ultimately extrapolates this methodology to more complex reactions. In addition to learning about reaction rates, students will also learn stoichiometry in this unit. Stoichiometry is, essentially, mathematical calculations of the effect of different factors on chemical reactions. For example, using stoichiometry can reveal how much of a product can be created with only a limited amount of reactant, or how much reactant must be used in order to make a specific amount of product. This unit introduces students to chemical reactions for the first time and allows them to learn and explore, using math, how both external factors (temperature and pressure) and internal factors (reactants and products) can affect a reaction.

In this unit, the math of rates, ratios, and proportions not only goes hand in hand with the science, but is essential to it. Calculating reaction rates and performing stoichiometric operations is not possible without a knowledge of rates, ratios, and proportions. Mathematically, the students learn about how rates, ratios, and proportions are related in this unit. They learn to solve for unit rates, to solve proportions, and to use
ratios as conversion factors in multi-step problems. With these techniques, they can solve the same problem in multiple ways. This unit is unique in that it not only teaches the students a new mathematical concept, but it teaches them how to think – how they can relate different quantities to one another, and use their knowledge to assess what they already know, what they want to know, and formulate a solution strategy.

I elected to create sample lessons for Unit 4, because I believe this unit most clearly exemplifies the meaning of an interdisciplinary curriculum. My sample lessons include three classroom lessons and homework assignments on rates and reactions, stoichiometry and proportions, and reaction rates. There are also two labs, one of which studies reactions using stoichiometry, proportions, and rates, and the other of which focuses on reaction rates. The unit also includes a test to serve as a final assessment of the sample lessons. These lessons, labs, and assessment exemplify that there is, quite simply, no way to teach the scientific concepts of reactions, rates, and stoichiometry without first teaching the mathematical concepts of rates and proportions, and reveal that these scientific concepts are a natural application of the math.
California Math Common Core Standards

6.RP.1: Understand the concept of a ratio and use ratio language to describe a ratio relationship between two quantities. For example, “The ratio of wings to beaks in the bird house at the zoo was 2:1, because for every 2 wings there was 1 beak.” “For every vote candidate A received, candidate C received nearly three votes.”

6.RP.2: Understand the concept of a unit rate \( \frac{a}{b} \) associated with a ratio \( a:b \) with \( b \neq 0 \), and use rate language in the context of a ratio relationship. For example, “This recipe has a ratio of 3 cups of flour to 4 cups of sugar, so there is \( \frac{3}{4} \) cup of flour for each cup of sugar.” “We paid $75 for 15 hamburgers, which is a rate of $5 per hamburger.”

7.RP.1: Compute unit rates associated with ratios of fractions, including ratios of lengths, areas and other quantities measured in like or different units. For example, if a person walks \( \frac{1}{2} \) mile in each \( \frac{1}{4} \) hour, compute the unit rate as the complex fraction \( \frac{\frac{1}{2}}{\frac{1}{4}} \) miles per hour, equivalently 2 miles per hour.

7.RP.2: Recognize and represent proportional relationships between quantities.

   a. Decide whether two quantities are in a proportional relationship, e.g., by testing for equivalent ratios in a table or graphing on a coordinate plane and observing whether the graph is a straight line through the origin.

   b. Identify the constant of proportionality (unit rate) in tables, graphs, equations, diagrams, and verbal descriptions of proportional relationships.

   c. Represent proportional relationships by equations. For example, if total cost \( t \) is proportional to the number \( n \) of items purchased at a constant price \( p \), the relationship between the total cost and the number of items can be expressed as \( t = pn \).

California Next Generation Science Standards

MS-PS1-2: Analyze and interpret data on the properties of substances before and after the substances interact to determine if a chemical reaction has occurred.

HS-PS1-5: Apply scientific principles and evidence to provide an explanation about the effects or changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs.

Table 4 – California Math Common Core and Next Generation Science Standards as Applicable to Unit 4
Unit 5:
Science Concept: Chemical Equilibrium
Math Concept: Solving single variable algebraic equations

Abstract: This unit conceptually integrates the concepts of maintaining equilibrium in chemical equations and balancing algebraic equations. Maintaining the balance and equality between both sides of the equation, whether in chemistry or math, is similar in nature and serves to conserve the value of the elements and variables in the equations.

Energy is neither created nor destroyed, simply transferred, and atoms cannot appear or disappear, rather compounds are formed or broken apart. The reactants of a chemical equation must balance the products, ensuring that every reactant and every Joule of energy is accounted for as it transforms into a product. Each side of a chemical equation is a different rearrangement of the same elements and energy. For example, consider the following chemical equation: \(2\text{H}_2 + \text{O}_2 \rightarrow 2\text{H}_2\text{O}\). In this equation Hydrogen gas combines with Oxygen gas to form water. The equation is balanced, such that 4 Hydrogen atoms exist in both the reactants and the products as do 2 Oxygen atoms. They are simply moved from one side to another and regrouped in a different way.

This concept is paired with solving single variable equations, as the underlying principles are conceptually similar. When solving algebraic equations, the primary rule is that whatever is done to one side of the equation, must be done to the other in order to maintain equality and preserve the value of the unknowns. Terms cannot be eliminated from one side in order to isolate the variable, but rather they must be moved from one side of the equation to the other in order to solve for the unknown value. While the math in this unit is not particularly complex, as it is only comprised of basic operations and grouping like terms, this unit is unique in that it represents a conceptual integration. The chemistry concept of balancing equations is similar to the math concept of solving
algebraic equations. In both science and math equations, there exists a balance and equality between both sides of the equation that must be preserved in order for the value of unknowns to be maintained. For example, in the mathematical equation $3x + 2 = 2x + 8$, the equality of the two sides must be preserved in order for $x = 3$ to be preserved. Likewise, in the chemical equation $xH_2 + 12O_2 \rightarrow 24H_2O$, the balance must be maintained in order for the number of $H_2$ molecules to continue to equal 24. Ultimately, the core concept of balancing equations and not eliminating matter in chemistry is similar to that of maintaining equality and conserving the value of variables in math.

While the similarities unify the disciplines, it is essential to elucidate some of the distinct differences between chemical and mathematical equations. For example, one lesson that is emphasized in pre-Algebra is the equivalency of both sides of a mathematical equation. For example, given the equation $4 + 7x = 3x + 20$, whether students start solving from the left or the right side of the equation, so long as their calculations are correct, their answer will be correct and there is no distinction between an answer of $x = 4$ and $4 = x$. This does not hold true in chemistry, as there is a distinct difference between joining reactants to form a product, as in $2H_2 + O_2 \rightarrow 2H_2O$, or decomposing a product into its reactants, as in $2H_2O \rightarrow 2H_2 + O_2$. As previously noted, even when emphasizing these differences, an interdisciplinary curriculum allows for such distinctions to be more readily compared and contrasted, and compels the students to consider and appreciate these distinct differences. Ultimately, the underlying unifying concept in this unit is a conceptual one. Whether students use this knowledge in an individual or simultaneous approach of the disciplines, they have learned to explore equations through various lenses and apply their knowledge in multiple ways.
California Math Common Core Standards

6.EE.3: Apply the properties of operations to generate equivalent expressions. For example, apply the distributive property to the expression $3(2 + x)$ to produce the equivalent expression $6 + 3x$; apply the distributive property to the expression $24x + 18y$ to produce the equivalent expression $6(4x + 3y)$; apply properties of operations to $y + y + y$ to produce the equivalent expression $3y$.

6.EE.5: Understand solving an equation or inequality as a process of answering a question: which values from a specified set, if any, make the equation or inequality true? Use substitution to determine whether a given number in a specified set makes an equation or inequality true.

6.EE.6. Use variables to represent numbers and write expressions when solving a real-world or mathematical problem; understand that a variable can represent an unknown number, or, depending on the purpose at hand, any number in a specified set.

6.EE.7. Solve real-world and mathematical problems by writing and solving equations of the form $x + p = q$ and $px = q$ for cases in which $p$, $q$ and $x$ are all nonnegative rational numbers.

7.EE.4: Use variables to represent quantities in a real-world or mathematical problem, and construct simple equations and inequalities to solve problems by reasoning about the quantities.

a. Solve word problems leading to equations of the form $px + q = r$ and $p(x + q) = r$, where $p$, $q$, and $r$ are specific rational numbers. Solve equations of these forms fluently. Compare an algebraic solution to an arithmetic solution, identifying the sequence of the operations used in each approach.

b. Solve word problems leading to inequalities of the form $px + q > r$ or $px + q < r$, where $p$, $q$, and $r$ are specific rational numbers. Graph the solution set of the inequality and interpret it in the context of the problem.

California Next Generation Science Standards

MS-PS1-5: Develop and use a model to describe how the total number of atoms does not change in a chemical reaction and thus mass is conserved.

HS-PS1-7: Use mathematical representations to support the claim that atoms, and therefore mass, are conserved during a chemical reaction.

Table 5 – California Math Common Core and Next Generation Science Standards as Applicable to Unit 5

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Unit 6:
Science Concept: Thermodynamics
Math Concept: Introduction to functions and function notation

Abstract: This unit pairs a challenging topic for 7th graders, functions and function notation, with scientific phenomena that they are familiar with – heat and energy, specifically thermodynamics. Students will learn to write thermodynamic equations using function notation, \( f(x) = cx \), where \( c \) is the number of Joules per mole necessary for molecules to either bond or dissociate, and \( x \) is the number of moles. This will allow students to enhance their knowledge of thermodynamics and to become familiar with rates of change, functions, and function notation.

Kinetic energy is ubiquitous - sometimes energy is felt in the form of heat or movement, and sometimes energy is simply an invisible force allowing molecules to move and collide and chemical bonds to be formed or broken. Energy dictates every universal action and reaction. Thermodynamics is the study of this energy, specifically the transfer of energy through molecular collisions, or the creation or dissolution of chemical bonds. This unit allows the students to study universal and often unnoticed phenomena, such as hot and cold temperatures and states of matter, and teaches them about the energy required for these chemical processes to take place.

Energy, measured in Joules, is used to describe chemical reactions. For example, it takes a certain number of Joules to join two Hydrogen molecules to one Oxygen molecule to create two water molecules \((2\text{H}_2 + \text{O}_2 \rightarrow 2\text{H}_2\text{O})\), and a certain number of Joules are released every time those bonds are broken \((2\text{H}_2\text{O} \rightarrow 2\text{H}_2 + \text{O}_2)\). This is true of this reaction every time. While functions are initially introduced at a basic level – as a machine that takes inputs, applies a function rule, and produces outputs, the students will progress to writing thermodynamic equations as functions using function notation. Thermodynamic equations can be written algebraically, where the number of Joules necessary per bond created or broken is a constant, and the number of molecules being
joined or broken is variable. For example, it takes 237 kilojoules to dissociate one mole of water. When teaching this to the students, I would model this as $f(x) = 237x$, where $x$ is moles of water and $f(x)$ is the total number of kilojoules associated with this reaction, showing students the direct relationship between the input and the output. This allows students to learn about the concepts of kinetic energy and thermodynamics, while providing them an opportunity to practice function notation and enhance their understanding of rates of change. Generally, function notation tends to be a difficult mathematical concept for 7th graders to grasp, so pairing it with thermodynamics may provide students a practical application and help them to better comprehend this material.

Thus far in this curriculum, the math and science coalesce naturally and the units, themselves, follow fluidly as the math and science build upon previous units. This unit is well placed as it precedes the following unit on states of matter and linear equations. After learning about thermochemistry, the students will have a greater appreciation for simple chemical reactions, like the melting of ice or evaporation of water, and the energy necessary for them to occur. Learning about states of matter next is a natural segue, as the students will better understand how a compound transforms states of matter. Likewise, the following unit will segue mathematically, teaching the students about linear equations. This unit introduced students to proportional relationships, functions with a constant rate of change and a y-intercept of zero. The following unit will teach them to model general linear relationships, with a constant rate of change and non-zero y-intercepts. With a basic understanding of functions, the concept of linear functions should be easier for the students to grasp. As in any curriculum, it is important that the concepts build upon those previously taught and prepare for those to follow.
California Math Common Core Standards

8.F.1: Understand that a function is a rule that assigns to each input exactly one output. The graph of a function is the set of ordered pairs consisting of an input and the corresponding output.

8.F.2: Compare properties of two functions each represented in a different way (algebraically, graphically, numerically in tables, or by verbal descriptions). For example, given a linear function represented by a table of values and a linear function represented by an algebraic expression, determine which function has the greater rate of change.

8.F.4: Construct a function to model a linear relationship between two quantities. Determine the rate of change and initial value of the function from a description of a relationship or from two (x,y) values, including reading these from a table or from a graph. Interpret the rate of change and initial value of a linear function in terms of the situation it models, and in terms of its graph or a table of values.

California Next Generation Science Standards

MS-PS1-4: Develop a model that predicts and describes changes in particle motion, temperature, and state of a pure substance when thermal energy is added or removed.

MS-PS1-6: Undertake a design project to construct, test, and modify a device that either releases or absorbs thermal energy by chemical processes.

MS-PS3-3: Apply scientific principles to design, construct, and rest a device that either minimizes or maximizes thermal energy transfer.

HS-PS1-4: Develop a model to illustrate that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy.

Table 6 – California Math Common Core and Next Generation Science Standards as Applicable to Unit 6
Unit 7:
Science Concept: States of Matter
Math Concept: Linear equations

Abstract: This unit follows the last on function notation by focusing on a specific type of function – linear functions. Students will learn about rates of change and constants, and will learn to distinguish between linear and nonlinear functions. Students will also learn about states of matter, and through classwork and labs, they will practice writing linear equations, identifying the y-intercept and understanding its meaning, and solving for the rate of change.

As previously stated, this unit naturally follows the previous one. With an understanding of thermochemistry, the students are able to appreciate the energy necessary for states of matter to change. This unit will look at states of matter both conceptually and in the lab. Students will practice changing the states of matter of substances and examine the rates at which these changes occur. They will measure how these changes occur under various conditions and examine how different conditions can alter the rate of a reaction. This, too, harkens back to Unit 4 on reaction rates and is another example of how the chemistry in the units relate to and follow one another.

This unit pairs well with linear equations because so much of the chemistry taught, be it in the classroom or the laboratory, can be described by linear equations. Students will get to see how, under a specific set of conditions, a substance can change its state of matter at the same rate over time. Students often struggle with understanding the difference between slope and y-intercept, and being able to do labs and record data of their own will be invaluable to aiding their overall comprehension and elucidating the difference between constants and rates of change. Students will see how the y-intercept represents the initial amount of the substance in its present state and is not variable, while rate of change represents the amount of substance that changes per unit of time. For example, in a lab on melting candle wax into liquid, height is examined as a linear
function of time. In this case, the y-intercept represents the initial height of the candle (which the students will measure in centimeters), while the slope represents the amount of wax melted per unit of time (measured in centimeters/minute). The input “x” variable represents time (measured in minutes), while the output “y” or “f(x)” variable represents the current height of the candle. The ability to do these labs provides students a tangible representation of constants versus rates of change, and helps to make these abstract concepts more concrete for them. This unit provides an application-based integration of the math and science, as the science provides a natural application of linear equations.

It is essential in this unit to touch upon non-linear patterns, and to explain that not all states of matter behave in a linear fashion. As we are studying basic chemistry suitable for 7th graders, much of what we do will be deliberately chosen to illustrate linear relationships, slopes, and constants, but this unit will provide an opportunity to extend the material slightly and introduce more advanced concepts. This, hopefully, will not seem so intimidating to the students if presented with the unifying concept of rates of change in mind. Ideally, at the end of this unit students will be able to identify constant rates of change and, therefore, distinguish between linear and nonlinear functions.

In addition to the natural correlation of the math and science, this unit serves to enhance those previously taught. In this unit, students review reaction rates (covered in Unit 4) and look at them in greater depth. As the students’ knowledge increases, concepts learned at a basic level at the beginning of the year can now be expanded upon in greater depth and detail. In designing this scope and sequence, the focus was primarily on creating an interdisciplinary curriculum, but an additional, and perhaps unanticipated bonus of this experience has been the creation of a spiraling curriculum as well.
California Math Common Core Standards

6.EE.9: Use variables to represent two quantities in a real-world problem that change in relationship to one another; write an equation to express one quantity, thought of as the dependent variable, in terms of the other quantity, thought of as the independent variable. Analyze the relationship between the dependent and independent variables using graphs and tables, and relate these to the equation. For example, in a problem involving motion at constant speed, list and graph ordered pairs of distances and times, and write the equation \( d = 65t \) to represent the relationship between distance and time.

8.EE.6: Use similar triangles to explain why the slope \( m \) is the same between any two distinct points on a non-vertical line in the coordinate plane; derive the equation \( y = mx \) for a line through the origin and the equation \( y = mx + b \) for a line intercepting the vertical axis at \( b \).

California Next Generation Science Standards

2-PS1-4: Construct an argument with evidence that some changes caused by heating or cooling can be reversed and some cannot.

5-PS1-2: Measure and graph quantities to provide evidence that regardless of the type of change that occurs when heating, cooling, or mixing substances, the total weight of matter is conserved.

MS-PS3-4: Plan an investigation to determine the relationships among the energy transferred, the type of matter, the mass, and the change in the average kinetic energy of the particles as measured by the temperature of the samples.
Unit 8:
Science Concept: Limiting Reagents and Catalysts
Math Concept: Graphing Linear Equations

Abstract: This unit teaches the students about limiting reagents and catalysts. These scientific concepts are conducive to graphical representations, as the rate of change can symbolize the amount of product being produced either given a specific amount of reactant (if studying limiting reagents) or over time (if studying catalysts). Hence, these concepts are paired with the mathematical concept of graphing linear equations. Students will use the science they have learned to enhance their understanding of slopes and intercepts, and in graphing linear equations they will enhance their understanding of the effects of limiting reagents and catalysts on the products being produced.

At this point in the curriculum, the students have learned the basics about chemical reactions and stoichiometry, and they have the chemical knowledge necessary to learn more advanced chemistry concepts such as limiting reagents and catalysts. Limiting reagents and catalysts both affect the course of a chemical reaction. Limiting reagents are reactants that limit how much product can be made. As the students previously learned, certain amounts of products can be made from a given amount of reactants. Hence, each reactant can only produce a limited amount of product, and the reactant in a chemical equation expected to produce the least amount of product is deemed a limiting reagent. Catalysts, on the other hand, do not affect how much product can be formed, but rather they affect the rate of a reaction, and can be used to speed up a chemical reaction, forcing it to occur more quickly. These concepts draw on the material the students have learned throughout the year and build upon it.

Likewise, the math concepts in this unit also build upon previously learned lessons. The students have now learned about linear equations, specifically how to analyze them, write them, and solve them, but they must now learn how to graph them. Seventh graders are often very concrete thinkers, so even though they have a verbal and
conceptual understanding of linear equations, slopes, and y-intercepts, they often cannot extrapolate this to a graphical representation. In this unit, students will learn how linear functions appear graphically, and the graphical representations of slope and y-intercept.

In the previous unit, the students learned that the slope represents the rate of change. In this unit, they will come to understand that the slope determines the steepness of a graph, which provides a pictorial representation of the rate of change. They will learn how to graph various slopes by looking at the change in the “rise” and the change in the “run.”

Likewise, the students have previously learned that the y-intercept represents a constant. In this unit, they will see that constant represented graphically, and they will come to understand that the y-intercept is the value of y when \( x = 0 \). Additionally, whereas the students previously learned to evaluate and solve single variable equations, they will now learn that graphically any \((x,y)\) point represents a solution of the equation, and that the systems of equations they have been solving (for example, \( 4 + 7x = 3x + 20 \)) can be solved graphically by finding the intersection point of two linear graphs. While these concepts are not necessarily new for the students, their graphical representation is. This unit provides students a visual representation of that which they had previously learned and allows them to extrapolate previously learned concepts from a single graph.

Once the students have learned how to graph linear equations, they can integrate this with their knowledge of chemical equations. Given any balanced chemical equation, a certain amount of product can be formed from a given amount of reactants. These relationships can be represented by linear equations. For example, if \( y \) moles of \( \text{H}_2\text{O} \) can be produced from every \( \frac{1}{2} \) mole of \( \text{O}_2 \), assuming an unlimited amount of Hydrogen, this relationship can be represented by the line \( y = \frac{1}{2} x \). In this case, \( y \) represents the amount
of H₂O produced for every x moles of O₂. The slope is ½, indicating that for every two moles of H₂O desired, one mole of O₂ is necessary, and the y-intercept is 0, meaning that if there are 0 moles of O₂, 0 moles of H₂O can be created. Likewise, if y moles of H₂O can be produced from every 1 mole of H₂, assuming an unlimited amount of Oxygen, this relationship can be represented by the line y = x. In this case, y represents the amount of H₂O produced for every x moles of H₂. The slope is 1, indicating that for every one moles of H₂O desired, one mole of H₂ is necessary, and the y-intercept is 0, meaning that if there are 0 moles of H₂, 0 moles of H₂O can be created. By graphing equations such as these, students will have a visual representation of how much product can be formed given their reactants, and they will be able to deduce from these graphs information about their reactants and products, such as limiting reagents. For example, if the students were to graph the two aforementioned equations, they would be able to answer the following question and others similar to it: Given 6 moles of H₂ and 6 moles of O₂, how much H₂O can be created and which reactant was the limiting reagent? By observing the y values on each of their lines when x = 6 (also known as f(6)), the students will be able to determine how much H₂O could potentially be formed from 6 moles of H₂ and how much H₂O could potentially be formed from 6 moles of O₂. They will also be able to tell which reactant runs out more quickly (i.e. is able to form fewer moles of H₂O), and recognize that this is the limiting reagent.

Students will be able to do something similar with regards to catalysts. Reaction rates can often be represented by linear equations, and by running labs and extrapolating data, students will be able to graph linear equations associated with different reaction rates, and determine which reactions progressed more quickly than others. This will
provide the students with a visual representation of the effects of catalysts on their reaction. This will also provide the students an opportunity to practice graphing and analyzing linear equations in which the y-intercept is not 0, a concept learned in the previous chapter.

The integration in this unit is application-based as students will study the effects of limiting reagents and catalysts on chemical reactions. They will be able to represent their findings in multiple ways, through tables, algebraic equations, and graphs. Students will understand the correlation behind real life data, the relationships that dictate this data, and functional and visual representations of it.
California Math Common Core Standards

8.EE.5: Graph proportional relationships, interpreting the unit rate as the slope of the graph. Compare two different proportional relationships represented in different ways. For example, compare a distance-time graph to a distance-time equation to determine which of two moving objects has greater speed.

8.EE.8: Analyze and solve pairs of simultaneous linear equations.

a. Understand that solutions to a system of two linear equations in two variables correspond to points of intersection of their graphs, because points of intersection satisfy both equations simultaneously.

b. Solve systems of two linear equations in two variables algebraically, and estimate solutions by graphing the equations. Solve simple cases by inspection. For example, 3x + 2y = 5 and 3x + 2y = 6 have no solution because 3x + 2y cannot simultaneously be 5 and 6.

c. Solve real-world and mathematical problems leading to linear equations in two variables. For example, given coordinates for two pairs of points, determine whether the line through the first pair of points intersects the line through the second pair.

8.F.3: Interpret the equation \( y = mx + b \) as defining a linear function, whose graph is a straight line; give examples of functions that are not linear. For example, the function \( A = s^2 \) giving the area of a square as a function of its side length is not linear because its graph contains the points (1,1), (2,4) and (3,9), which are not on a straight line.

8.F.5: Describe qualitatively the functional relationship between two quantities by analyzing a graph (e.g., where the function is increasing or decreasing, linear or nonlinear). Sketch a graph that exhibits the qualitative features of a function that has been described verbally.

California Next Generation Science Standards

HS-PS1-6: Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium.

Table 8 – California Math Common Core and Next Generation Science Standards as Applicable to Unit 8

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Unit 9:
Science Concept: Bonding and Orbitals
Math Concept: Geometric Figures

Abstract: This final unit focuses on geometric figures and bonding. Students will learn that electron interactions dictate which elements may bond and in what form. They will build geometric models of molecules and gain a sense of the distance between electron pairs, the names of various shapes, and the angles commonly associated with these shapes.

The final unit of the year is on bonding and orbitals. Students have learned about elements, how they behave, and when they react. The curriculum ends by teaching the students what these elements actually look like. They will learn about the shapes of atomic orbitals and what this means for the angles at which atoms form bonds. Due to orbital shapes and ionic charge, atomic bonds can only be formed at very specific angles, creating elements in specific geometric figures. While some of these concepts are too advanced for 7th graders, they can learn the basic ideas, and through molecular geometry kits, they will have manipulatives that will help expose them to these higher-level chemistry concepts. The students have learned about atoms and that they combine and react, and now they will understand how this is guided by geometry. It is only fitting the students end their year of basic chemistry by enhancing their understanding of subatomic particles.

Mathematically, ending the year with geometry is also fitting because while the year has been focused on guiding the students from the concrete math of elementary school to the abstract nature of variables and pre-algebra, geometry allows the students to think even more abstractly. Students can visualize and create shapes, and in this case elements and compounds. While a lot of the geometry involved with atomic bonding will be too complex for 7th graders, this unit at least affords the opportunity to discuss angles
and orbitals on a broad scale. For example, the students will learn a few of the most common bonding shapes and angles, and that the purpose behind these angles is due to electron interaction. Students will learn about molecules that bond linearly with 180° angles between them, in a trigonal planar fashion with 120° angles between them, in a tetrahedral structure with 109.47° angles, in a trigonal bipyramidal way with 90° and 120° angles, and finally in an octahedral fashion with 90° angles. The students will be able to create visuals and manipulate them, allowing them to gain a sense of chemical bonding, geometric shapes, and their integration.

Throughout the year, the class has examined elements broadly as members of the periodic table, looked at subatomic particles closely, discussed the possible ways in which elements can act and react, and finally, the students will observe on a microscopic level the way in which everything they have been learning takes place. Students will witness how the bonding of the simplest and smallest subatomic particles is described by both math and science, as the total bonding number of electron groups dictate which elements may bond, at what angles, and in which form. In this way, students connect their knowledge of geometry and angles and experience how math and science are integrated on a microscopic level.
**California Math Common Core Standards**

7.G.2: Draw (freehand, with ruler and protractor, and with technology) geometric shapes with given conditions. Focus on constructing triangles from three measures of angles or sides, noticing when the conditions determine a unique triangle, more than one triangle, or no triangle.

7.G.3: Describe the two-dimensional figures that result from slicing three-dimensional figures, as in plane sections of right rectangular prisms and right rectangular pyramids.

7.G.5: Use facts about supplementary, complementary, vertical, and adjacent angles in a multi-step problem to write and solve simple equations for an unknown angle in a figure.

7.G.6: Solve real-world and mathematical problems involving area, volume and surface area of two- and three-dimensional objects composed of triangles, quadrilaterals, polygons, cubes, and right prisms.

8.G.5: Use informal arguments to establish facts about the angle sum and exterior angle of triangles, about the angles created when parallel lines are cut by a transversal, and the angle-angle criterion for similarity of triangles. For example, arrange three copies of the same triangle so that the sum of the three angles appears to form a line, and give an argument in terms of transversals why this is so.

**California Next Generation Science Standards**

K-PS2-1: Ask questions to determine cause and effect relationships of electric or magnetic interactions between two objects not in contact with each other.

MS-PS2-3: Ask questions about data to determine the factors that affect the strength of electric and magnetic forces.

MS-PS2-5: Conduct an investigation and evaluate the experimental design to provide evidence that fields exist between objects exerting forces on each other even though the objects are not in contact.

**Table 9 – California Math Common Core and Next Generation Science Standards as Applicable to Unit 9**
Chapter 7: Summary and Conclusions

Interdisciplinary education is a tool by which to not only teach students multiple disciplines, but to allow them to see the interconnectedness between the disciplines as they exist in the world around us. By elucidating these connections for students, their relationship with mathematics will be enhanced, as “ultimately, connections within mathematics, connections between mathematics and everyday experience, and connections between mathematics and other disciplines can support learning. Building on the connections can also make mathematics a challenging, engaging, and exciting domain of study” (NCTM, 2000, p. 113). The National Council of Teachers of Mathematics states that interdisciplinary studies can enhance mathematical competency, as allowing students to relate mathematical topics to their daily life allows them to view mathematics as both useful and interesting (Russo, 2011).

While scholars, researchers, and educators alike have defined interdisciplinary education in their own ways, I have chosen to abide by a fairly stringent definition, in which an interdisciplinary curriculum must inextricably link at least two disciplines, such that no single discipline can be fully taught or appreciated without the inclusion of the other. In this thesis, I present an original sample curriculum for a course in which basic chemistry and pre-algebra are integrated, in accordance with my definition of interdisciplinary, such that the math is necessary to understanding the science and the science is a natural application of the mathematics.
In addition to integrating multiple disciplines, an interdisciplinary curriculum is able to integrate critical thinking skills and problem solving methodologies across the disciplines. As the National Council of Teachers of Mathematics purports, and as supported by the design of my sample curriculum, the processes in science can encourage a way of thinking and problem solving that enhance external disciplines, mathematics included. Ultimately, integrating the disciplines enhances the understanding of each subject. As noted in my sample curriculum, for example, it was imperative to teach the students the distinction between exponents in mathematics and atomic charge in chemistry, despite the similar notation. While such lessons could be taught in individual classes, teaching them together compels the students to understand the material to a greater degree, as they must, within a single problem, evaluate the notation and the context in which it is given. Likewise, the conceptual integration of balancing chemical equations and balancing algebraic equations takes a rather abstract concept for 7th graders and applies it to multiple disciplines, allowing them not only to see the ubiquity and utility of this concept, but to practice its application in a variety of forms. This, thereby, serves to enhance their understanding of the specific material and their appreciation of the need to learn it. In my sample unit on rates, proportions, and stoichiometry, the students come to see that so many of the calculations necessary to chemistry require math. It is impossible to perform stoichiometric calculations or calculate reaction rates without having a basic understanding of rates and proportions. Learning these concepts through an integrated curriculum compels the students to see math and science, not as individual disciplines taught by individual teachers in individual classrooms, but as interconnected fields, inextricably linked through mathematics, science, and nature.
Future Directions and Conclusion

While this thesis specifically focused on an integrated pre-algebra and basic chemistry curriculum, the integration of math and science curricula is possible, if not easier at both higher and lower levels of math and science. Young students often learn about the scientific method and deductive reasoning, and do basic experiments involving counting and measuring. At the higher-levels, advanced chemistry and advanced physics necessitate the use of mathematics for a comprehensive understanding of the disciplines. Pairing the two disciplines and teaching them as a single course, allows a natural pairing to enhance the study of both disciplines, where the math is integral to understanding the science, and the science provides context for the math. Additionally, if these disciplines were to be integrated year after year, students would be able to see the ubiquity of math, as they would see math related to basic science, chemistry, physics, and so much more. The universality of mathematical ideas and their applicability to not just one, but multiple disciplines, would be evident. It would be interesting to develop interdisciplinary curricula involving mathematics at both the elementary and high school levels, and to examine whether the adoption of such curricula at a young age alters students’ attitudes towards and successes in math. Ultimately, as the National Council of Teachers of Mathematics purports, interdisciplinary curricula could have significant benefits for math instruction:

“School mathematics experiences at all levels should include opportunities to learn about mathematics by working on problems arising in contexts outside of mathematics. These connections can be to other subject areas and disciplines as well as to students’ daily lives…The opportunity for students to experience mathematics in a context is important. Mathematics is used in science, the social sciences, medicine, and commerce. The link between mathematics and science is
not only through content but also through process. The processes and content of science can inspire an approach to solving problems that applies to the study of mathematics.” (NCTM, 2000, p. 65)

In sharing my experiences, processes, scope and sequence, and sample lessons, I hope to offer other educators some insight into this approach to interdisciplinary curriculum development. While developing a curriculum such as this one was not an easy task, and requires concerted effort, time, and commitment from teachers and schools, such projects are worthwhile for the aforementioned reasons. Ultimately, the primary goal of any math teacher is to help their students gain an appreciation for mathematics, and by connecting math to external disciplines and to the real world, students have the opportunity to strengthen their understanding of mathematical concepts and applications, and to see the relevancy and the beauty of mathematics.
Appendix 1: Unit 4
Teacher’s Guide, Lessons, Labs, and Assessments
(Answer Key and Sample Student Produced Responses Included)

Science Concepts: Reaction Rates and Stoichiometry
Math Concepts: Rates, Ratios, and Proportions
Teacher’s Guide on Class Notes 1: Rates and Reactions

Learning Objectives:
Students will be able to perform computations using rates to convert between units, specifically between moles and grams. They will apply this knowledge to chemical reactions, and be able to assess how much product can be produced given a specific amount of reactant, or how much reactant is needed in order to produce a specific amount of product. With an enhanced understanding of rates, students will also briefly review key factors that affect the reaction rates. Using units when performing rate calculations will be stressed, as it will help the 7th graders to properly set up their rate equations and to ensure that they are cancelling similar units from the numerator and denominator. The units of reaction rates, however, are very complicated as they deal with concentration and volume and these will not be discussed until Class 3, which will focus specifically on calculating reaction rates.

Prerequisite Knowledge:
Students must already know how to multiply fractions and cross-cancel. While it is reviewed briefly in this lesson, it is expected that students have this knowledge from previous mathematics instruction. It is also expected that students have a basic knowledge of the periodic table, specifically the atomic weights of elements and molecules, which they would have learned in Unit 1, and that students know of the existence of chemical reactions.

Execution:
Mathematically, it will be key to emphasize to the students that while units may cross-cancel, the numbers associated with them do not. Students will have a tendency to eliminate the entire numerator or denominator, and must be reminded that the numerical values must be retained even as unit conversions are being performed. Scientifically, while students have been exposed to basic chemical reactions in previous years, it would be worthwhile to review the meaning of “→” or “←” in chemistry, and to reiterate to students the differences and similarities between these symbols and an “=” in a mathematical equation. Given that the students are, in large part, already familiar with this, this can be done efficiently and verbally as the main lesson proceeds.

Additional Supplements:
As I was only allowed a one-week interdisciplinary unit, in the coming weeks, I will supplement these lessons with additional practice materials. I often create Jeopardy games for my students to review the material. We will do worksheets with additional practice problems, and I often have students that need additional math support use online programs such as Khan Academy and iXL.
Class Notes 1: Rates and Reactions

We have already talked about the importance of using the proper units in math. It is essential that we label what it is we are measuring. I, as a mathematician, cannot simply give an answer of 8. I need to know if I am talking about 8 pounds? 8 cm? 8 years? 8 apples? It is very important to always keep track of your units and label your numbers properly.

One type of unit in mathematics is known as a rate.

Rate: A rate is the quotient of two quantities with different units.

For example, if I am driving at 40 miles/hour (this is read as 40 miles per hour), this is a rate because I am measuring my distance relative to time. I did not simply drive 40 miles, nor did I drive one hour, but rather I am driving at 40 miles per hour.

How far, in miles, will I have gone if I drive for 2 hours at this speed?

I will have gone 80 miles.

How long, in hours, have I been driving if I have made it 20 miles at this speed?

I will have driven for ½ an hour.

Since I know that I am driving at a rate of 40 miles/hour, if I know how long I have been driving I can figure out how far I have gone, or if I know how far I have gone I can figure out how long I have been driving. We will look at an example where we convert between rates.

First, let us review some basic fraction multiplication. Take a look at the following problem:

\[
\frac{3}{4} \cdot \frac{1}{3} = \frac{1}{4}
\]

As you may remember, you can cancel the same number from the numerator and denominator when multiplying fractions, because this is equivalent to eliminating a factor of one. When the same number or variable is in both the numerator and denominator, they “cancel each other out.” A similar thing can happen with rates, where, just like with fractions, the units of a rate can be crossed out of the numerator and denominator. As you will see in the following examples, we will use these to convert between rates!
Let’s look at an example.

**Problem:** I have been driving down the highway for 6 hours at a rate of 40 miles/hour. How far have I travelled?

**Solution:**

\[
6 \text{ hours} \cdot \frac{40 \text{ miles}}{\text{hour}} = ?
\]

\[
\frac{6 \text{ hours}}{1} \cdot \frac{40 \text{ miles}}{\text{hour}} = \frac{6 \cdot 40 \text{ miles}}{1} = 6 \cdot 40 \text{ miles} = 240 \text{ miles}
\]

We have the unit “hours” in both the numerator and denominator, meaning that they cancel each other out, and we can go ahead and cross them out. When we do so, our answer is left with just the unit miles, which is perfect since we were trying to measure distance! Logically, this makes perfect sense, because if we are trying to figure out how far we traveled in 6 hours, and we are traveling at a rate of 40 miles per hour, then, in total, we should travel 6 \cdot 40 miles, just as the multiplication would suggest!

Using units is an excellent way to check your work. If you have done a problem properly and crossed out all of the units correctly, your answer will be left with the units you desire. If you are left with the wrong units, you know you have done something wrong and you can go back and check your work.

Now you try a couple of problems yourself.

**Problem:** If a child grows at a rate of 2.5 inches per year between the ages of 4-10, what is the total gain in height between the ages of 4 and 10?

**Solution:**

\[
6 \text{ years} \cdot \frac{2.5 \text{ inches}}{\text{year}} = (6)(2.5) \text{ inches} = 15 \text{ inches}
\]

**Problem:** Absalom has been absent and has 5 chapters of a book to read. Each chapter is 20 pages long. Each page takes 2 minutes to read. How many hours will it take him to read these 5 chapters?

**Solution:**

\[
5 \text{ chapters} \cdot \frac{20 \text{ pages}}{\text{chapter}} \cdot \frac{2 \text{ minutes}}{\text{page}} = (5)(20)(2) \text{ minutes} = 200 \text{ minutes}
\]
So, how can we use our knowledge of rates to better understand chemical reactions?

Let’s do some problems.

**Problem:**  
Iron + water + oxygen $\rightarrow$ rust  
$4 \text{Fe} + 6 \text{H}_2\text{O} + 3 \text{O}_2 \rightarrow 4 \text{Fe(OH)}_3$

As you can see from the chemical equation above, 4 moles of Iron transforms to become 4 moles of rust (assuming we have the necessary amount of water and oxygen present). You can figure out from the periodic table that 1 mole of Iron weighs about 56 grams, and 1 mole of Fe(OH)$_3$ weighs about 107 grams. How many grams of rust would 100 grams of iron produce?

**Solution:**

$$
\frac{100 \text{ grams iron}}{56 \text{ grams iron}} \cdot \frac{4 \text{ moles rust}}{4 \text{ moles iron}} \cdot \frac{107 \text{ grams rust}}{1 \text{ mole rust}} = \frac{(100)(4)(107)}{(56)(4)} \text{ grams rust}
$$

$$
= \frac{191.07 \text{ grams rust}}{100} = 191.07 \text{ grams rust}
$$

In this single problem, we used two different types of rates! We recognized that 4 moles of Iron produce 4 moles of rust. Relating rust to iron allowed us to convert between reactants and products. We also used rates to convert between grams and moles. This is no different than converting between feet and inches – we are simply measuring the amount of a substance through a different lens. By using multiple rates, we were able to convert the grams of a reactant $\rightarrow$ moles of a reactant $\rightarrow$ moles of a product $\rightarrow$ grams of a product! You are now rate experts!
We have seen how conversion rates can help us determine how much is produced in a chemical reaction. Let’s learn a little bit more about chemical reactions. Some chemical reactions occur nearly instantaneously and others over the course of hundreds of years. Reactions that take a long time to occur have what is known as a low reaction rate, like the fossilization of bones, while reactions that occur quickly have what is known as a high reaction rate, like explosions and combustions!

Many factors can affect the rate of a reaction. Here are a few:

**Temperature:** Higher temperatures mean more heat, and more heat means that the molecules have a lot more energy. This makes them move faster and collide with each other more, so reactions occur more quickly. Basically, high temperatures result in faster reaction rates, and low temperatures result in slower reaction rates.

One example is how cookies will bake faster at a higher temperature!

**Concentration:** The more molecules you have, the more molecules there are to bounce around and collide, so the faster a reaction can occur. So, higher concentrations result in faster reaction rates, and lower concentrations result in slower reaction rates.

One example is that 2 doses of antacids (sodium bicarbonate) will help to neutralize your stomach acids (hydrochloric acid) more quickly than just a single dose.

**Catalysts:** Catalysts increase the rate of a reaction. They can be different substances depending on the reaction, and they increase the rate of a reaction by lowering the energy needed to make that reaction take place, allowing the reaction to happen more easily.

One example is how, in a room filled with hydrogen gas and oxygen gas, very little happens. However, if you light a match in that room or produce a spark, most of that hydrogen and oxygen combines to create water molecules. In this case, fire is a reaction catalyst.
Homework 1: Rates and Reactions

For questions 1-3, name the 3 factors we learned that affect reaction rates and give one example of each. Use the internet to research if you need to:

1. Temperature:
   Answers will vary. Sample student-produced responses below:
   - Glowsticks are brighter in hot water because the chemical reaction making the light runs faster at the higher temperature.
   - Ice melts more quickly at hotter temperatures.

2. Concentration:
   Answers will vary. Sample student-produced responses below:
   - Higher concentrations of acid erode pennies faster.
   - You can make elephant toothpaste by combining hydrogen peroxide, soap, and yeast. The hydrogen peroxide breaks down into hydrogen and oxygen, the oxygen gets released quickly and pushes the water and soap, which combine to make a foam, out of the tube, creating elephant toothpaste. This reaction happens more slowly with 3% Hydrogen peroxide, than with 30% Hydrogen peroxide.

3. Catalysts:
   Answers will vary. Sample student-produced responses below:
   - There are catalytic converters in cars where the presence of platinum, the catalyst, allows carbon monoxide to change into carbon dioxide more quickly.
   - We knew that Matt and Katie liked each other but they were too shy to talk to each other, so we tricked Matt into texting Katie. We catalyzed their relationship. (This is not a chemical catalyst).
**Instructions:** Use the chemical equation below to answer questions 4 and 5.

The combustion of propane in oxygen gas to create carbon dioxide and water is described by the equation,

\[ \text{C}_3\text{H}_8 + 5\text{O}_2 \rightarrow 3\text{CO}_2 + 4\text{H}_2\text{O} \]

Assume there is unlimited Oxygen and 70 grams of propane at your disposal. Use your periodic table to figure out how many moles this is. Use this information to answer questions 4 and 5 below.

4: How many grams of carbon dioxide will be produced?

\[
\frac{70 \text{ grams Propane} \cdot \frac{1 \text{ mole Propane}}{44 \text{ grams Propane}} \cdot \frac{3 \text{ moles Carbon Dioxide}}{1 \text{ mole Propane}} \cdot \frac{44 \text{ grams Carbon Dioxide}}{1 \text{ mole Carbon Dioxide}}}{1} = 210 \text{ grams Carbon Dioxide}
\]

5: How many moles of water will be produced?

\[
\frac{70 \text{ grams Propane} \cdot \frac{1 \text{ mole Propane}}{44 \text{ grams Propane}} \cdot \frac{4 \text{ moles Water}}{1 \text{ mole Propane}}}{1} = 6.36 \text{ moles Water}
\]

**Instructions:** Use the same chemical equation to answer questions 6 and 7. This time, your starting amounts of Oxygen and propane are unknown.

\[ \text{C}_3\text{H}_8 + 5\text{O}_2 \rightarrow 3\text{CO}_2 + 4\text{H}_2\text{O} \]

6: If 90 grams of water were produced, how many moles of Oxygen gas were used in this reaction?

\[
\frac{90 \text{ grams Water} \cdot \frac{1 \text{ mole Water}}{18 \text{ grams Water}} \cdot \frac{5 \text{ moles Oxygen gas}}{4 \text{ moles Water}}}{1} = 25 \text{ moles Oxygen gas}
\]

7: If 27 moles of carbon dioxide were produced, how many grams of propane were used in this reaction?

\[
\frac{27 \text{ moles Carbon Dioxide} \cdot \frac{1 \text{ mole Propane}}{3 \text{ mole Carbon Dioxide}} \cdot \frac{44 \text{ grams Propane}}{1 \text{ mole Propane}}}{1} = 396 \text{ grams Propane}
\]
Instructions: Answer questions 8, 9, and 10 in complete sentences.

8. Name one thing you learned about reactions from this lesson.
   Answers will vary. Sample student-produced responses below:
   - I learned that reactions happen at different rates.
   - I learned that you can affect the rate of a reaction by changing the temperature, the concentration, or by adding a catalyst.

9. Name one thing you learned about rates from this lesson.
   Answers will vary. Sample student-produced responses below:
   - I learned that you can cross cancel units just like you can cross cancel numbers when working with rates.
   - I learned that using rates can tell you a lot of information about a simple problem.

10. How is what you learned in this lesson relevant to you?
    Answers will vary. Sample student-produced responses below:
    - Everything around us is a chemical reaction happening at different rates because of different factors.
    - We can use rates to understand a lot about chemistry.

Extra Credit:

11. Why might we want an answer in moles sometimes and in grams sometimes?
    Answers will vary. Sample student-produced responses below:
    - If we are working in the lab and need to measure reactants and products, working in grams is easier than moles.
    - If we are talking about a chemical equation and comparing the ratio of different reactants and products, using moles is easier than grams.
Teacher’s Guide on Class Notes 2: Stoichiometry and Proportions

Learning Objectives:
Students will directly build on the material from Lesson 1 and enhance their knowledge of the previous concepts. In Lesson 1, students learned to calculate the amount of various substances in chemical reactions using rates. In Lesson 2, they will learn that this study is a branch of chemistry known as stoichiometry, as they go a bit more in depth, learning about limiting reagents. In the last lesson, they learned how to examine chemical reactions using rates. In this lesson, they will learn to use proportions to perform such calculations, learning specifically about the means-extremes property.

Prerequisite Knowledge:
Students must already know how to multiply and divide fractions. Additionally, this lesson builds directly on the material covered in Lesson 1, so it is expected that students have covered Lesson 1 before attempting Lesson 2.

Execution:
This lesson is particularly nice in that, together with Lesson 1, students will have learned two methods with which to examine chemical reactions – rates and proportions. It is always nice when students can learn multiple ways to approach the same problem, as it aides in critical thinking, provides them with a variety of options, and allows them to solve the problem using one method and check their work in a different way.
Class Notes 2: Stoichiometry and Proportions

Stoichiometry studies the amount of substances that are involved in reactions. Using stoichiometry, you can measure reactants or products or both. Stoichiometry can tell you how much product you can make given a certain amount of reactants or vice versa.

Let’s think about a simple example. Sodium ions combine with chloride ions to make salt. Remember that ions are elements that have lost or gained an electron for stability. The + or – near the element’s symbol represents its ionic charge (which you learned how to calculate in Unit 1). In this case, sodium ions and chloride ions generally combine in a 1:1 ratio, as per the following equation:

\[ \text{Na}^+ + \text{Cl}^- \rightarrow \text{NaCl} \]

Stoichiometry tells us that even if we have 100 Na\(^+\) ions and only 1 Cl\(^-\) ions we can still only make 1 NaCl molecule, we will simply have 99 Na\(^+\) ions left over.

\[ 100\text{Na}^+ + \text{Cl}^- \rightarrow \text{NaCl} + 99\text{Na}^+ \]

In this case, chloride is known as the **limiting reagent**. This means that because there is less chloride, this is the element that is limiting how many molecules of NaCl can be formed.

One concept in math that will be very helpful in determining our limiting reagent is proportions. What is a proportion? A proportion is an equation stating that two ratios are equal. In this case, we will be examining the ratios of reactant per product.

Let’s look a simple example.

**Example:** If every 1 mole of O\(_2\) forms 2 moles of H\(_2\)O, how many moles of H\(_2\)O will be formed from 2 moles of O\(_2\)? Let’s set up a proportion to look at this information.

\[ \frac{1 \text{ mole O}_2}{2 \text{ moles H}_2\text{O}} = \frac{2 \text{ moles O}_2}{? \text{ moles H}_2\text{O}} \]

We know that the ratio of moles of O\(_2\) to moles of H\(_2\)O is 1:2, so we can set up a proportion. Since the ratio of moles of O\(_2\) to moles of H\(_2\)O is constant, we can easily figure out how many moles of H\(_2\)O will be formed if we double the moles of O\(_2\). If we double the moles of O\(_2\), we need to double the moles of H\(_2\)O to maintain the 1:2 ratio, so 4 moles of H\(_2\)O would be formed from 2 moles of O\(_2\).
This is a fairly simple example, but let’s learn how we might go about solving similar proportion problems.

Solving Proportions Method 1 – Equivalent Fractions:

Solving proportions is very similar to finding equivalent fractions. For example, you already know that

\[
\frac{3}{9} = \frac{1}{3}
\]

But what if you didn’t? What if I gave you the following problem and asked you to solve for \(x\)? How would you go about it?

\[
\frac{3}{9} = \frac{1}{x}
\]

One of the ways we can solve proportions is by thinking about equivalent fractions and comparing numerator to numerator, and denominator to denominator. Here, we know both numerators, so we can go ahead and compare those. We see that the numerator in Fraction A (the 1\textsuperscript{st} fraction) is 3, and the numerator in Fraction B (the 2\textsuperscript{nd} fraction) is 1. The essential question we must ask ourselves is:

**What number do we have to multiply or divide A by to get B?**

In this case, what number do we have to divide 3 by to get 1?

We have to divide 3 by 3 to get 1.

So let’s go ahead and set this up, and remember the most important rule of working with fractions – when we are trying to get a similar fraction, whatever we do to the numerator, we must do to the denominator!

This means that if we are dividing the numerator by 3, we must also divide the denominator by 3.

\[
\frac{3}{9} \div \frac{3}{3} = \frac{1}{x}
\]

\[
\frac{3}{9} = \frac{1}{3}
\]

This is one way to solve proportions!
Let’s review the three most important rules of solving proportions:

**Rules to Solve Proportions:**

1) Compare the numerator of A to the numerator of B, and the denominator of A to the denominator of B.

2) Ask yourself, “What number do we have to multiply or divide A by to get B?”

3) Whatever we do to the numerator, we must do to the denominator

Now you try a couple of problems.

**Problem:**

\[
\frac{68}{170} = \frac{x}{5}
\]

**Solution:**

\[
\frac{68}{170} \div \frac{34}{34} = \frac{x}{5}
\]

So, \(x = 2\)

**Problem:** If 4 moles of compound A can create 7 moles of compound B, how many moles of compound A are needed to create 84 moles of compound B?

**Solution:**

\[
\frac{4 \text{ moles of A}}{7 \text{ moles of B}} = \frac{x \text{ moles of A}}{84 \text{ moles of B}}
\]

\[
\frac{4}{7} \cdot \frac{12}{12} = \frac{x}{84}
\]

So, \(x = 48\) moles of compound A.
Solving Proportions Method 2 - The Mean-Extremes Property:

Let’s think about a problem similar to the previous example.

**Problem:** If 4 moles of compound A can create 7 moles of compound B, how many moles of compound A are needed to create 80 moles of compound B?

**Solution:**

\[
\frac{4 \text{ moles of A}}{7 \text{ moles of B}} = \frac{x \text{ moles of A}}{80 \text{ moles of B}}
\]

Now what? It is not straightforward what we need to multiply 7 by to get 80. So, how else can we solve this proportion? Let’s clear our fractions by multiplying both sides by \(80 \cdot 7\). For now, we are just going to focus on the numbers and not worry about units.

\[
(80 \cdot 7) \cdot \frac{4}{7} = \frac{x}{80} \cdot (80 \cdot 7)
\]

\[
320 = 7x
\]

\[
\frac{320}{7} = x
\]

So, \(x = 45 \frac{5}{7}\) moles of compound A.

Luckily, there is a helpful trick in math known as the means-extremes property that uses the principle of clearing fractions and allows us to do calculations like these much more quickly.

The means-extremes property states that in any proportion,

\[
\frac{a}{b} = \frac{c}{d}
\]

you can clear the fractions by multiplying both sides of the equation by \((b \cdot d)\) and you will be left with

\[
ad = bc
\]

This will make solving proportions so much easier!
Always remember this handy little diagram when trying to use the means-extreme property.

Let’s look at a familiar problem and use the Means-Extreme Property to solve it now!

**Problem:** If 4 moles of compound A can create 7 moles of compound B, how many moles of compound A are needed to create 80 moles of compound B?

**Solution:**

\[
\frac{4 \text{ moles of A}}{7 \text{ moles of B}} = \frac{x \text{ moles of A}}{80 \text{ moles of B}}
\]

\[
7x = 4 \cdot 80
\]

\[
7x = 320
\]

\[
x = \frac{320}{7} \text{ moles of compound A} = 45 \frac{5}{7} \text{ moles of compound A}
\]
So, how can we use this knowledge of proportions to think about limiting reagents? Let’s look back at one of our basic equations first.

\[ \text{Na}^+ + \text{Cl}^- \rightarrow \text{NaCl} \]

**Problem:** If 5 grams of Sodium react with 10 grams of Chloride, how many grams of Sodium Chloride can be produced? And which substance is our limiting reagent?

**Solution:** Since the question gives us a specific number of grams of Sodium and a specific number of grams of Chloride, we will work in grams. The first step is to use the periodic table to figure out the mass of 1 mole of each of these elements or compounds.

1 mole of Sodium = 23 grams  
1 mole of Chloride = 35.5 grams  
1 mole of Sodium Chloride = 58.5 grams

Now, we will set up two proportions, one to examine the ratio of Sodium to Sodium Chloride produced and one to examine the ratio of Chloride to Sodium Chloride produced. This will help us to figure out our limiting reagent.

Let’s start with our first proportion setting up a ratio of Sodium to Sodium Chloride.

We know that 1 mole of Sodium can produce 1 mole of Sodium Chloride, assuming an infinite amount of Chloride. So, 23 grams of Sodium (1 mole) can produce 58.5 grams of Sodium Chloride (1 mole). Let’s set up a proportion and cross multiply.

\[
\frac{23 \text{ g Na}}{58.5 \text{ g NaCl}} = \frac{5 \text{ g Na}}{x \text{ g NaCl}}
\]

\[23x = 292.5\]

\[x = \frac{292.5}{23}\]

\[x = 12.7 \text{ grams NaCl}\]
Now let’s set up our second proportion setting up a ratio of Chloride to Sodium Chloride.

We know that 35.5 grams of Chloride (1 mole) can produce 58.5 grams of Sodium Chloride (1 mole), assuming an infinite amount of Sodium. So, let’s set up a proportion and cross multiply.

\[
\frac{35.5 \text{ g Cl}}{58.5 \text{ g NaCl}} = \frac{10 \text{ g Cl}}{x \text{ g NaCl}}
\]

\[35.5x = 10(58.5)\]

\[35.5x = 585\]

\[x = \frac{585}{35.5}\]

\[x = 16.5 \text{ grams NaCl}\]

From this, we see that Sodium is our limiting reagent, and that we would only be able to produce 12.7 grams of NaCl given the amount of Sodium that we began with.
Now you try a problem.

\[ 2\text{H}_2 + \text{O}_2 \rightarrow 2\text{H}_2\text{O} \]

**Problem:** Above is the basic equation for the synthesis of Hydrogen and Oxygen to create water. If you have 8 grams of Hydrogen, and 10 grams of Oxygen, how many grams of water can you make? And which substance is your limiting reagent?

*Hint* Please do not forget to consider the fact that it is \( \text{H}_2 \) and \( \text{O}_2 \), as in there are two Hydrogen atoms and 2 Oxygen atoms, and that there are 2 moles of \( \text{H}_2 \).

**Solution:**

1 mole of \( \text{H}_2 \) = 2 grams
1 mole of \( \text{O}_2 \) = 32 grams
1 mole of \( \text{H}_2\text{O} \) = 18 grams

Ratio of \( \text{H}_2 \): \( \text{H}_2\text{O} \) (in moles) is 1:1
Ratio of \( \text{H}_2 \): \( \text{H}_2\text{O} \) (in grams) is 2:18

Ratio of \( \text{O}_2 \): \( \text{H}_2\text{O} \) (in moles) is 1:2
Ratio of \( \text{O}_2 \): \( \text{H}_2\text{O} \) (in grams) is 32:36

\[
\frac{2 \text{ grams Hydrogen}}{18 \text{ grams Water}} = \frac{8 \text{ grams Hydrogen}}{x \text{ grams Water}} \quad \frac{32 \text{ grams Oxygen}}{36 \text{ grams Water}} = \frac{10 \text{ grams Oxygen}}{x \text{ grams Water}}
\]

\[
2x = 144 \quad 32x = 360
\]

\[
x = 72 \text{ grams of Water} \quad x = 11.25 \text{ grams of Water}
\]

We can make 11.25 grams of water, because Oxygen is our limiting reagent in this case.
Homework 2: Stoichiometry and Proportions

**Instructions:** For questions 1-7, solve the following stoichiometry problems using the following equation.

The combustion of a sample of butane, C\(_4\)H\(_{10}\) (lighter fluid), produced 2.46 grams of water.

\[2\text{C}_4\text{H}_{10} + 13\text{O}_2 \rightarrow 8\text{CO}_2 + 10\text{H}_2\text{O}\]

1. How many moles of water were formed?

\[
\frac{x \text{ moles Water}}{2.46 \text{ grams Water}} = \frac{1 \text{ mole Water}}{18 \text{ grams Water}}
\]

\[18x = 2.46\]

\[x = 0.14 \text{ moles Water}\]

2. How many grams of carbon dioxide were formed?

\[
\frac{0.14 \text{ moles Water}}{x \text{ moles Carbon Dioxide}} = \frac{10 \text{ mole Water}}{8 \text{ moles Carbon Dioxide}}
\]

\[10x = 1.12\]

\[x = 0.11 \text{ moles Carbon Dioxide}\]

\[
\frac{x \text{ grams Carbon Dioxide}}{0.11 \text{ moles Carbon Dioxide}} = \frac{44 \text{ grams Carbon Dioxide}}{1 \text{ moles Carbon Dioxide}}
\]

\[x = 4.84 \text{ grams Carbon Dioxide}\]

3. How many moles of butane burned?

\[
\frac{0.14 \text{ moles Water}}{x \text{ moles Butane}} = \frac{10 \text{ moles Water}}{2 \text{ moles Butane}}
\]

\[10x = 0.28\]

\[x = 0.03 \text{ moles Butane}\]
4. How many grams of butane burned?

\[
\frac{0.03 \text{ moles Butane}}{x \text{ grams Butane}} = \frac{1 \text{ mole Butane}}{58 \text{ grams Butane}}
\]

\[x = 1.74 \text{ grams Butane}\]

5. How much oxygen was used up in moles?

\[
\frac{0.14 \text{ moles Water}}{x \text{ moles Oxygen}} = \frac{10 \text{ mole Water}}{13 \text{ moles Oxygen}}
\]

\[10x = 1.82\]

\[x = 0.18 \text{ moles Oxygen}\]

6. How much oxygen was used up in grams?

\[
\frac{0.18 \text{ moles Oxygen}}{x \text{ grams Oxygen}} = \frac{1 \text{ mole Oxygen}}{32 \text{ grams Oxygen}}
\]

\[x = 5.76 \text{ grams Oxygen}\]

7. If we were given 10 grams of each of the reactants to begin with, which would be the limiting reagent?

1 mole of C\textsubscript{4}H\textsubscript{10} = 58 grams
1 mole of O\textsubscript{2} = 32 grams
1 mole of H\textsubscript{2}O = 18 grams
1 mole of CO\textsubscript{2} = 44 grams

\begin{align*}
\text{Ratio of } \text{C}_{4}\text{H}_{10} : \text{H}_{2}O \text{ (in moles) is } & 1:5 \\
\text{Ratio of } \text{C}_{4}\text{H}_{10} : \text{H}_{2}O \text{ (in grams) is } & 58:90 \\
\text{Ratio of } \text{O}_{2} : \text{H}_{2}O \text{ (in moles) is } & 13:10 \\
\text{Ratio of } \text{O}_{2} : \text{H}_{2}O \text{ (in grams) is } & 416:180
\end{align*}

\[
\frac{58 \text{ grams C}_{4}\text{H}_{10}}{90 \text{ grams H}_{2}O} = \frac{10 \text{ grams C}_{4}\text{H}_{10}}{x \text{ grams H}_{2}O}
\]

\[x = 15 \frac{15}{29} \text{ grams of H}_{2}O\]

\[
\frac{416 \text{ grams O}_{2}}{180 \text{ grams H}_{2}O} = \frac{10 \text{ grams O}_{2}}{x \text{ grams H}_{2}O}
\]

\[x = 4 \frac{17}{52} \text{ grams of H}_{2}O\]

\begin{align*}
\text{Ratio of } \text{C}_{4}\text{H}_{10} : \text{CO}_{2} \text{ (in moles) is } & 1:4 \\
\text{Ratio of } \text{C}_{4}\text{H}_{10} : \text{CO}_{2} \text{ (in grams) is } & 58:176 \\
\text{Ratio of } \text{O}_{2} : \text{CO}_{2} \text{ (in moles) is } & 13:8 \\
\text{Ratio of } \text{O}_{2} : \text{CO}_{2} \text{ (in grams) is } & 416:352
\end{align*}

\[
\frac{58 \text{ grams C}_{4}\text{H}_{10}}{176 \text{ grams CO}_{2}} = \frac{10 \text{ grams C}_{4}\text{H}_{10}}{x \text{ grams CO}_{2}}
\]

\[x = 30 \frac{10}{29} \text{ grams of CO}_{2}\]

\[
\frac{416 \text{ grams O}_{2}}{352 \text{ grams CO}_{2}} = \frac{10 \text{ grams O}_{2}}{x \text{ grams CO}_{2}}
\]

\[x = 8 \frac{6}{13} \text{ grams of H}_{2}O\]

Oxygen would be the limiting reagent because it would run out first.
Instructions: Answer questions 8, 9, and 10 in complete sentences.

8. What is stoichiometry and how is it important?
   Answers will vary. Sample student-produced responses below:
   - Stoichiometry lets us measure the amount of reactants and products in a reaction in grams and moles.
   - Stoichiometry is a part of chemistry where we can use proportions to find relationships between reactants and products.

9. How are cross products useful and how else might you use them?
   Answers will vary. Sample student-produced responses below:
   - Cross-products are an easy way to figure out proportions. As long as we know one piece of information about a chemical reaction, the moles or the grams of any reactant or product, we can use them to solve for the rest of the information.
   - If we are comparing two measurements using proportions, we can use cross-products to solve for equivalent values.

10. How is what you learned in this lesson relevant to you?
    Answers will vary. Sample student-produced responses below:
    - We are going to be using math a lot in chemistry. I will use cross-products to solve math problems and chemistry problems, so I definitely need to know them.
    - We can use cross products everywhere! We can use them at the grocery store to figure out equivalent costs, or at amusement parks to predict line lengths, or with my allowance to figure out future savings.

Extra Credit:

11. In what instances might it not be appropriate to use cross-products?
    Answers will vary. Sample student-produced responses below:
    - We cannot use cross-products to solve things that are not proportions. For example, we cannot use cross-products to solve $\frac{2}{3} < \frac{x}{9}$.
    - We cannot use cross-products if we can’t set up a proportion with the same units. For example, we cannot set up a proportion or use cross products to answer the question “If there are 12 inches in 1 foot, how many inches are there in a meter?” without first converting meters to feet.
Teacher’s Guide on Class Notes 3: Reaction Rates

Learning Objectives:
In Lessons 1 and 2, students learned a great deal about reactions. In this lesson, they will learn how to calculate reaction rates. They will learn about rate constants, proportionality, and the effect of concentration on reaction rates. Mathematically, students will begin practicing solving basic algebraic equations for defined variables, and working with exponents.

Prerequisite Knowledge:
It is expected that students have a basic working knowledge of exponents. They have been exposed to it in previous years in mathematics and theoretically in Unit 2 of this interdisciplinary unit. Students must also be very adept with reducing fractions and eliminating factors of 1.

Execution:
Conceptually and mathematically, this lesson is a bit tougher for students. The notes are organized in such a way that it will guide the lesson step by step, first with a single reactant, then two reactants. From experience, I would simply encourage an instructor to take the lesson very slowly, and have students show every step of their work (a task that is difficult for a lot of 7th graders), as this will be key to helping guide their understanding. Group work on the problems in class, and in the homework can also be very helpful for students, as it will allow them to discuss the concepts.
Class Notes 3: Reaction Rates

Now that we know what different factors affect reaction rates, we can actually begin to measure the rates of reactions. When discussing reaction rates, we will often be looking at the concentrations of different reactants in relation to the speed at which the reaction takes place.

In the reactions we will be examining, we will assume that they are occurring at a fixed temperature with no catalysts. This way, we can assume that the driving forces of the reaction rate are the concentrations of the reactants. We already learned that a higher concentration means a faster reaction rate. We are now going to learn how to calculate how much faster the reaction rate is based on the concentration.

Before we can do that, we have to learn a little bit of terminology. Think about combining two reactants, A and B, to form products. Our equation will look something like this:

\[ A + B \rightarrow \text{products} \]

To examine reaction rates, we will be looking at the initial concentrations of the reactants, and the rate of formation of the products. Of course, the concentration of the reactants will change throughout the reaction, as they disappear to form product. Likewise, the rate of formation of the product will change as the concentration of the reactants change. For our purposes, however, we will only look at the initial concentration of the reactants, and the initial rate of formation of the products.

The concentration of a reactant, compound A, for example, will be written as \([A]\). Concentration of reactants is often measured by the number of moles per unit of volume. For our purposes, we will be using moles/mL as our units, which means the number of moles of compound A per milliliter of solution. Obviously, when looking at \([B]\), or of any other reactants there might be in the experiment, the units should be the same.

When we talk about the rate of formation of the product, we will be talking about how many moles of the product were formed per unit of time, so our units will be moles/minute.

Of course, there can be multiple reactants in a chemical reaction, but in our studies, we will look at reactions that either have 1 or 2 reactants. This way, we can examine two main options. Either the rate of the reaction will only be proportional to the concentration of one of the reactants, so either \([A]\) OR \([B]\), or it will be proportional to the concentration of both reactants, so \([A]\) AND \([B]\).

Now, we are ready to look at some problems!
Option 1 – The Reaction Rate is Proportional to the Concentration of 1 Reactant:

\[ \text{A + B } \rightarrow \text{ products} \]

The rate of the reaction could be proportional to the concentration of just one of the reactants. Let’s assume that the rate of the reaction is proportional to [A] in some way. This means that as [A] changes, the rate of the reaction also changes.

In this case, the rate of the reaction is proportional to [A], and they can be equated like this,

\[ \text{Rate} = k_a [A] \]

where \( k_a \) is the rate constant. The rate constant represents how the concentration is proportional to the reaction rate. For example, a reaction where \( k_a = 6 \) occurs twice as fast as a reaction where \( k_a = 3 \), assuming that the [A] stays the same.

This can, of course, also be true of B. If the rate is dependent on [B], then the equation would be,

\[ \text{Rate} = k_b [B] \]

It is not always necessary to the rate to be directly proportional to [A]. The rate reaction could also be proportional to a power of [A]. For example,

\[ \text{Rate} = k_a [A]^2 \]

This would mean that if we double [A], we quadruple the rate of the reaction. Likewise, if we triple [A], the rate of the reaction would increase by a factor of 9, and so on and so forth. Generally, this rate equation would be the following:

\[ \text{Rate} = k_a [A]^a \]

This can, of course, also be true of B, and the equation would be

\[ \text{Rate} = k_b [B]^b \]

An important note is that the exponents do not necessarily have to be whole numbers. We will look at some examples like this.
Let’s do a couple of problems. In the following problems, we will use lab data to
determine the form of the reaction rates for various reactions. Remember, our reaction
rates will look like rate = \( k[A]^a \) and we will be solving for the rate constant, \( k \), and the
exponent, \( a \), as these will allow us to write an equation that describes how the reaction
rate varies with the concentration of \( A \).

**Problem:** Take a look at the following experimental data for a reaction in which Ozone
is converted into Oxygen gas, and determine the form of the reaction rate.

\[
2O_3 \rightarrow 3O_2
\]

<table>
<thead>
<tr>
<th>Reaction #</th>
<th>Initial [( O_3 )] (moles/mL)</th>
<th>Initial Rate of Formation of ( O_2 ) (moles/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6</td>
<td>1.5</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>1</td>
</tr>
</tbody>
</table>

Our generic rate law is rate = \( k[A]^a \) and our goal is to solve for \( k \) and \( a \). By setting up a
ratio comparing reaction #1 (\( r_1 \)) and reaction #2 (\( r_2 \)), we will be able to solve for \( a \) first
(because the \( k \) values will cancel out), and then we can solve for \( k \). Let’s take a look.

\[
\frac{r_1}{r_2} = \frac{k[6]^a}{k[4]^a} = \frac{1.5}{1}
\]

\[
[1.5]^a = 1.5
\]

Therefore, \( a = 1 \).

To solve for \( k \) we simply plug \( a \) into either one of our rate equations and solve for \( k \).

rate = \( k[A]^a \)

\[
1 = k[4]^1
\]

\[
k = \frac{1}{4} = 0.25
\]

So, our final rate equation for this experiment is rate = 0.25[\( O_3 \)]^1.

Of course since \( a = 1 \), you can choose to not write it in since [\( O_3 \)] = [\( O_3 \)]^1 but I think it is a
good habit to fill in the power.

What does this rate law tell us? This rate law tells us that, according to our data, the
reaction rate is directly proportional to the [\( O_3 \)] by a factor of 0.25. Basically, if we
divide [\( O_3 \)] by 4, that should be the rate of the reaction.
Now you try a problem.

**Problem:** Take a look at the following experimental data for a reaction in which $\text{N}_2\text{O}_4$ is converted into $\text{NO}_2$, and determine the form of the reaction rate. Discuss what information this reaction rate gives us.

\[
\text{N}_2\text{O}_4 \rightarrow 2\text{NO}_2
\]

<table>
<thead>
<tr>
<th>Reaction #</th>
<th>Initial $[\text{N}_2\text{O}_4]$ (moles/mL)</th>
<th>Initial Rate of Formation of $\text{NO}_2$ (moles/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.5</td>
<td>0.05</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Rate = $k[A]^a$

\[
\frac{r_2}{r_1} = \frac{k[1.00]^a}{k[0.50]^a} = \frac{0.20}{0.05} = 4
\]

\[2]^a = 4

\[a = 2\]

Rate = $k[A]^a$

\[0.20 = k[1.00]^2\]

\[k = \frac{0.20}{1.00} = 0.20\]

Rate = $0.20[\text{N}_2\text{O}_4]^2$.

This tells us that the reaction rate varies proportionally with the square of $[\text{N}_2\text{O}_4]$ by a factor of 0.2.
Option 2 – The Reaction Rate is Proportional to the Concentrations of 2 (or more) Reactants:

Option 1 looked at rate reactions that were dependent on either [A] OR [B]. In reality, however, most rate reactions will depend on the concentration of both reactants, [A] AND [B]. Thus, a general rate equation will look like this:

\[
\text{Rate} = k_{a,b} [A]^a [B]^b
\]

Why do we combine them like this – multiplying [A] and [B] instead of adding them, for example? Remember, the higher the concentration of reactants, the more likely collisions occur. More simply, if we have one particle of A and one particle of B, particle B only has one possible particle to collide with. However, if we add a second particle of A, B now has two particles it can collide with, so the chance of a collision is now twice as likely! So, the reaction rate is proportional to the product of the two reactant concentrations.

The process for reaction rates with multiple reactants is conceptually very similar to solving for a single reactant. We will do what we always try to do in math – take a complex problem and break it up into smaller, simpler problems!

Let’s look at a problem. Remember, in this case, the rate equation will be Rate = k [A]^a [B]^b, and we will be solving for k, a, and b.

Here are some hints on how we will approach this problem:

- The methodology is generally the same. Set up a ratio to compare two experiments.
- You will have to solve for a and b separately, so first pick two experiments to compare where [B] is the same, so that they will cancel each other out and you can focus on solving for a.
- Then, you will pick two experiments to compare where [A] is the same, so that they will cancel each other out and you can focus on solving for b.
- Then, you will be able to solve for k.
- Keep in mind that because we are working with a lot of experimental data, a, b, and k may not always be whole numbers, so we may make some approximations along the way. I will let you know when it is okay to do this.

Let’s try!
**Problem:** Take a look at the following experimental data for a reaction in which Xe (which we can call element A) and F₂ (which we can call compound B) combine to form XeF₆ and determine the form of the reaction rate. Discuss what information this reaction rate gives us.

\[
\text{Xe} + 3\text{F}_2 \rightarrow \text{XeF}_6
\]

<table>
<thead>
<tr>
<th>Reaction #</th>
<th>Initial [Xe] (moles/mL)</th>
<th>Initial [F₂] (moles/mL)</th>
<th>Initial Rate of Formation of XeF₆ (moles/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.5</td>
<td>0.25</td>
<td>0.00156</td>
</tr>
<tr>
<td>2</td>
<td>0.5</td>
<td>1</td>
<td>0.00625</td>
</tr>
<tr>
<td>3</td>
<td>1.5</td>
<td>0.25</td>
<td>0.01406</td>
</tr>
</tbody>
</table>

Rate = \( k [A]^a[B]^b \)

**Step 1:**

\[
\frac{r_3}{r_1} = \frac{k [1.5]^a[0.25]^b}{k [0.5]^a[0.25]^b} = \frac{0.01406}{0.00156} \approx 9
\]

\([3]^a \approx 9\)

\(a \approx 2\)

**Step 2:**

\[
\frac{r_2}{r_1} = \frac{k [0.50]^2[1.00]^b}{k [0.50]^2[0.25]^b} = \frac{0.00625}{0.00156} \approx 4
\]

\([4]^b \approx 4\)

\(b \approx 1\)

**Step 3:**

Rate = \( k [A]^a[B]^b \)

\[0.00625 = k [0.50]^2[1.00]^1\]

\[0.025 = k\]

Rate = 0.025 \([A]^2[B]^1\)

If we wanted to increase the reaction rate, would it be better to double the amount of Xe, F, or does it not matter? Why?

If we want to increase the reaction rate, it would be better to double the amount of Xe, because this would quadruple the reaction rate, whereas doubling the amount of F would only double the reaction rate.
Last but not least, let’s learn some helpful vocabulary words regarding reaction rates.

The same reaction can have different rates depending on which direction the reaction is going – are the reactants combining to form products? Or are the products disassociating to form reactants?

**Forward Rate:** The rate of the forward reaction, when the reactants combine to form products.

Example: For example, the reaction rate of \(2O_3 \rightarrow 3O_2\) could be considered a forward rate.

**Reverse Rate:** The rate of the reverse reaction, when the products break apart to become reactants.

Example: If the rate of \(2O_3 \rightarrow 3O_2\) is considered to be the forward rate, then the rate of \(3O_2 \rightarrow 2O_3\) is the reverse rate.

**Net Rate:** The forward rate minus the reverse rate.

Example: If the rate of \(2O_3 \rightarrow 3O_2\) is considered to be the forward rate, \(r_f\), and the rate of \(3O_2 \rightarrow 2O_3\) is the reverse rate, \(r_r\), then the net rate would be \(r_f - r_r\).

As a reaction proceeds, reactants are disappearing and products are forming.

**Rate of Formation:** The rate at which products are forming. In our sample data, we measured this in moles/minute.

Example: In reaction #1 of the first problem we did, \(O_3\) formed at a rate of 1.5 moles/minute. We learned from doing the problem that this rate of formation was dependent upon the concentration of \(O_2\) in that reaction.

**Rate of Disappearance:** The rate at which reactants are disappearing. In our sample data, I only gave you the initial concentration the reactants for each reaction, but, of course, the concentration is changing throughout the reaction as reactant disappears. The rate of disappearance would be measured by the change in concentration per unit of time. For example, we would have measured it in moles/(mL ⋅ min).

Example and Extra Credit: Think about our reaction in which Ozone was transforming into Oxygen gas? If every 2 moles of Ozone can transform into 3 moles of Oxygen gas, and we know that Oxygen gas was forming at a rate of 1.5 moles/min, what was the rate of disappearance of Ozone?
Homework 3: Reaction Rates

Instructions: Answer questions 1-7 about the reaction below.

\[ A + 2B \rightarrow C \]

<table>
<thead>
<tr>
<th>Reaction #</th>
<th>Initial [A] (moles/mL)</th>
<th>Initial [B] (moles/mL)</th>
<th>Initial Rate of Formation of C (moles/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.1</td>
<td>0.1</td>
<td>3.0 x 10^{-4}</td>
</tr>
<tr>
<td>2</td>
<td>0.1</td>
<td>0.3</td>
<td>3.0 x 10^{-4}</td>
</tr>
<tr>
<td>3</td>
<td>0.3</td>
<td>0.3</td>
<td>9.0 x 10^{-4}</td>
</tr>
</tbody>
</table>

1. Solve for \( a \).

Rate = \( k [A]^a[B]^b \)

\[
\frac{r_3}{r_2} = \frac{k[0.30]^a[0.30]^b}{k[0.10]^a[0.30]^b} = \frac{9.0 \times 10^{-4}}{3.0 \times 10^{-4}} = 3.0
\]

\[ [3]^a = 3.0 \]

\( a = 1 \)

2. Solve for \( b \).

\[
\frac{r_2}{r_1} = \frac{k[0.10]^1[0.30]^b}{k[0.10]^1[0.10]^b} = \frac{3.0 \times 10^{-4}}{3.0 \times 10^{-4}} = 1.0
\]

\[ [3]^b = 1.0 \]

\( b = 0 \)

3. Solve for \( k \).

Rate = \( k [A]^a[B]^b \)

\( 3 \times 10^{-4} = k [0.10]^1[0.10]^0 \)

\( 0.003 = k \)

4. Write a reaction rate to describe this equation.

Rate = 0.003 [A]^1[B]^0 = 0.003 [A]^1
5. How is the reaction rate affected by the concentration of A?

The rate of this reaction varies proportionally with A by a factor of 0.003. If [A] doubles, the reaction rate will also double. If [A] triples, the reaction rate will also triple, and so on.

6. How is the reaction rate affected by the concentration of B?

The reaction rate is not affected by the concentration of B. The change in the reaction rate did not depend at all on the change in the concentration of B.

7. Without even solving for the reaction rate, what could you look at in the table to hypothesize what your reaction rate equation should look like?

If you look at reactions #2 and #3, when the [A] triples, the rate of formation also triples. This indicates that the rate is proportional to [A]. If you look at reactions #1 and #2, when [B] triples, the rate of formation did not change. This indicates that the rate is not necessarily proportional to [B].

**Instructions:** Answer questions 8, 9, and 10 in complete sentences.

8. Name one thing you learned about reaction rates from this lesson.

   Answers will vary. Sample student-produced response below:
   - We can solve for the rate of a reaction using lab data.
   - In most instances, reaction rates are determined by both a reaction constant, and the concentration of the reactants.

9. What math did we use in this lesson?

   Answers will vary. Sample student-produced response below:
   - We performed operations with decimals and numbers in scientific notation.
   - We used ratios to solve for various constants.

10. How is what you learned in this lesson relevant to you?

    Answers will vary. Sample student-produced response below:
    - I learned that I can solve multi-step problems by breaking them down into smaller problems.
    - I learned that I can solve for chemical equations using lab data.
Teacher’s Guide on Lab 1: Stoichiometry Lab

Learning Objectives:
In this lab, students will have the opportunity to practice the stoichiometry concepts that they learned and even go a bit more in depth. Students will be performing an experiment, and estimating, based on the amount of reactants they began with, the amount of product that should be formed. Using either rates or proportions, students will perform stoichiometric calculations. They will learn about the concepts of actual yield, theoretical yield, and percent error. Most importantly, the students will get to witness the concepts they have been learning in action and perform calculations based on their own experiments.

Prerequisite Knowledge:
Lessons 1 and 2, in addition to their homework assignments are prerequisites for this lab. Additionally, students need to have a working knowledge of percents, which would be covered in Unit 2. Also, it is expected that students have done chemistry labs before and understand proper lab etiquette with regards to handling chemicals, lab equipment, and recording data.

Execution:
I found that this lab ran smoothly for the students. It is a relatively simple lab and the instructions guide students through it step by step. The hardest part for the students was identifying possible sources of error, but this presented an opportunity for the students to discuss and brainstorm ideas as a class.

Additional Supplements:
No additional supplements are needed for this lab.
Lab 1: Stoichiometry Lab

**Purpose:** To predict the amount of Carbon Dioxide gas that should be produced in a chemical reaction; then calculate the % yield.

\[
\text{CH}_3\text{COOH} + \text{NaHCO}_3 \rightarrow \text{NaCH}_3\text{COO} + \text{H}_2\text{O} + \text{CO}_2
\]

**Materials:** Baking Soda (NaHCO₃), Vinegar (CH₃COOH), and 2 plastic cups, scale.

**Procedure:**

1. Find and record the mass of cup A. With cup A still on the scale, add approximately 10.0 g of baking soda to the cup. The mass does not have to be exact, as long as you carefully record the mass of cup A by itself, and the mass of cup A with baking soda in it.

2. Place cup B on the scale, weigh and record approximately 50.0 g of vinegar. The mass does not have to be exact, as long as you carefully record the mass of cup B with the baking soda.

3. Slowly add vinegar to cup A until the reaction has stopped. DO NOT add all of the vinegar, just enough to complete the reaction. Reweigh and record both cup A and B. Calculate the mass of CO₂ that escaped.
Data: Sample student responses below.

a. Mass of Cup A 10.3 g (Actual: 10.1 g)

b. Mass of Cup A and baking soda 21.0 g (Actual: 20.1 g)

c. Calculate mass of baking soda (b - a) 10.7 g (Actual: 10.0 g)

d. Mass of Cup B 10.2 g (Actual: 10.1 g)

e. Mass of Cup B with vinegar 61.6 g (Actual: 60.1 g)

f. Calculate mass of vinegar (e - d) 51.4 g (Actual: 50.0 g)

g. Mass of Cup B after reaction 52.4 g (Actual: 53.0 g)

h. Calculate mass of vinegar poured into Cup A (d - e) 9.2 g (Actual: 7.1 g)

i. Mass of Cup A after reaction 24.9 g (Actual: 22.0 g)

j. Calculate mass of product after reaction (g - a) 14.6 g (Actual: 11.9 g)

k. Calculate baking soda + vinegar (c + f) 19.9 g (Actual: 17.1 g)

l. Calculate mass of CO₂ lost (i - h) 5.3 g (Actual: 5.2 g)
Discussion:

1. Using the mass of the baking soda in your cup A to calculate the mass of CO₂ you would expect.

\[
\frac{10.7 \text{ grams Baking Soda}}{84 \text{ grams Baking Soda}} \times \frac{1 \text{ mole Baking Soda}}{1 \text{ mole Carbon Dioxide}} \times \frac{44 \text{ grams Carbon Dioxide}}{1 \text{ mole Carbon Dioxide}} = 5.6 \text{ grams Carbon Dioxide}
\]

2. How does this compare to the amount of CO₂ actually produced?

Our experiment should have produced 5.6 grams of CO₂ but we calculated that we only produced 5.3 grams.

3. Calculate the percent yield (percent yield is a ratio of how much CO₂ was actually produced to how much CO₂ you predicted would theoretically be produced).

\[
\frac{\text{actual yield}}{\text{theoretical yield}} \times 100\% = \text{percent yield}
\]

\[
\frac{5.3}{5.6} \times 100\% = 94.6\%
\]

4. Calculate percent error (percent error is a ratio of how “off” the actual yield was as compared to theoretical yield).

\[
\left| \frac{\text{actual yield} - \text{theoretical yield}}{\text{theoretical yield}} \right| \times 100\% = \text{percent error}
\]

\[
\frac{|5.3 - 5.6|}{5.6} \times 100\% = 5.4\%
\]
5. Is baking soda or vinegar the limiting reagent in this reaction? How do you know?

We already calculated that 5.6 grams of Carbon Dioxide could be produced from our baking soda. We need to calculate how many grams of Carbon dioxide could be produced from our 51.4 grams of vinegar.

\[
\frac{51.4 \text{ grams Baking Soda}}{60.05 \text{ grams Vinegar}} \cdot \frac{1 \text{ mole Vinegar}}{1 \text{ mole Carbon Dioxide}} \cdot \frac{44 \text{ grams Carbon Dioxide}}{1 \text{ mole Carbon Dioxide}} = 37.66 \text{ grams Carbon Dioxide}
\]

Given our starting reactants, it is clear that we would run out of baking soda before running out of vinegar, so baking soda is our limiting reagent.

6. What are some possible sources of error that can contribute to your percent error? What could be done to reduce the percent error?

We could have performed our measurements incorrectly and used less baking soda than we thought, or spilled tiny bits of vinegar or baking soda in the process. We could have used dirty instruments that affected our weight measurements or contaminated our substances. There are lots of possible sources of human error in this lab.
Teacher’s Guide on Lab 2: Reaction Rates Lab

Learning Objectives:
In this lab, students will have the opportunity to examine the effects of temperature, concentration, and catalysts on rate reactions, and they will perform rate reaction calculations based on their lab data.

Prerequisite Knowledge:
Lesson 3, in addition to its homework assignment is a prerequisite for this lab. Once again, it is expected that students have done chemistry labs before and understand proper lab etiquette with regards to handling chemicals, lab equipment, and recording data.

Execution:
This lab is a bit tougher for students, as it includes more materials, has more materials and more steps. The key with this lab will really be to micromanage the students to make sure they are meticulously completing each step. The students also had a bit of a hard time describing the reactions they were seeing in a detailed enough manner that their descriptions were distinguishable from one another (i.e. simply saying “it fizzed” is not detailed enough, as that happens in multiple reactions). If I were to run this lab again, I would brainstorm descriptive language with the students beforehand. All in all, however, the lab was a success.

Additional Supplements:
No additional supplements are needed for this lab.
Lab 2: Reaction Rates Lab:

**Purpose:** To examine factors that increase reaction rates.

**Materials:**

<table>
<thead>
<tr>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>-3 Alka Seltzer tablets</td>
<td>-1M HCl, 5 mL per group</td>
<td>- 3% hydrogen peroxide, H\textsubscript{2}O\textsubscript{2}</td>
</tr>
<tr>
<td>-3 250-mL beakers</td>
<td>-3M HCl, 5 mL per group</td>
<td>– 10 mL per group</td>
</tr>
<tr>
<td>-water at three temperatures: with ice, room temperature, warm (around 70°C)</td>
<td>-6M HCl, 5 mL per group</td>
<td>-0.1 M FeCl\textsubscript{3}</td>
</tr>
<tr>
<td></td>
<td>-3 pieces of zinc metal, each approximately 1 cm × 1 cm</td>
<td>-0.1 M KI</td>
</tr>
<tr>
<td></td>
<td>-3 test tubes</td>
<td>- 0.1M Pb</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- 0.1 M MnO\textsubscript{2}</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-100-mL graduated cylinder</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- 10-mL graduated cylinder</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- 7 test tubes per group</td>
</tr>
</tbody>
</table>
**Procedure:**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>NaHCO₃ + H₃C₆H₅O₇ → H₂O + O₂ + Na₃C₆H₅O₇</td>
<td>Zn + 2 HCl → ZnCl₂ + H₂</td>
<td>H₂O₂ → 2 H₂O + O₂</td>
</tr>
</tbody>
</table>

1. Half fill three 250-mL beakers with water. In one beaker add several ice cubes. A second beaker will contain water at room temperature. In the third beaker add water that has been heated to about 70°C.

2. Record the water temperature in the three beakers, then add an Alka Seltzer tablet to each.

3. Record the time it takes for the Alka Seltzer tablet to completely dissolve, and any other observations that you may have.

| 1. Pour 5 mL of each of the three HCl solutions into separate test tubes. Place the test tubes in a test tube rack. |
| 2. Add one piece of zinc to each test tube and quickly place a balloon over the top of your test tubes. |
| 3. Record the time you added the zinc to the tubes, and the time each reaction stops. Also record your observations for each tube. You will see bubbles form in your test tubes – can you guess what they are? (Hint: what kind of gas is being produced in this reaction). |

1. Dilute the hydrogen peroxide by adding 10 mL of 3% H₂O₂ to a 100-mL graduated cylinder. Add 90 mL of distilled water to obtain 100 mL of diluted (0.3%) hydrogen peroxide.

2. Use a small amount of this solution to rinse out a 10-mL graduated cylinder and 7 test tubes. Pour the rinses away.

3. Place 5-mL of the 0.3% H₂O₂ solution into each of the 7 test tubes.

4. Add 5 drops of each of the following solutions to separate test tubes:
   - 0.1 M FeCl₃
   - 0.1 M KI
   - 0.1 M Pb
   - 0.1 M MnO₂

5. Mix each tube by swirling the test tube or gently stirring with a clean stirring rod.

6. Observe each solution, noting the production of any gas bubbles that form. Record each reaction rate as **fast, slow, very slow**, or very fast in your data table, and any other observations that you may have.
Data: Answers may vary. Sample student responses below.

Part 1: Effect of Temperature:

<table>
<thead>
<tr>
<th>Water Condition</th>
<th>Water Temperature</th>
<th>Time to Completion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cold</td>
<td>41° Fahrenheit</td>
<td>6 minutes, 37 seconds (397 seconds)</td>
</tr>
<tr>
<td>Room Temperature</td>
<td>76° Fahrenheit</td>
<td>3 minutes, 13 seconds (197 seconds)</td>
</tr>
<tr>
<td>Warm</td>
<td>122° Fahrenheit</td>
<td>42 seconds</td>
</tr>
</tbody>
</table>

Part 2: Effect of Concentration

<table>
<thead>
<tr>
<th>Acid Concentration</th>
<th>Start Time</th>
<th>Time at Completion</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 M HCl</td>
<td>09:02:00</td>
<td>09:09:04</td>
<td>This reaction took 7:04. The reaction fizzed a little, and small amounts of Hydrogen gas were produced.</td>
</tr>
<tr>
<td>3 M HCl</td>
<td>09:14:00</td>
<td>09:17:58</td>
<td>This reaction took 3:58. The reaction fizzed, and Hydrogen gas was produced - enough to blow up a balloon!</td>
</tr>
<tr>
<td>6 M HCl</td>
<td>09:20:00</td>
<td>09:22:11</td>
<td>This reaction took 2:11. The reaction fizzed a lot, and enough Hydrogen gas was produced to very quickly blow up the balloon!</td>
</tr>
</tbody>
</table>

Part 3: Effect of a Catalyst

<table>
<thead>
<tr>
<th></th>
<th>FeCl₃</th>
<th>KI</th>
<th>Pb</th>
<th>MnO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reaction Rate</td>
<td>Very Fast</td>
<td>Very Slow</td>
<td>Fast</td>
<td>Slow</td>
</tr>
</tbody>
</table>
Discussion: Write a paragraph for each part of this lab describing which reactions were carried out and what your findings were. Be sure to discuss how the rate of the reaction was affected and to use your results as evidence.

Part 1: Answers may vary. Sample student response below:

In the first part of this lab, we looked at how temperature affects the rate of a reaction. We put Alka Seltzer in water and timed how long it took to dissolve. We learned that the colder the temperature, the slower a reaction will go. This means that heat increases the rate of a reaction.

Part 2: Answers may vary. Sample student response below:

In the second part of this lab, we looked at how concentration affects the rate of a reaction. We used different concentrations of HCl. The higher the concentration, the faster the rate of reaction. This makes sense, because the higher the concentration, the more molecules there are floating around to react.

Part 3: Answers may vary. Sample student response below:

In the third part of this lab, we looked at how different chemicals affected the rate of a reaction. We found that FeCl₃ was most effective in speeding up the reaction, then Pb, then MnO₂, then KI. This means that some of these were catalysts and sped up the reaction and some were not.
Teacher’s Guide on Assessment: Quest 4

**Learning Objectives:**
Students take a formal test, much like the tests I have given them earlier in the year, to assess their understanding and retention of everything learned in this interdisciplinary unit.

**Prerequisite Knowledge:**
The test covers Lessons 1, 2, and 3, and an understanding of the two labs would be productive.

**Execution:**
The test was formatted similarly to tests the students have previously taken, so it ran smoothly. The test average was an 89%, with a standard deviation of 6%, which is on par for the scores normally received on my math tests throughout the year. This indicates that the students were able to answer science, math, and interdisciplinary questions with proficiency.

**Additional Supplements:**
No additional supplements are needed for this assessment.
Quest 4

Instructions: Answer the following questions, and be sure to show all of your work for partial credit! Each question is worth 5 points.

Part 1: Mole → Mass Conversions
Use your periodic table to convert the following number of moles of chemical into its corresponding mass in grams.

1. 0.436 moles of ammonium chloride (NH₄Cl)

\[
\frac{0.436 \text{ moles}}{\text{grams}} = \frac{1 \text{ mole}}{53.491 \text{ grams}} \rightarrow x = 23.322 \text{ grams Ammonium Chloride}
\]

2. 2.360 moles of lead (II) oxide (PbO)

\[
\frac{2.360 \text{ moles}}{\text{grams}} = \frac{1 \text{ mole}}{223.2 \text{ grams}} \rightarrow x = 526.752 \text{ grams Lead (II) Oxide}
\]

3. 0.031 moles of aluminum iodide (AlI₃)

\[
\frac{0.031 \text{ moles}}{\text{grams}} = \frac{1 \text{ mole}}{407.695 \text{ grams}} \rightarrow x = 12.639 \text{ grams Aluminum Iodide}
\]

4. 1.077 moles of magnesium phosphate (Mg(H₂PO₄)₂)

\[
\frac{1.077 \text{ moles}}{\text{grams}} = \frac{1 \text{ mole}}{218.280 \text{ grams}} \rightarrow x = 235.088 \text{ grams Magnesium Phosphate}
\]
**Part 2: Mass \( \rightarrow \) Mole Conversions**

Use your periodic table to convert the following masses into their corresponding number of moles.

5. 23.5 g of sodium chloride (NaCl)

\[
\frac{x \text{ moles}}{23.5 \text{ grams}} = \frac{1 \text{ mole}}{58.44 \text{ grams}} \rightarrow 58.44x = 23.5 \rightarrow x = 0.402 \text{ moles Sodium Chloride}
\]

6. 0.778 g of sodium cyanide (NaCN)

\[
\frac{x \text{ moles}}{0.778 \text{ grams}} = \frac{1 \text{ mole}}{49.007 \text{ grams}} \rightarrow 49.007x = 0.778 \rightarrow x = 0.016 \text{ moles Sodium Cyanide}
\]

7. 0.250 g of water (H₂O)

\[
\frac{x \text{ moles}}{0.250 \text{ grams}} = \frac{1 \text{ mole}}{18.015 \text{ grams}} \rightarrow 18.015x = 0.250 \rightarrow x = 0.014 \text{ moles Water}
\]

8. 169.45 g of calcium acetate (Ca(C₂H₃O₂)₂)

\[
\frac{x \text{ moles}}{169.45 \text{ grams}} = \frac{1 \text{ mole}}{158.166 \text{ grams}} \rightarrow 158.166x = 169.45 \rightarrow x = 1.071 \text{ moles Calcium Acetate}
\]
Part 3: Stoichiometry

9. Using the following equation:

\[ 2 \text{ NaOH} + \text{H}_2\text{SO}_4 \rightarrow 2 \text{ H}_2\text{O} + \text{Na}_2\text{SO}_4 \]

How many grams of sodium sulfate will be formed if you start with 200 grams of sodium hydroxide and you have an excess of sulfuric acid?

\[
\frac{200 \text{ g NaOH}}{40 \text{ g NaOH/mol Na}_2\text{SO}_4} \cdot \frac{1 \text{ mol Na}_2\text{SO}_4}{2 \text{ mol NaOH}} \cdot \frac{142 \text{ g Na}_2\text{SO}_4}{1 \text{ mol Na}_2\text{SO}_4} = 355 \text{ g Na}_2\text{SO}_4
\]

10. Using the following equation:

\[ \text{Pb(SO}_4)_2 + 4 \text{ LiNO}_3 \rightarrow \text{Pb(NO}_3)_4 + 2 \text{ Li}_2\text{SO}_4 \]

How many grams of lithium nitrate will be needed to make 250 grams of lithium sulfate, assuming that you have an adequate amount of lead (IV) sulfate to do the reaction?

\[
\frac{250 \text{ g Li}_2\text{SO}_4}{110 \text{ g Li}_2\text{SO}_4/mol LiNO}_3} \cdot \frac{1 \text{ mol Li}_2\text{SO}_4}{2 \text{ mol LiNO}_3} \cdot \frac{69 \text{ g LiNO}_3}{1 \text{ mol LiNO}_3} = 313.64 \text{ g LiNO}_3
\]

11. Using the following equation, calculate how many grams of iron can be made from 16.5 grams of Fe\textsubscript{2}O\textsubscript{3} by the following equation.

\[ \text{Fe}_2\text{O}_3 + 3 \text{ H}_2 \rightarrow 2 \text{ Fe} + 3 \text{ H}_2\text{O} \]

\[
\frac{16.5 \text{ g Fe}_2\text{O}_3}{160 \text{ g Fe}_2\text{O}_3/mol Fe} \cdot \frac{1 \text{ mol Fe}}{2 \text{ mol Fe}_2\text{O}_3} \cdot \frac{56 \text{ g Fe}}{1 \text{ mol Fe}} = 11.55 \text{ g Fe}
\]

12. Using the following equation, calculate how many grams of iodine are needed to prepare 28.6 grams of ICl by this reaction.

\[ 2 \text{ I}_2 + \text{KIO}_3 + 6\text{HCl} \rightarrow 5\text{Cl} + \text{KCl} + 3\text{H}_2\text{O} \]

\[
\frac{28.6 \text{ g ICl}}{162.4 \text{ g ICl/mol ICl}} \cdot \frac{1 \text{ mol ICl}}{2 \text{ mol ICl}} \cdot \frac{253.8 \text{ g ICl}}{5 \text{ mol ICl}} = 17.9 \text{ g ICl}
\]
Part 4: Rate Laws

13. Determine the proper form of the rate law for:

\[
\text{CH}_3\text{CHO}(g) \rightarrow \text{CH}_4(g) + \text{CO}(g)
\]

<table>
<thead>
<tr>
<th>Exp.</th>
<th>([\text{CH}_3\text{CHO}])</th>
<th>([\text{CO}])</th>
<th>Rate (M s(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.30</td>
<td>0.20</td>
<td>0.60</td>
</tr>
<tr>
<td>2</td>
<td>0.10</td>
<td>0.30</td>
<td>0.067</td>
</tr>
<tr>
<td>3</td>
<td>0.10</td>
<td>0.20</td>
<td>0.067</td>
</tr>
</tbody>
</table>

\[
\text{Rate} = k \ [A]^a[B]^b
\]

\[
\frac{r_1}{r_3} = \frac{k[0.30]^a[0.20]^b}{k[0.10]^a[0.20]^b} = \frac{0.600}{0.067} \approx 9
\]

\[3]^a = 9\]

\[a = 2\]

\[
\frac{r_2}{r_3} = \frac{k[0.10]^a[0.3]^b}{k[0.10]^a[0.2]^b} = \frac{0.067}{0.067} = 1.0
\]

\[\left(\frac{3}{2}\right)^b = 1.0\]

\[b = 0\]

\[
\text{Rate} = k \ [A]^a[B]^b
\]

\[0.60 = k \ [0.3]^2[0.2]^0\]

\[\frac{20}{3} = k\]

\[
\text{Rate} = \frac{20}{3} \ [A]^2[B]^0
\]
14. For the following reaction,

\[ A + B \rightarrow 2C \]

it is found that doubling the amount of A causes the reaction rate to double while doubling the amount of B causes the reaction rate to quadruple. What is the best rate law equation for this reaction? Explain your choice.

(a) \( \text{rate} = k [A]^2 [B] \)
(b) \( \text{rate} = k [A] [B] \)
(c) \( \text{rate} = k [A] [B]^2 \)
(d) \( \text{rate} = k [A]^{1/2} [B] \)

Choice C: Given that \( \text{rate} = k [A]^a [B]^b \)
- If \( 2 \times \text{rate} = k [2A]^a [B]^b \), then \( a = 1 \)
- If \( 2 \times \text{rate} = k [A]^a [2B]^b \), then \( b = 2 \)

15. A rate law is 1/2 order with respect to a reactant. What is the effect on the rate when the concentration of this reactant is doubled? Explain your reasoning.

Given \( \text{rate} = k [A]^{1/2} \)
- Then, \( (2^{1/2}) \times \text{rate} = k [2A]^{1/2} \), so the rate is increased by a factor of \( \sqrt{2} \).
Extra Credit: What did you learn from this unit about how math and science are related?

Answers may vary. Sample student response below:

I learned that we need proportions and rates to be able to do stoichiometry. For example, if I am trying to make a certain amount of something in the lab, I can know how much of the reactants I need just by using ratios. By using math we can know a lot more about different chemical equations.

Math is everywhere! Everything we learned about in chemistry needed math. We needed to know rates, ratios, and proportions just to be able to understand chemical reactions! Using that math, we can convert between mass and moles, tell how much we need of reactants and products, and calculate the rate of a reaction. I didn’t know that there was so much math in chemistry!


