SUPPORTING TRADITIONAL INSTRUCTIONAL METHODS WITH A CONSTRUCTIVIST APPROACH TO LEARNING: PROMOTING CONCEPUTAL CHANGE AND UNDERSTANDING OF STOICHIOMETRY USING E-LEARNING TOOLS

by

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Abstract (Section I)

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Stoichiometry is a fundamental topic in chemistry that measures a quantifiable relationship between atoms, molecules, etc. Stoichiometry is usually taught using expository teaching methods. Students are passively given information, in the hopes they will retain the transmission of information to be able to solve stoichiometry problems masterfully. Cognitive science research has shown that this kind of instructional teaching method is not very effecting in meaningful learning practice. Instead, students must take ownership of their learning. The students need to actively construct their own knowledge by receiving, interpreting, integrating and reorganizing that information into their own mental schemas. In the absence of active learning practices, tools must be created in such a way to be able to scaffold difficult problems by encoding opportunities necessary to make the construction of knowledge memorable, thereby creating a usable knowledge base. Using an online e-learning tool and its potential to create a dynamic and interactive learning environment may facilitate the learning of stoichiometry.

The study entailed requests from volunteer students, IRB consent form, a baseline questionnaire, random assignment of treatment, pre- and post- test assessment,

and post assessment survey. These activities were given online. A stoichiometry-based assessment was given in a proctored examination at the University of Texas at Arlington (UTA) campus. The volunteer students who took part in these studies were at least 18 of age and were enrolled in General Chemistry 1441, at the University of Texas at Arlington. Each participant gave their informed consent to use their data in the following study. Students were randomly assigned to one of 4 treatments groups based on teaching methodology, (Dimensional Analysis, Operational Method, Ratios and Proportions) and a control group who just received instruction through lecture only.

In this study, an e-learning tool was created to demonstrate several methodologies, on how to solve stoichiometry, which are all supported by chemical education research. Comparisons of student performance based on pre- and post-test assessment, and a stoichiometry-based examination was done to determine if the information provided within the e-learning tool yielded greater learning outcomes compared to the students in the absence of scaffold learning material. The e-learning tool was created to help scaffold the problem solving process necessary to help students (N=394) solve stoichiometry problems. Therein the study investigated possible predictors for success on a stoichiometry based examination, students' conceptual understanding of solving stoichiometry problems, and their explanation of reasoning. It was found that the way the student answered a given stoichiometry question (i.e. whether the student used dimensional analysis, operational method or any other process) was not statistically relevant ($p=0.05$). More importantly, if the students were able to describe their thought process clearly, these students scored significantly higher on stoichiometry test (mean 84, $p<0.05$). This finding has major implications in teaching the topic, as lecturers tend to stress and focus on the *method* rather than the *process* on how to solve stoichiometry problems

Abstract (Section II)

INVESTIGATION INTO THE MECHANISM OF TWO BIOLOGICALLY ACTIVE, RUTHENIUM POLYPYRIDYL COMPLEXES

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It is well known that many metal complexes cause oxidative damage to DNA in the presence of oxygen through Fenton like chemistry via the formation of reactive oxygen species (ROS). The MacDonnell group has develop two novel ruthenium polypyridyl complexes, the dinuclear complex, $(phen)_2Ru^{II}$ tatppR$(phen)_2Ru^{II\,4+}$ and the mononuclear analogue $(phen)_2Ru^{II}$ tatpp $^{2+}$ cause damage to DNA in the presence of a reducing agent like glutathione (GSH). Although these complexes require oxygen to damage DNA, it has been shown that the oxidative damage caused by these complexes is enhanced under hypoxic conditions. It also has been shown, through the use of radical scavengers and EPR data, that the radical produced is an organic radical and not an ROS. This paper explores the possibility that a 2 H^+/ 1 e^- process is necessary for this reaction to occur.

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List of Abbreviations

ACS	American Chemical Society
Avg	average
BLM	Bleomycin
bp	Base-pair
bpy	2,2´-Bipyridine
BDE	Bond Dissociation Energy
BDFE	Bond Dissociation Free Energy
CCDT	California Chemistry Diagnostic Test
CDC	Center for Disease Control
CDDP	*cis*-Diamminedichloroplatinum(II)
cisplatin	*cis*-Diamminedichloroplatinum(II)
DA	Dimensional Analysis
DHB	3,4-dihyodroxybenozate ethyl ester
DNA	Deoxyribonucleic Acid
dppn	Benzo[*i*]dipyrido [3,2-*a*:2',3'-*c*]phenazine
dppz	Dipyrido[3,2-a: 2',3'-c]phenazine
dpq	2,3-Bis(2-pyridyl)pyrazine
GSH	Glutathione
IC_{50}	Half maximal inhibitory concentration
Im	Imidazole
In	Indazole
J	Joule
IRB	Institutional Review Board

kJ	kilojoule
MP	$[(phen)_2Ru(tatpp)]^{2+}$
MTD	Maximum tolerated dose
NAMI-A	[ImH][trans-$RuCl_4$(DMSO)(Im)]
NCI	National Cancer Institute
OM	Operational Method
P	$[(phen)_2Ru(tatpp)Ru(phen)_2]^{4+}$
phen	1,10- Phenanthroline
RP	Ratio and Proportions
RPCs	Ruthenium Polypyridyl complexes
Ru	Ruthenium
STD	Standard Deviation
tatpp	9,11,20,22-Tetraaza tetrapyrido[3,2-a:2'3'-c:3'',2''-1:2''',3''']-pentacene
tpphz	Tetrapyrido[3,2-a: 2′,3′-c: 3″,2″-h: 2″,3‘’’-j]phenazine

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Section I

SUPPORTING TRADITIONAL INTRUCTIONAL METHODS WITH CONSTRUCTIVIST, APPROACH TO LEARNING: PROMOTING CONCEPTUTAL CHANGE AND UNDERSTANDING OF STOICHOMETRY USING E-LEARNING TOOLS

Chapter 1

Overview of Dissertation

This dissertation is a unique dissertation for the Department of Chemistry and Biochemistry and the University and could potentially serve as a model for students who are interested in chemistry education research. This dissertation is separated into two sections. The first section and a majority of this dissertation will focus on an in-depth chemical education research project. The second section will focus on a mechanistic study of ruthenium polypyridyl complexes as potential anti-cancer agents.

1.1 Introduction

There is growing concern that the United States is losing its edge on scientific endeavors and innovation. An influx of more scientifically literate professionals is needed to compete in an emerging scientific global market.[1] Therefore, there has been a call from the greater scientific community to improve interest and retention in the Science, Technology, Engineering and Mathematics (STEM) fields, starting with K-12 and continuing through graduation with a Bachelors Degree at the secondary level. In order for this to occur, an overall improvement in attitudes towards STEM education must occur.

Attitudes of students embarking in the study of chemistry, and ultimately other STEM fields, have not changed. Students who are already highly motivated can manage to succeed regardless of what is presented. Average students, or students whose motivation is highly practical, simply regard chemistry courses as a series of artificial and unpleasant hurdles, which, for obscure reasons, they are required to surmount in order to earn certification of education to the Bachelor's level.[2] On the other side of the podium, the attitude of instructors reflect an unwillingness to change their teaching methods.

Many neither have the time nor the inclination to keep with current instructional pedagogy related through modern chemical education research. As a result, success in chemistry has also remained stagnant due to limited improvement in student attitudes.

The study of chemistry is difficult for a number of students. A large number of papers in chemical education research have been published that have alluded to the fact that not only is the study of chemistry difficult, but the communication of topics is equally as difficult to convey to students.[3-5] An even larger number of studies have been published to reach out to educators and inform them of various learning theories, such as conceptual change,[6] constructivism,[7] Piaget,[8, 9] or guided-inquiry and learning cycles.[10] Unfortunately, there is a disconnect between educators and those with a background in education research. This is due to the apathy that exists within the general education community. As a result, any message provided by the educational research community and recommendations for improvements is lost.

1.2 Stoichiometry

One topic that has universally given students problems is stoichiometry. The word stoichiometry is denoted from *stoicheion,* which, in the Greek language, denotes something which cannot be further subdivided, and *metron,* which means finding proportions of magnitude.[11] Stoichiometry is the branch of chemistry that attempts to quantify the measured relationships or ratios between two or more items. The importance of stoichiometry is clear among those who practice it, mostly chemists or chemical engineers. One simple example is that it allows practitioners to know exactly what quantity of reagents to use in a reaction, so that waste can be avoided.

Jeremias Benjamin Richter first formalized stoichiometry in 1792. Stoichiometry is the science of measuring the quantitative proportions or mass ratios in which chemical

elements relate to one another.[12] As the definition implies, proportional understanding, or the use of ratios lies at the heart of stoichiometry.[13] In fact, the use of ratios and proportions constitutes one of the ways through which educators can teach stoichiometry. This approach is also supported by recommendations in the science education research literature.[14]

Regardless of this recommendation it is uncommon to find stoichiometry being taught using ratios in a secondary or post-secondary educational setting. Instead, stoichiometry is most commonly taught using a factor-labeled method known as dimensional analysis. Many General Chemistry textbooks introduce the concept of stoichiometry using dimensional analysis. The importance of dimensional analysis is well understood amongst its practitioners, and the technique can be universally applied to other STEM fields. However, the technique of unit cancelling, a process essential for dimensional analysis, can be used to find answers to questions without fully understanding the question. Even with the promotion of dimensional analysis as a particularly strong scaffolding tool, instructors have noticed their students still find it difficult to master the topic of stoichiometry. Students often find themselves at odds with this particular subject during study time. It is posed that through the use of technology, specially developed e-learning tools focused on stoichiometry can help better scaffold this troublesome topic and lead student to greater conceptual understanding.

1.3 The Student of Today

The students today are very connected to their technology compared to a majority of the students of the 20th century. Since the advent of the Internet and the ever increasing pace of the creation of new mobile technology, students have access to copious information through their mobile devices (i.e., smart tablets, laptops, smart

phones). With increasing class times and limited in-person contact hours, instructors need to find ways to provide supplemental instruction (homework) that is both interactive and meaningful. One of the tools that instructors have used is online homework system such as WebAssign, Mastering Chemistry (Pearson), and ALEKS. Work done by Brewer[15] showed that algebra students who used an online homework system achieved higher scores on exams; but, the results were not statistically significantly different that those students who had text based homework. These results are similar to the results found by Belland[16], who compared various online homework program in chemistry such as WebAssign and Mastering Chemistry. The promise of online homework systems has been sold to instructors in the hopes of improving student achievement, but has yielded mixed results. In this study, an e-learning tool was created using constructivist methods focused on the topic of stoichiometry. The tool was created using constructivist methods with the intent of improving students' ability to solve stoichiometry problems.

1.4 Purpose of the Study

The purpose of this study was to examine student performance on various stoichiometry topics after providing an online, story scaffolded, and interactive approach to three informed sets of instructional methods to solving stoichiometry problems. These students achievement was compared to students who received no scaffolded material and thus relied on learning the material provided by lecture only. The study also examined whether the e-learning tools provided matched or exceeded student performance on a stoichiometry-based examination. Finally, the study was designed to determine possible predictors provided by the e-learning tool that had matched or exceeded student performance.

In Chapter 2, a review of literature pertinent to the study is provided. It begins with a brief discussion on why the topic of chemistry and more specifically stoichiometry is difficult to learn. Secondly, the chapter describes a general discussion on how novice students versus experts think and how it potentially affects a student's ability to solve stoichiometry problems. Third, in this chapter is a brief description on how technology can be used to support learning. The chapter concludes by presenting and discussing the results of a pilot study using an e-learning tool, created at this university, used to scaffold the problem solving process using various chemistry education research-backed methodologies.

Due to the limitations of the pilot study, several changes were made to the pilot study and carried out in a three semester longitudinal study and those results are described in Chapter 3. Chapter 3 also includes a brief description of cognitive theory as it relates to student learning. This description has been followed by a brief description of how these theories can be tied to the technology developed and used in this study.

Chapter 4 addresses the nature and design of the e-learning tool used in this study. First, the chapter provides a constructivist descriptive view as the basis for the creation of the curriculum in the e-learning tool. Importantly, the chapter describes how the story-led, interactive problem solving heuristics used in the tool support student learning. This chapter describes the results of a three semester longitudinal study as a follow-up to the pilot study. The longitudinal study addresses the limitations the pilot study encountered, such as limited numbers in student samples, which prevented some analysis from being performed. Second, the results of the longitudinal study examined the extent to which the e-learning tool created may show possible interrelationships and predictive influences of student achievement upon examination.

1.5 Limitations of the Study

Several limitations of the study are noted for current and future consideration. First, this study was conducted with volunteer students from the targeted university and therefore, results are specific to this environment and may differ from other general chemistry programs. Another limitation is the number of volunteer students who took part in this study. Every year, 1000 students enroll in general chemistry - 600 in the fall semester and 400 in the spring. This study took place over the fall 2011 through the spring of 2013, with a potential population pool of 2000 students. The total number of students who took part in this study is about 600, with an uneven distribution of respondents each semester. Although 600 students completed the activities, not all students responded to questions in such a way that any meaningful information could be gathered. Even though each student received dimensional analysis as their primary mode of instruction, several instructors were still involved and teaching methods were not easily standardized.

1.6 Teaching as Research

Chapter 5 is a reflective chapter as it briefly describes the work that the author of this dissertation has done and how the chemistry education research experiment came to be. In doing so, it provides information in what Chemical Education Research is and what it can potentially do for this department and this university. Chapter 5 also provides an avenue to promote the idea of potentially creating another degree path for students like myself who is interested in Chemical Education Research.

Section II

Section II of this dissertation is devoted to traditional Inorganic Chemistry research. This section is broken up into two chapters. The chapters will describe the

examination of a probable mechanism of action for two biologically active ruthenium polypyridyl complexes that have shown to have some interesting anti-cancer properties.

1.7 Ruthenium Polypyridyl Complexes (RPC's) as Anti-Cancer Agents

Chapter 6 will cover some overarching themes in the use of metals complexes as anti-cancer agents. More importantly, advances in ruthenium chemistry, as it is relates to chemotherapy are also described, with special emphasis on two Ruthenium complexes currently in clinical trials, NAMI-A and KP1019. Previous work done by Dewey in the 1950's to the 1960's, is also reviewed in this chapter. Dewey's early work with RPC's provided the groundwork for much the work that is done in MacDonnell lab. The MacDonnell lab has synthesized two biologically active ruthenium polypyridyl complexes (P and MP). It was found that these complexes are more effective at causing damage to DNA under hypoxic conditions, which has important ramifications for its potential use against cancerous tumors. These results gave inspiration for this study, which is to determine a potential mechanism based on experimental evidence already obtained. Finally, the results of a study determine the extent of which oxygen plays a role in that mechanism.

Chapter 7 is more a theoretical discussion behind the thermodynamics of the proton coupled electron transfer reaction between MP and DNA. A brief discussion behind the theoretical framework of PCET reactions is addressed. Afterwards a model system is created using the PCET framework. This quantitative data used in thermodynamic calculations was obtained from previous work from our lab and other pertinent sources. The results obtained will help in the formulation of a thermodynamic explanation of how MP can act as a reducing agent and can oxidize the one of the carbon hydrogen bonds on a deoxyribose sugar and thereby potentially causing damage to DNA.

1.8 Future Work

Finally Chapter 8 will discuss any future research that could potentially be undertaken.

Chapter 2

Why is Stoichiometry so Difficult?

An Investigative Look into the Use of E-learning Tools to Help Students Solve Soichiometry Problems:

A Pilot Study

2.1 Introduction

Chemistry is a difficult subject to learn. The various topics that are covered in general chemistry and the associated learning difficulties student experience with the subject have been reviewed by many.[17-21] Taber[22] reports that chemistry is a very conceptual subject and many of its topics are rather abstract. Unfortunately for students, that means chemistry requires a high-level skill set.[23] Because of the overall difficulty, students tend to shy away from the subject. More importantly, this apprehension can impact any meaningful learning that might be achieved while taking the class. The most identifiable topic in general chemistry, which has given students hardship, is stoichiometry.

2.2 Why is Stoichiometry so Difficult to Learn?

In order to appreciate the level of complexity of use of stoichiometry is to look at some examples of chemistry problems to which stoichiometry can be applied. For that, one can just turn to any general chemistry textbook. Several examples are shown in Figure 2-1 which were copied directly from Chemistry: A Molecular Approach 2nd edition, by Nivaldo Tro. A major part of the abstract nature on stoichiometry, and chemistry in general, is that chemistry is a language. As with any language, to understand any problem is to examine the underlying language and what it reveals.

A

Ammonia, NH_3, can be synthesized by the following reaction:

$2\ NO\ (g) + 5\ H_2\ (g) \rightarrow 2\ NH_3\ (g) + 2\ H_2O\ (g)$

Starting with 863 g NO and 25.6 g H_2, find the theoretical yield of ammonia in grams.

B

A 30.00 mL sample of H_3PO_4 solution is titrated with a 0.100 M NaOH. The equivalent point is reached when 26.38 mL of NaOH is added. What is the concentration of H_3PO_4?

C

Copper can be electroplated at the cathode of an electrolysis cell by the half reaction:

$Cu^{2+}\ (aq) + 2\ e^- \rightarrow Cu\ (s)$

How much time will it take for 325 mg of copper to be plated at a current of 5.0 A

Figure 2-1 Several examples of stoichiometry problems: A) Limiting Reagent B) Titrations and C) Electrochemistry and Electroplating

To a novice chemistry student who is still learning to name compounds, just reading the problems can be very intimidating. The questions are densely packed with information. It is up to the student to dissect the problem, process that information, and select the necessary information to solve the stoichiometry problem.

The first problem, (Figure 2-1A), begins by telling a story about ammonia, NH_3. A novice chemistry student may know what ammonia is, but as for symbol NH_3, they might not have a clue. It may appear to be a nonsensical conglomerate of elements and a number. But to the chemist, both the word ammonia and the symbol NH_3 contains a wealth of information. To the chemist, the word ammonia conjures up images of what it

physically looks like, what it smells like (the odor emanating from a dirty cat litter box), as well as other properties. The symbol NH_3 is two different elements together in a certain ratio, which forms a compound. The elements each can be considered the alphabet to a chemist and in this case, the elements together form a word. That word is azane, otherwise commonly known as ammonia. The symbolic nature of NH_3 also describes what ammonia looks like at the atomic or submicroscopic level. At this level, chemists can describe how the atoms are bonded to one another, what its molecular geometry is, and much more. A chemist can deftly read and communicate through these three cognitive domains of chemistry, the macroscopic (e.g., what we can see, feel, smell), the atomic or submicroscopic, and the symbolic view. In contrast, a novice student cannot read and communicate in this way. Work by Johnstone[24-26], provides insight as to why novice students have difficulties with these cognitive domains; it is because these cognitive domains place a large cognitive burden on the novice students. However, through time and practice, students can become adept at learning the basic language of chemistry and linking various chemical formulae to both their macroscopic properties and microscopic view through pattern recognition.

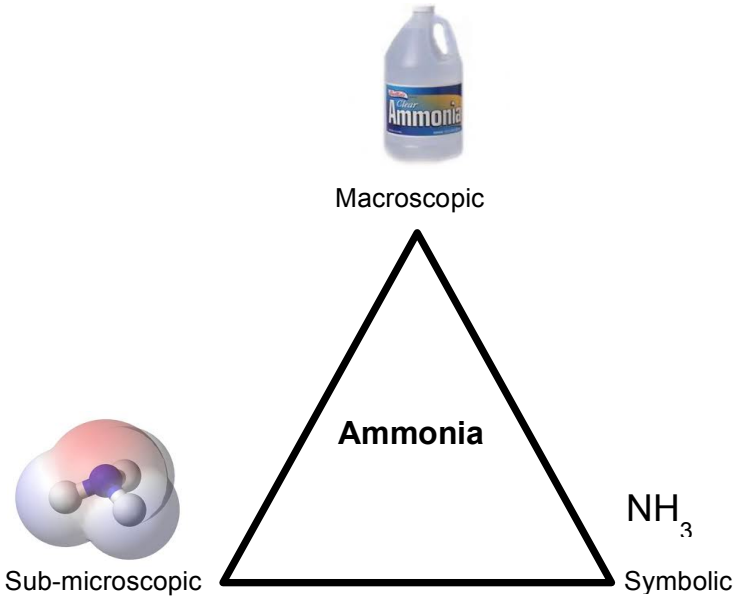


Figure 2-2 Macroscopic, Symbolic and sub-microscopic examples of ammonia

In returning to the problem (Figure 2-1A), it contains a chemical reaction as represented by the arrow. The arrow represents the progress of a chemical reaction. In this case, the reaction progresses through to completion. The arrow is a useful separator and separates the reactants on the left side of the arrow, to the products on the right side of the arrow. Every compound in the reaction is followed by a letter encased in parentheses; this provides a macroscopic view on the physical state of the molecule. In this case of problem (A), all the molecules are (g)ases. The numbers preceding each compound represent the ratios to which the compounds are reacting and producing. The chemical reaction itself is a physical description of what is happening at the submicroscopic level. Even here, the students have to move between the submicroscopic, the symbolic, as well as the macroscopic domain.

Moving onto the question, the problem gave the mass of two of the reactants in grams and is asking to find the theoretical yield of ammonia in grams. What makes this

problem somewhat complicated is that the symbol for mass is also the letter (g)rams. Regardless, the students needs to figure out how to go from one mass to another. First, all reactions work under the premise of the Law of Conservation of Matter, where all the matter (and energy) in a closed system can neither be created nor destroyed, but can be converted from one form to another, and must remain constant. Therefore all chemical reactions must be balanced, which is represented by the coefficients. Ultimately, the student must be able to tackle the symbolic nature of the reaction itself by somehow using the masses and coefficients to be able to solve this problem.

Unfortunately, for the student there is no direct connection between the masses. Masses are a macroscopic property, but to be able to solve this problem, chemists use a submicroscopic number, called the "mole". The mole is a quantitative descriptor, like a dozen. One dozen eggs is 12 eggs. In the context of a mole, one mole of eggs represents 6.023×10^{23} eggs. A mole is the amount of a substance, which represents 6.023×10^{23} units. For many novices, the concept of the mole is very difficult to comprehend, as research has shown.[27] Research has also indicated that teachers are not good at it either.[28] Both these related issues, the learning and the teaching of the mole concept, have consequences for solving stoichiometry problems.[29, 30]

2.3 Experts Versus Novices

Returning to the problems in Figure 2-1, there are 3 different types of stoichiometry problems. To the novice chemistry student, all these problems are just stoichiometry problems to be solved, and one can use "dimensional analysis" to solve them. But to someone with more expertise, such as a chemist or a chemistry instructor, the first problem is a limiting reagent problem, the second a titration problem, and the third an electroplating problem, which involves a little electrochemistry. Each problem has

certain checks (e.g., Is there a balanced chemical reaction? Which is the limiting reagent?) as well as a specific pathway or "scheme" necessary to solve the problem. A chemist can also solve the problems using dimensional analysis or by using a set of algorithms he/she has developed. The different approaches to the way a chemist and a student approaches a problem is the difference between an expert and a novice.

How do chemists or experts so quickly dissect a problem if there is so much information that has to be processed? Chemists, or experts for that matter, take advantage of their well-practiced and honed organization of knowledge and recall skills. These skills represent the primary difference between how experts think and how novices think. There is substantial research on the differences between experts and novices.[31] An example from physics education research; Chi et al. performed an experiment where the researchers asked experts and novices (college students) how to solve several different physics problems. They found that experts usually mention major principles or laws, and how those principles and laws can be used to solve the problem. In contrast, a novice might recall different equations and how they can manipulate those equations to solve the problem.[32] Work done by Larkin showed that experts stored physics questions into tightly connected "chunks," whereas novices would store physics questions individually.[33] With the ability to "chunk," experts are able to draw upon meaningful patterns of information that are not noticed by novices.

In the end, the problems in Figure 2-1 share the same common features that novices have to contend with. The problems are written in the macroscopic and symbolic domain, but in order to solve every problem the concept of the "mole" is involved, a sub-microscopic domain. If novice students are unable process all this information through the three cognitive domains of chemistry, students will be cognitively overloaded at the outset of the problem solving process.[34]

2.4 Challenges for Instruction

In today's classroom, most students are introduced to the topic of stoichiometry through expository instruction. It has been shown that passive learning is not an effective way of communicating a lesson. Instead, a more social and interactive mode of learning acquisition can lead to development of more complicated mental structures.[35] Additionally, as mentioned earlier, students are often introduced to the technique of dimensional analysis when being taught how to solve stoichiometry problems. Dimensional analysis is a "factor-labeled" technique as it is applied to unit conversion. A student does not necessarily need to understand the question completely but can apply this technique to solve the problem, so as long as the student cancels the units properly. This approach is very mechanical and algorithmic. Unfortunately, research has shown that this type of mechanistic learning tends to impede the reflective component to learning, leaving students unable to learn from the problem they have done.[36] Therefore any instruction given to a student needs to take every opportunity to promote active construction of knowledge so student gain deeper conceptual understandings. The information has to be meaningful and at the same time not over burden the student's ability to process the information.

2.5 Use of Technology to Support Learning

With limited time to interact personally with students in typical large college chemistry courses, instructors need to find a way to create activities (e.g., homework) that are interesting, fun, interactive, and promote learning. In response, instructors have turned to interactive capabilities of on-line learning tools to provide homework to their students. An Internet search for on-line homework tools reveals a number of resources,

including, MasteringChemistry, WebAssign, Sapling Learning, ALEKS, and others. The creators of each online homework system expounds on its ability to enhance student learning and thus increase student achievement. But in order for e-learning tools to be truly effective they must be compatible with the human learning experience.[37] In other words, each learning tool must be specifically crafted to support students in forming meaningful connections between solving stoichiometry problems and the chemical concepts underlying those problems. This study specifically explored three e-learning tools using constructivist instructional treatment methods in comparison with a control method: 1) dimensional analysis, 2) operational method, and 3) ratio and proportions. Therefore, the purposes of this pilot study were:

1. To explore possible differential shifts in students' scores over time (from pre-test to post-test and pre-test to final stoichiometry test), according to treatment/control groups, and possible interactions between time and treatment/control groups (1. Dimensional Analysis (DA), 2. Operational Method (OM), 3. Ratio and Proportions (RP), and 4. Control).

2. To explore possible differential shifts in scores over time (from pre-test to post-test) according type of student (novice or non-novice) and possible interactions between time and type of student.

3. To explore possible differential shifts in prior knowledge versus novice students' scores over time (from pre-test to post-test and pre-test to final stoichiometry test), according to treatment/control groups, and possible interactions between time and treatment/control groups.

4. To examine differences in achievement among novice students whose problem solving method matched the treatment they experienced in their e-learning module (dimensional analysis, operation method) based on pre- and post-test, and a stoichiometry test.

2.6 Method

2.6.1Student Sample

The sample of this study consisted of all students enrolled in a semester of general chemistry at a large university in the southwest United States. The

demographics of the student sample are shown in Table 2-1. The study was conducted during the fall 2011 semester, which consisted of 4 total class sections and 3 different full-time professors. Every student enrolled in general chemistry 1 was presented IRB consent form if they were 18 years of age or older. Of the students who gave their consent, 149 completed the activities presented in this experiment. All students received instruction in stoichiometry during the course through regular lecture; the primary method of instruction was dimensional analysis in the lectures. The students were notified in their syllabus that the research project was assigned as homework.

Table 2-1 Demographic data for pilot study performed on fall 2011 general chemistry

Fall 2011 General Chemistry I Demographics	**N**	**%**
Gender		
Male	76	51.0
Female	73	49.0
Year		
Freshman	78	52.3
Sophomore	36	24.2
Other	35	23.5
Ethnicity**		
White	62	35.2
Black	18	10.2
Asian	48	27.3
Hispanic	27	15.3
Other	21	11.9
HS Math Level		
Calculus	73	49.0
Pre-Calculus	58	38.9
Algebra	6	4.0
Trigonometry	8	5.4
Geometry	1	0.7
Other	3	2.0
Major		
Biology	68	45.6
Chemistry	7	4.7
Math	2	1.3
Physics	3	2.0
Engineering	8	5.4
Other	34	22.8
Undeclared	27	18.1
Parent Education		
Not Finished College	133	44.6
College Grad	88	59.1
Graduate	77	51.7

** Students were allowed to choose more than one ethnicity

2.6.2 Research

This research was conducted separately from regular class lecture as an on-line homework assignment. The design of this study is schematized in Figure 2-3. The research utilized a treatment-control design. 149 students completed all the activities presented to them. Table 2-2 shows the student distribution to their randomly assigned

treatment groups. Group A was given lecture supplemented with dimensional analysis (DA). Group B was given lecture supplemented with operational method (OM) instruction. Group C was given lecture supplemented with ratio and proportions (RP) instruction. Group D was the control group; students in this group were still given a module to complete (practice), but relied solely on what they had learned in lecture. Figure 2-3 is a schematic of the design of the research study. The dimensional analysis, operational method, and ratios and proportions methodology as it is applied to stoichiometry is shown in Figure 2-4.

Table 2-2 Number of randomly distributed students placed in each treatment group

Treatment	N
Dimensional Analysis	34
Operational Method	30
Ratio and Proportions	49
Control	36
Total	149

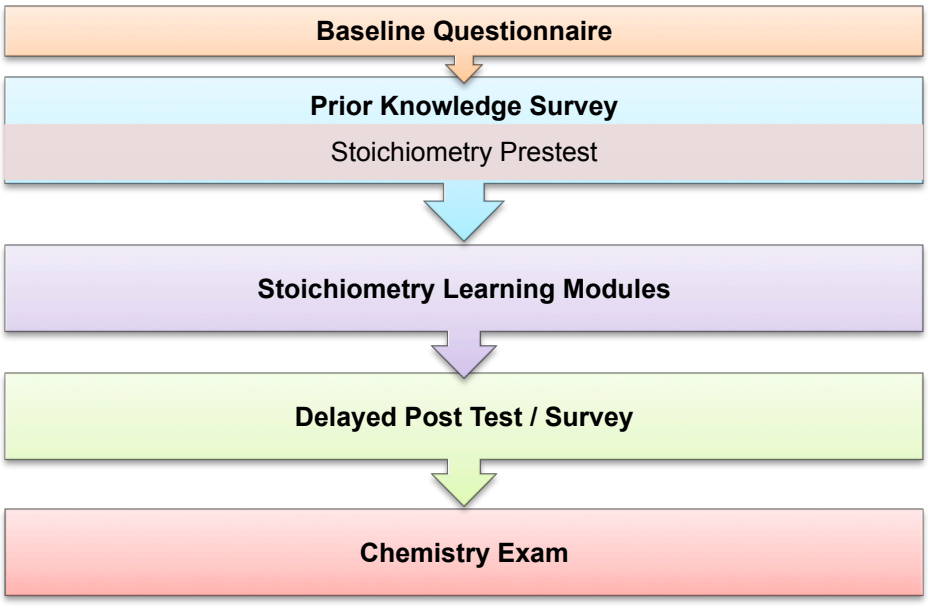


Figure 2-3 General experimental design of the research experiment used to assess the effectiveness of using e-learning tools to supplement the teaching of stoichiometry

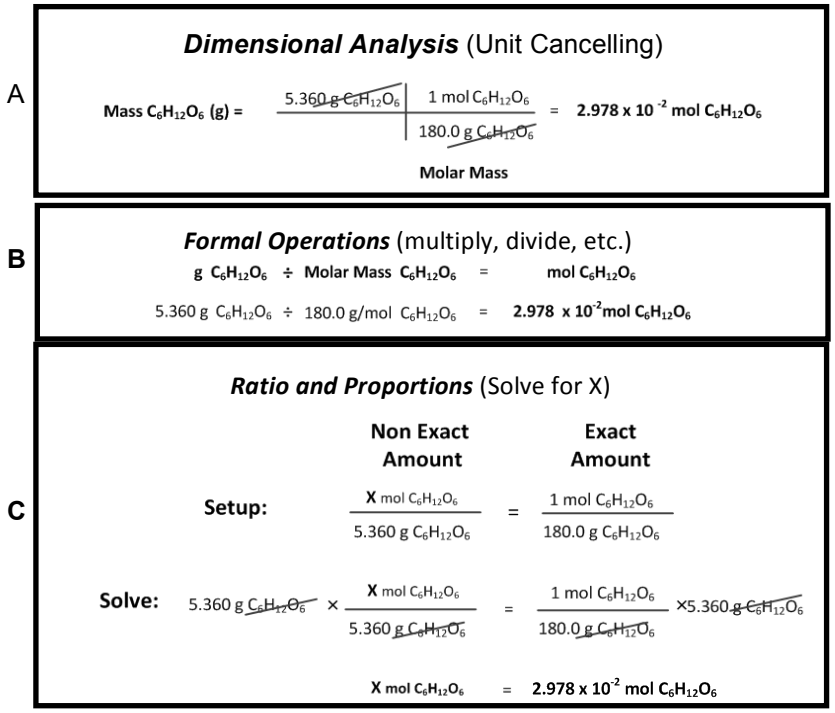


Figure 2-4 A typical stoichiometry problem and three different ways to solve it, the effectiveness of which were assed in this study: A) Dimensional Analysis (DA); B) Operational method (OM); and ratio and proportions (RP)

Activities were made available using a learning management system (MOODLE; Modular Object-Oriented Dynamic Learning Environment v.2.2.1, a software package copyrighted by Martin Dougiamas under the GNU GPL) to be accessed over an extended time period (between Exams 1 and 2). The time period between the exams was three weeks, allowing students ample time to proceed through and process the information provided.

The e-learning activities were designed to assess and compare the instructional methods as potentially providing differential support for understanding and mastery of the topic. At the beginning of the semester, before any instruction was given, a request for volunteer students to take part in a chemistry education research project involving

stoichiometry was explained. Every student was given secured online access to an IRB consent form which first they gave their informed consent, provided they were 18 years or older. After his or her consent, a request to complete a baseline questionnaire was given to collect background information for each student (such as, demographics, prior coursework). Following the questionnaire, a prior knowledge survey was immediately provided to measure the extent to which students could accurately answer and explain a stoichiometry question. Alongside the prior knowledge survey, a pre-test was also given to determine possible differences among the treatment groups and control group in baseline knowledge and skill at the start of the study. In the prior knowledge survey, each student was asked to carefully describe how he or she solved the stoichiometry problems. If the students did not know how to solve the question, they were instructed to type, "I don't know". The stoichiometry pre-test contained several additional stoichiometry problems. The items on the pre- and post- test were obtained from resources in the Chemical Education Digital Library [38]. A specific stoichiometry problem was selected where the student was again asked to describe their strategies, allowing analysis of the progression of their understanding and their use of different models for solving the problem. The following are examples of problems administered:

Prior Knowledge Question 1 (PK Q1) Solid lithium hydroxide (LiOH) is used in space vehicles to remove exhaled carbon dioxide (CO_2). The lithium hydroxide reacts with gaseous carbon dioxide to form solid lithium carbonate (Li_2CO_3) and liquid water (H_2O). How many grams of carbon dioxide can be absorbed by 1.00 g of lithium hydroxide?

Pre- and Post-Question: Aspirin is a common analgesic. If you want to produce 250 mg of aspirin ($C_9H_8O_4$) from the reaction of $C_7H_6O_3$ and $C_4H_6O_3$, what is the

minimum amount of $C_7H_6O_3$ that is needed? 2 $C_7H_6O_3$(s) + $C_4H_6O_3$(l) ⟶ 2 $C_9H_8O_4$(s) + H_2O(l)

With access to the Internet, the student could potentially obtain information on the questions provided from outside sources. MOODLE was set up to reduce cheating by preventing copying and pasting from outside sources.

Three weeks following the initial release of the activities, the students engaged in problem solving through one of the instructional modules. The modules were presented to the students during the same time period when the topic of stoichiometry was being covered in their regular class lecture. Each treatment module represented a different methodology to solving stoichiometry problems. In this study, those methodologies were dimensional analysis and operation method. The control group was given the same stoichiometry problems, but was expected to simply solve the problem using the knowledge they had learned in class. Each module incorporated immediate pre- and post-tests, to judge the initial impact of the modules on conveying concepts. These tests were also used to ensure students had sufficient interaction with the treatments, as they were required to complete these tests before they could move on to subsequent activities in the e-learning modules.

Two e-learning modules were created using Adobe Captivate and uploaded into MOODLE using an e-learning module-packaging standard, SCORM (Sharable Content Object Reference Model). The students securely logged into MOODLE and accessed the modules. The first package presented a mass-to-mass stoichiometry module and the second, a limiting reagent module. The modules were created using step-by-step interactive process on how to solve each type of problem. The problem solving process in each module including “scaffolding,” provided in two phases. Scaffolding refers to providing questions and clues that guide students toward successfully solving the

problems while also supporting conceptual chemistry understandings of the problems. The first phase was exploratory learning. Interactive questions were strategically placed to provide opportunities for "points-of-learning". Figure 2-5 shows side-by-side screen shots of one "point-of-learning" example used as *scaffolding material*. Following the initial, learning phase within the modules, the second phase, considered the application phase, began. In this phase, the students were presented with a different problem in which the students were asked the same scaffolding questions, this time without the supporting scaffolding material.

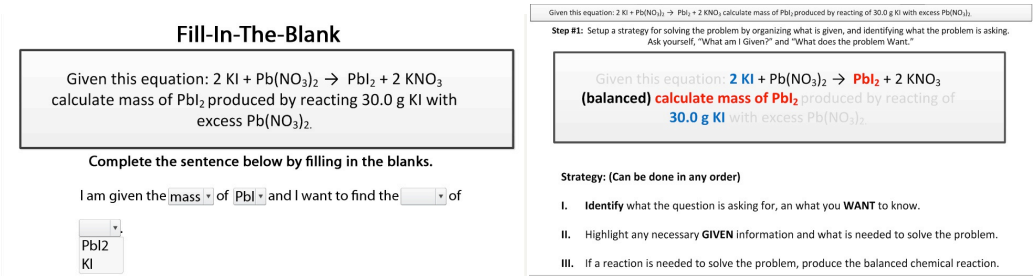


Figure 2-5 Side-by-side screenshots of one of the "points of learning" first step in problem solving, analyzing the problem, followed by scaffolding support contained within the learning modules

Three weeks into the experiment, after giving students time to participate in their randomly assigned the e-learning modules, a post-test was released to students. The post-test also was released a few days prior to their scheduled stoichiometry test. The students were given a week to finish the post-test. The post-test was exactly the same as the pre-test. The students were again asked to answer the same stoichiometry question from the pre-test, allowing analysis of the progression of their understanding and their use of different models for solving the problem. The scores obtained from the pre- and post-test were used to examine if there were any differential shifts in scores over the course of the treatment.

Alongside the post-test, a stoichiometry-based examination was given. Each professor agreed that the exam should focus primarily on problems using stoichiometry. The stoichiometry-based examination contained 20-25 questions, depending on the length of time of the examination. The topics covered a range of topics. Some topics included balancing the given reaction or calculating the number of moles of a given compound. A majority of the questions covered more complicated topics, such as limiting reagent problems, percent yield, and determination of empirical formulas. Listed below are examples of questions taken from the Fall 2011 stoichiometry test.

1. Combustion of 5.000 g of an unknown hydrocarbon resulted in 15.14 g of CO_2 and 7.751 g of H_2O. What is the empirical formula of this compound?

2. Consider the balanced equation below:

If 15.00 g of Fe_3O_4 reacts with excess aluminum to form 3.50 g of Al_2O_3, what is the percent yield? (The molar mass of Fe_3O_4 is 231.6 g/mol; the molar mass of Al_2O_3 is 102.0 g/mol.)

The exam also included some advanced topics such as aqueous stoichiometry and gaseous stoichiometry. Even though the test covered these advanced topics, the story-led interactive problem solving scaffolding process contained within each e-learning module could potentially help students solve those types of problems as well.

Immediately following the completion of the post-test, a post survey was released to students. The post survey was a Likert scale survey (1 “Strongly Disagree” – 5 “Strongly Agree”), where the students were asked to give their impression of the experiment. Below are two examples of statements used in the Likert survey.

1. The problem solving techniques presented in the modules were organized and easy to follow.

2. The application of (insert treatment type), was helpful in learning how to solve a stoichiometry problem.

The post survey also included an open-ended inquiry asking students what they liked about the modules, what they did not like about the modules, and what could be done to improve future student experiences.

2.6.3 Statistical Analysis

For analysis purposes, each answer to a question in the modules was assigned a score of 0 (incorrect) or 1 (correct). The open-ended free response questions were analyzed using constant comparative analysis [39] which was needed to ascertain whether the student answered the question using a particular strategy, specifically a dimensional analysis or operational method. If students were unable to answer the prior knowledge question they were considered novices. There were a number of students who were able to answer the questions correctly and describe the correct schemata or process needed to solve the given stoichiometry problem. For example, a student's unaltered response to the post question is as follows:

"First, I converted 250 mg to 0.250 g. I then converted 0.250 g of aspirin to moles of aspirin, then to moles of C7H6O3 and finally grams of C7H6O3."

This type of answer does not clearly indicate if this student used dimensional analysis or the operational method; the explanation of the process was sound and correct. These students, as well as the students who answered using one of the methodologies presented in this study, demonstrated *clarity* in their thought process. Several examples of unedited student responses are shown in Table 2-3.

Table 2-3 Examples of unedited student responses to specified stoichiometry questions

Dimensional Analysis	
Prior Knowledge	I wrote the balanced equation first: LiOH (s)+CO2 (g) ---> Li2CO3 (s)+H2O(l) #g of CO2= 1 g LiOH × (1 moll LiOH / 23.95 g LiOH) × (1 mol CO2 / 2 mol LiOH) × (44.01 g CO2 / 1 mol CO2) = 0.9187 g CO2 I started off balancing the chemical reaction getting 2LiOH+CO2--> Li2CO3+H2O. With one gram of LiOH, I then converted to moles of LiOH by mulitiplying by (1mol LiOH/23.948g LiOH). I then multiplied by the conversion factor of (1mol CO2/2 mol LiOH). Finally, I mulitiplied by (44.01g of CO2/1 mol CO2) to get how many grams CO2 can be absorbed with 1.00 grams of LiOH.
Post-Question	.25 g C9H8O4 x 1 mol C9H8O4 / 180 g C9H8O4 x 2 mol C7H6O3 / mol C9H8O4 x 138 g C7H6O3 / 1 mol C7H6O3 = .192 So we need .192 g of C7H6O3 to produce 250. mg of aspirin. Use stoichiometry. Convert 250 mg of aspirin to .250 g. Multiply .250g of aspirin by 1 mole of aspirin/180.154g aspirin. then mulitply by the ratio of C7H6O3 to aspirin, which is 2:2 (or 1:1). Then multiply this by 138.118 g of C7H6O3/1 mole of C7H6O3. You would then end with the amount of C7H6O3 in grams.
Operational Method	
Prior Knowledge	1)balance reaction 2)convert moles of LiOH to grams of LiOH by dividing 1.00 by the molar mass of 23.95 3)convert moles of LiOH to moles of CO2 using the conversion factor 2:1 4)convert moles of CO2 to grams of CO2 by multilpying by the molar mass of 44.01 I divided the given mass of lithium hydroxide by its molar mass. ThanI multiplied by the mole to mole ratio of carbon dioxide to lithium hydroxide then I multiplied it by the molar mass of carbon dioxide.
Post-Question	I used the mass to moles to moles to mass converson for C9H804 and C7H6O3. By doing so, I first used the given mass of 250 mg (converting it to grams) of aspirin then divided that with mass of it (180.152 grams) then multiplied the mole ratios of 2 moles of C7H6O3 and 2 moles aspirin and then multiplied with mass of C7H6O3 and recieved the 1.92*10^-1 grams. 250 mg / 1000 = .25g .250g/180.15= 1.39x10^-3 mol C9H8O4 1.39x10E-3 x 138.12 g = 1.92 x10^-1 mol C7H6O3
Undefined Category	
First, I converted 250 mg to 0.250 g. I then converted 0.250 g of aspirin to moles of aspirin, then to moles of C7H6O3 and finally grams of C7H6O3.	

2.7 Results

The first purpose of the study was to explore possible differential shifts in novice students' scores over time from pre-test to post-test and pre-test, according to treatment/control groups, and possible interactions between time and treatment/control groups. The descriptive data are shown in Table 2-4.

Table 2-4 Pre- and Post-test means achieved by students in each treatment group

Treatment	N	Pre Score	STD	Post Score	STD	Δ
Control	34	55.9	23.4	64.5	22.2	8.6
Dimensional Analysis	30	63.3	21.3	68.4	21.7	5.1
Operational Method	49	56.3	19.0	65.0	21.3	8.7
Ratio and Prop.	36	61.4	23.1	68.9	21.6	7.5

Examining the pre- and post- test scores reveals a range of students' pre-test scores from a low of 55.9 achieved by students in the control group to a 63.3 achieved by students from the dimensional analysis treatment group. Post treatment, students in the dimensional analysis and ratio and proportions treatment group scored higher than those in the operational method treatment group and the control group.

To determine if observed descriptive level differences were statistically significant, a 2x3 repeated measures analysis was performed to determine possible shifts over time (pre to post), according to treatment, or interactions between time and treatment. Prior to conducting these analyses, a test for equality of variance was conducted, shown in Table 2-5, and results show no significant differences ($p > 0.05$) in the variances of pre- and post-test means between any of the treatment groups thus the assumption of homogeneity of variance was not violated. Thus assuming equal variance among the groups, the results of the 2x3 repeated measures analysis is shown in Table 2-6. Results revealed that over the course of the treatment, pre- and post-test scores were statistically significantly different ($p < 0.001$) showing an increase in scores over

time as shown in Tables 2.4 and 2.6. The type of treatment did not yield any statistically significant difference in pre and post-test scores ($p = 0.84$). According to Table 2-5 there was a descriptive level, though not significant interaction between time and treatment ($p = 0.38$).

Table 2-5 Levene's Test of Equality for pre- and post-test scores based on treatment groups

	F	**Sig.**
Pre-Test	1.694	0.072
Post-Test	0.157	0.925

Table 2-6 Repeated measures analysis on pre-, post-, and stoichiometry based examinations analyzing differences between time, treatment, and the interaction of time and treatment.

	Mean^2	**F**	**Sig.**
Time	21281.321	68.002	0.000
Treatment	179.049	0.282	0.838
Time*Treatment	323.911	1.035	0.379

The second purpose of the study was to explore possible differential shifts between the types of students' (novice versus non-novice) scores over time (from pre-test to post-test). Upon examination of the 149 students who took part in this study, it was found that 75 students had prior knowledge. These students were then considered to be *non-novices*. The other 74 students were then considered *novices*. The descriptive means of student performance on the pre- and post-test for non-novices and novices are shown in Table 2-7. Levene's Test for equality of variance was conducted and the results show the variances obtained for both pre- and post-test means between novices and non-novices was not significantly different ($p > 0.05$), thus the assumption of homogeneity of variance was not violated.

Table 2-7 Pre- and Post-test means based novices and non-novices.

Type of Student	N	Pre Score	STD	Post Score	STD	Δ
Non-Novice	75	68.9	17.6	75.9	17.0	7.0
Novice	74	48.6	20.4	57.1	21.6	8.5

The pre- and post- test scores descriptively shown in Table 2-7 reveal that the novice students scored lower on the pre-test than the non-novice students. Post treatment, the results also showed that both types of students displayed a positive trend level increase from pre- to post-test. Although the novice students still scored lower on the post-test (difference in average mean~18). This trend level is represented in Figure 2-6. Levene's Test for equality of variance was conducted and the results. The results show the variances in student means for the pre-test based on type of student (novice or non-novice) was not significant differences ($p = 0.10$), thus the assumption of homogeneity of variance was not violated. But, the variances in the means was a significant difference for the post-test score, thus the assumption of homogeneity of variance was violated. Therefore, the interpretation of the post-test should be done with caution.

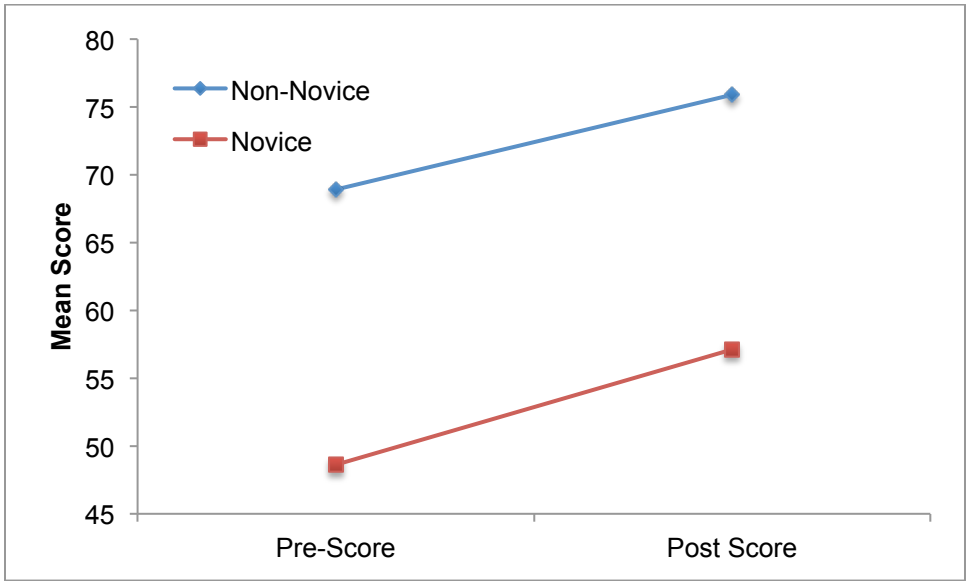


Figure 2-6 Difference in pre- and post-test scores achieved by novices and non-novices

To determine if a descriptive level differences between the types of students (novice versus non-novice) observed was statistically significant, a 2x3 repeated measures analysis was performed to determine possible shifts over time (pre to post), according to treatment, or interactions between time and treatment. The results shown in Table 2-9 reveal that over the course of the treatment, the difference in pre- and post-test scores were statistically significantly different ($p < 0.001$). The results also show that novices scored significantly lower than the students that were not novices ($p < 0.001$). Even though there was a greater trend level increase in novice student achievement pre to post test score, as descriptively shown in Table 2-9, there was not a significant interaction between time and types of students ($p = 0.43$), whether they are novice or non-novices.

Table 2-8 Test of Homogeneity based on pre- and post-test score according between novices and non-novices

	F	**Sig.**
Pre-Test Score	2.765	0.098
Post-Test Score	6.170	0.015

Table 2-9 Repeated measures analysis of pre- and post test scores based on time, type of student (novice or non-novice) and the interaction of time and type of student.

	Mean^2	**F**	**Sig.**
Time	4444.908	69.413	< 0.001
Type of Student	28524.392	42.301	< 0.001
Time*Type of Student	39.812	1.035	0.432

Due to the statistically significantly lower scores and the descriptively larger increase novice student scores over the course of the treatment, a third question was proposed to explore possible differential shifts in prior knowledge versus novice students' scores over time (from pre-test to post-test), according to treatment/control groups, and

possible interactions between time and treatment/control groups. The descriptive means of the pre- and post-test scores for both novice and non-novice students based on treatment groups are shown in Table 2-10.

Table 2-10 Pre-, post-, and stoichiometry test means achieved by students separated by students non-novices and novices in each treatment group

Non-Novice							
Treatment	**N**	**Pre-Test**	**STD**	**Post-test**	**STD**	**Stoich.**	**STD**
Control	21	63.7	18.9	72.1	19.4	88.3	9.4
Dim. Analysis	20	71.3	18.4	77.7	14.7	84.5	14.5
Operational Method	19	66.9	16.3	71.9	18.0	83.6	16.6
Ratio & Prop.	17	74.2	17.1	82.5	13.3	84.9	16.0
Novice							
Control	15	46.0	25.3	55.0	20.7	61.0	30.8
Dim. Analysis	10	47.3	20.5	49.8	22.1	58.5	22.6
Operational Method	30	49.5	15.7	60.7	16.1	73.4	21.4
Ratio & Prop.	19	49.9	21.9	56.8	20.5	68.1	22.8

First, the separation of novice students from non-novice students revealed an uneven distribution of novice participants as shown in Table 2-10. There were nearly twice as many operational method students (N=30) amongst the novices, compared to the students in the control group (N=15). Pre-test scores (average mean ~48) show the novice scores to be lower than the non-novice students (average means ~ 69). In all cases, the novice students scored lower than the non-novice students post treatment. Over the course of the treatment there was a positive descriptive level increase from pre- to post-test

To determine if the descriptive level differences for novice students were statistically significant, a 2x3 repeated measures analysis was performed to describe any possible shifts over time (pre to post), or interactions between time and novice students. Results of the 2x3 repeated measures analysis are shown in Table 2-11. . Levene's Test for equality of variance was conducted and the results show no significant differences ($p > 0.05$) for both pre- and post-test scores for novice students, thus the assumption of

homogeneity of variance was not violated. Results revealed that over the course of the treatment, pre- to post-test scores were statistically significantly different ($p < 0.001$), showing an increase in scores for novice students over time, as shown in Tables 2.10 and 2.11. The type of treatment did not yield any statistically significant difference in pre- and post-test scores ($p = 0.79$). According to Table 2-10, even though there was a positive trend level increase, there was no significant interaction between time and treatment ($p = 0.30$) for novice students. Although, the students in the operational method group had the most positive trend level increase pre- to post-test, descriptively. The novice students who were supplemented with dimensional analysis experienced the least positive trend increase pre- to post-test. This descriptive trend level increase is shown in Figure 2-7.

Table 2-11 Repeated measures analysis of Pre- to Post-test scores achieved by novice students based o time, treatment and the interaction of time and treatment

	Mean[2]	**F**	**Sig.**
Time	1727.146	20.449	<0.001
Treatment	845.325	0.344	0.793
Time*Treatment	315.192	1.244	0.300

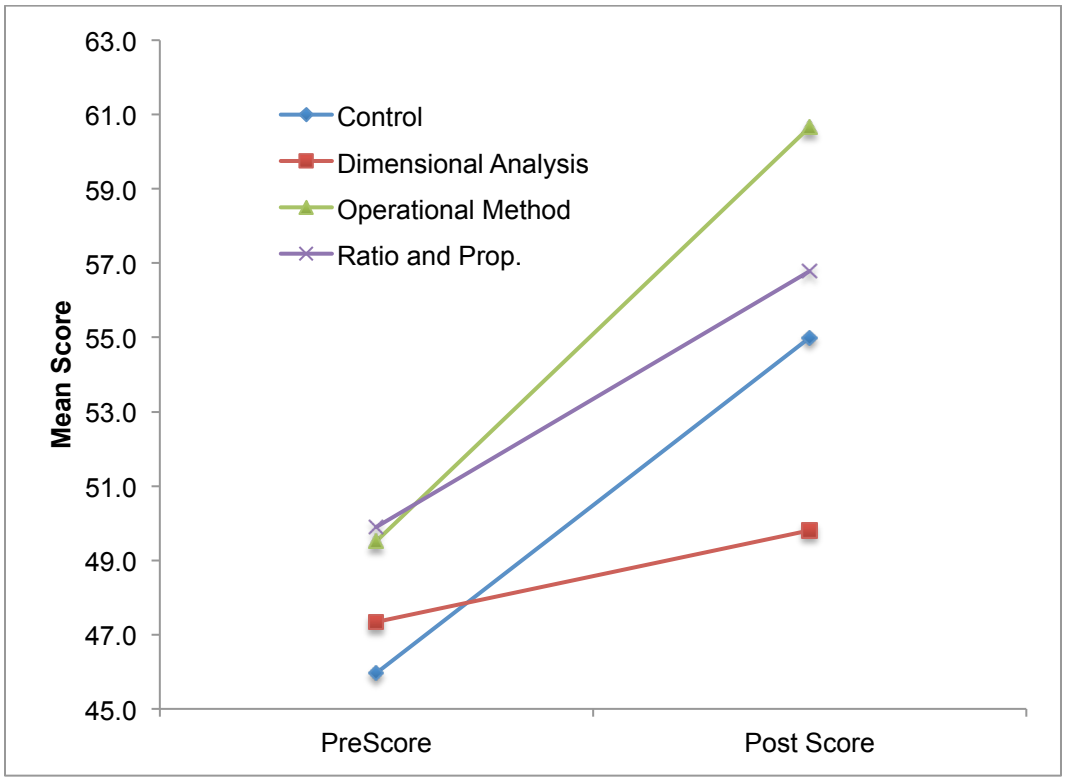


Figure 2-7 Difference in pre and post test scores achieved by novice students based on treatment group over the course of the treatment

An analysis of novice scores was conducted to determine if the descriptive level differences for non-novice students were statistically significant. A 2x3 repeated measures analysis was performed to describe any possible shifts experienced by non-novice students (pre to post) based on type of treatment, or interactions between time and type of treatment, over the course of the experiment. Levene's Test for equality of variance was conducted and the results show no significant differences ($p > 0.05$) for both pre- and post test scores for non-novice students, thus the assumption of homogeneity of variance was not violated. The results of the 2x3 repeated measures analysis are shown in Table 2-12. The results of the non-novice repeated measures analysis revealed that the descriptive level increase based on pre- to post test scores

was statistically significant ($p < 0.001$), albeit a smaller increase compared to the novice students. Also, the type of treatment non-students experience did not yield anything significant ($p=0.21$). Finally there was no significant interaction between the time and treatment effect ($p=0.32$).

Table 2-12 Repeated measures analysis of pre- to post test scores achieved by non-novice students based on time, treatment, and the interaction of time and treatment

	Mean[2]	**F**	**Sig.**
Time	1849.740	42.223	<0.001
Treatment	833.230	1.537	0.212
Time*Treatment	25.115	0.573	0.634

Returning to the third research question, in order to determine if the descriptive level differences were statistically significant, a 2x6 repeated measures analysis was performed to describe any possible shifts over time (pre to stoichiometry test), treatment, type of student (novice or non-novice), or interactions between the variables. Levene's Test for equality of variance was conducted and the results show no significant differences ($p > 0.05$) for both pre- and stoichiometry test scores for novice students, thus the assumption of homogeneity of variance was not violated. The results of the 2x6 repeated measures analysis are shown in Table 2-12. The results revealed that over the course of the treatment, pre- to stoichiometry test scores were statistically significant ($p < 0.001$), showing an increase in scores, as shown in Tables 2-9 and 2-10. The differences between scores achieved by novice and non-novice students were also statistically significant ($p < 0.001$). The type of treatment had little effect on achievement scores ($p = 0.52$). Thus, each statistical test of an interaction between time, type of treatment and type of student yielded no statistically significant difference ($p > 0.05$). Descriptively, the students in the operational method treatment group experienced the most positive

increase compared to the other treatment groups, as shown in Figure 2-8. These results are similar to the examination of student achievement between pre and post test scores.

Table 2-13 Repeated measures analysis between pre- and stoichiometry test scores based on treatment or type of student, over the course of the experiment

	Mean[2]	F	Sig.
Time	19118.247	60.675	< 0.001
Type of Student	28669.365	64.014	< 0.001
Treatment	338.165	0.755	0.521
Time*Type of Student	9.814	0.031	0.860
Time*Treatment	268.836	0.853	0.467
Treatment*Novice	442.018	0.987	0.401
Time*Treatment*Type of Student	25.115	0.573	0.634

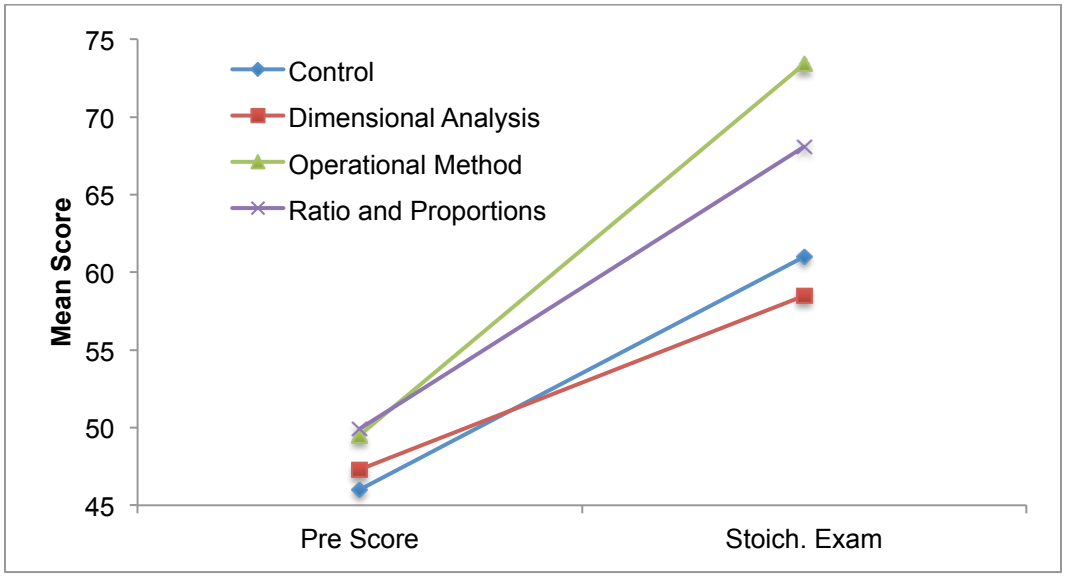


Figure 2-8 Difference in pre- to stoichiometry test scores achieved by novice students based on treatment group over the course of the treatment

In response to the fourth research question to examine differences in achievement among novice students who used the problem solving method as matched with the treatment they experienced in their e-learning module (dimensional analysis, operation method) based on pre-, post- and a stoichiometry test, a frequency table was

created. These results are shown in Table 2-14. It should be noted that in every treatment group there were a number of students who were unable to answer both pre- an post-test questions. Students also did not necessarily answer the post question according to their given treatment. A majority of the non-novice students also did not change their conceptual understanding on how they solved the stoichiometry problems (i.e., If they answered the prior knowledge question using dimensional analysis they continued to answer the post question using dimensional analysis). Also none of the students in the ratio and proportion treatment group used ratio and proportions in the post-test. Therefore that group was removed from analysis. By parsing the student sample into matching novice students based on treatment and post answer type, it left only one novice student in the dimensional analysis group and nine novice students in the operational method group. Due to the limited number of dimensional analysis students, only a descriptive analysis could be performed.

The descriptive evidence shown in Table 2-12 shows there was a greater number of novice students (N=9) in the operational method treatment group that correctly applied the method to the problems provided. Pre-test, both groups of students scored similarly. The dimensional analysis student scored a 52, while the average mean for the operational method students was a 57.8. On the post-test, both groups of students experience a positive level trend, but the students in the operational method groups experienced the greatest change (avg. mean ~82, diff: +24). Assuming the students used the same method on the post-test and the stoichiometry test, both groups experienced a positive level descriptive level increase, and again the operational students scored and even greater increase (avg. mean ~ 91, diff: +33).

Table 2-14 Frequency of novice students who's conceptual understanding matched the methodology they experienced

Treatment		Answered Using Dimensional Analysis	Answered Using Operational Method
Dimensional Analysis	Count	1	0
	Pre-test	52.0	
	Post-test	72.0	
	Stoic. Test	80.0	
Operational Method	Count	0	9
	Pre-test		57.8
	Post-test		**81.7**
	Stoic. Test		**90.7**

2.8 Discussion of Results

This study explored the use of e-learning tools to scaffold the process of solving stoichiometry problems. More specifically, the research focused on the three methodologies that are applied to solving stoichiometry problems. These methodologies are dimensional analysis method, operational method, and ratio and proportions method. The evidence in this study indicates that the operational method seems to scaffold the ability to solve stoichiometry problems better for novice students compared to the dimensional analyses method.

Before discussing the findings for each research questions, two observations are clear. First, in every single experiment the examination of difference in achievement scores pre- to post- test and pre- to stoichiometry test resulted in statistical significance for time over treatment ($p < 0.001$). This is not a surprising result as students are going to naturally study and attempt to do well on an examination. Secondly, there is no evidence in this study that ratio and proportions provides better or worse scaffolding toward better understanding. This finding does not necessarily dismiss the ratio and proportions method as ineffective. It is unknown if the results were due to the e-learning

tool not properly conveying the techniques involved in using ratio and proportions, or whether this method was simply ineffective in bringing about expected levels of understanding. Thus future research is needed to further explore this finding. There is work being performed to improve the teaching of stoichiometry using the ratio and proportions.[40]

The results of the initial research question, which includes all 149 students, reveal a positive trend level increase in understanding among all students, which are descriptively shown in Table 2-4. The finding indicates that achievement scores obtain from the students in the dimensional analysis treatment group, pre- to post-test, increased less markedly than either of the treatment groups including the control group. This finding may imply that scaffolding for dimensional analysis may not have been more effective than no scaffolding. This finding corroborates the work of Gabel & Sherwood, which showed the traditional dimensional analysis approach to be the least effective for successfully communicating the stoichiometry concept.[41] They also found, in contrast, the use of schematic diagrams and analogs supported greater mastery of the topic. Future research would be needed to clarify these findings.

In response to the results of the second research question, the modest level increases in pre and post-test score achievement could be a result of the presence of non-novice students among the student pool in each treatment. From a descriptive level, as observed in Table 2-7, and Figure 2-6, the achievement scores between novices and non-novices were significantly different. The results in Table 2-7 show non-novices achieving higher scores on every test. Even though the scores between the two groups were significantly different, there was a slight but greater increase achievement scores among novice students, whereas the non-novice students experienced a more modest increase. Research has shown that having prior knowledge in a particular subject can

have an effect on learning outcomes. It can be argued that if one has prior knowledge of a topic, that person will perform better upon examination, but work done by Chandler & Sweller revealed strong evidence that the effects of instructional techniques are more highly effective with inexperienced learners. These instructional methods can lose their effectiveness and even have negative consequences when used on more experienced learners.[42] They called this effect the Expertise Reversal Effect. This effect may be what has been observed among the non-novice students in the current study.

In response to the third and fourth research questions, the student sample was parsed to exclude non-novice students and focus only on novices. The ineffective treatment of ratio and proportions was also excluded in order to focus on those methods (DA and OM) that showed more promise in promoting greater learning. By parsing the student sample to include only novice students the research suffered the unforeseen consequence of having an uneven distribution in treatment groups. Further parsing the sample to include only students with responses on their tests that matched the treatment they received (e.g. students in the DA treatment who responded on the test using DA and students in the OM treatment who responded on test using OM) left the study with only 10 students upon which to draw conclusions. However, the evidence obtained from these "matching" students seems to indicate that the operational method was more effective in scaffolding stoichiometry problem solving compared to dimensional analysis. The operational method from pedagogical standpoint is a series of analogies and algorithms that simplify the conversion process from one step to another, which is supported in Gabel's work. Future studies with larger pools of students must be completed to elucidate this evidence.

Finally, there is some evidence that students can experience conceptual change from dimensional analysis to operational method. To exemplify, Table 2-15 shows the

answers from a student in the operational method treatment group who initially used dimensional analysis and in the post-test used the operational method.

Table 2-15 Example of conceptual change showing the unedited student answer to the stoichiometry problems

PKQ1 – Answer (Dimensional Analysis)
Before any calculations, I wrote down the reaction equation and balanced it. Given is the 1.00g of lithium hydroxide (LiOH, amu= 23.949g). I **multiplied this with 1mol LiOH over the 23.949g of LiOH** to leave me with moles of LiOH which **I multiplied with 1mol of carbon dioxide (CO2) over 2 moles of LiOH** to leave me with moles of CO2 which I **then multiplied the grams (amu) of CO2 over 1 mole of CO2** to get an answer in the grams of carbon dioxide asked in the question, resulting my answer to be 0.919g of CO2. Three significant figures are used because 1.00g of LiOH was the least number of sig figs in this equation of multiplication/division.
Post Q1 Answer (Operational Method)
I used the **mass to moles to moles to mass converson** for C9H804 and C7H6O3. By doing so, I first used the given mass of **250 mg (converting it to grams)** of aspirin **then divided that with mass of it (180.152 grams)** then **multiplied the mole ratios of 2 moles of C7H6O3 and 2 moles aspirin** and then **multiplied with mass of C7H6O3** and recieved the 1.92*10^-1 grams.

Dimensional analysis is currently the most popular way to teach stoichiometry. Stoichiometry is often taught this way because a majority of the time the instructor was taught using this methodology. However, from a constructivist point of view, this is not a learner centric way of teaching as it focuses on the instructor. A more diverse instructional curriculum including the different methodologies on how to solve stoichiometry problems would give students the more opportunities to learn and give them a choice with what method works better for them. Unfortunately time dictates what can be taught during lecture, but supplemental sections could address that issue. One important note is that instructors can't lose sight of the fact that using dimensional analysis alone to solve stoichiometry problem does not provide a complete understanding behind the problem solving process. Alternate ways to solve stoichiometry problem, such

as the processes used in this study, should be use to help students solve stoichiometry problems.

Chapter 3

A Follow-Up Study Investigating the Use of Technology to Support the Learning of Solving Stoichiometry

3.1 Introduction

General Chemistry is a gateway course for many students at universities and colleges. Success in this course and many like it can be an indicator for success and retention in the student's intended field. Stoichiometry in chemistry has been proven difficult to learn among students.[43] Research indicates that lack of both conceptual and mathematical fundamental knowledge, which has negative implications on students' "cognitive load," can adversely impact their learning and understanding on how to solve stoichiometry problems [44-47]. Cognitive load can be described as a person's ability to perceive a problem, dissect that problem in that person's working memory space (which is limited), retrieve any and all information needed to solve the problem, from long term memory, and at the same time disregard any unnecessary pieces of information. BouJaoude and Giulano[48] explain that difficulties with stoichiometry stem from the learners' lack of sufficient knowledge or cognitive development. Research by Reid[34] further supports these findings stating that students' difficulties arise from factors including psychological development, mathematical anxiety, visual abilities, or instructional methods. Therefore teaching and learning stoichiometry requires the use of specific strategies that will help students succeed.

Stoichiometry is typically introduced to students during their sophomore year in high school and then addressed again during their first or second year of college chemistry. Chemistry educators have consistently emphasized among students the importance of learning stoichiometry. Although for decades, constructivist, student-

centered, and active learning instruction has been emphasized as important,[49] the form of instruction that persists in high school and college is often behaviorist, teacher-centered, expository instruction [50, 51]. In expository teaching, students passively receive information in the form of lectures, where the instructor is situated in front of the class and with the goal of "imparting" the facts and information about stoichiometry; holding the assumption that they are providing knowledge necessary for students to solve a typical stoichiometry problem. The students are expected to mentally integrate and manipulate the information such that they can successfully solve stoichiometry problems on timed examinations. However, without direct and active learning experiences, student difficulties in solving stoichiometry persist. Chemistry instructors may fail to understand why students have difficulty, perhaps reorganizing lectures rather than using innovative, constructivist teaching strategies. In particular, constructivist teaching and learning experiences using technology may enhance students' conceptual understanding and problem solving skills in stoichiometry.

Theoretical Foundation

3.2 Constructivist Theory

Piaget[52] was one of the first who contended that knowledge is actively constructed based on students' previous knowledge and experiences. Piaget developed the mental functioning model of learning contending that learners' intellectual growth is promoted through two guiding principles, adaptation and organization. Learners experience adaptation by incorporating external phenomena into their mental structure through a series of cognitive events. These events begin with students experiencing or being faced with something new, which leads to *assimilation*, or "taking in" information through the senses. As what is assimilated may not immediately fit into their mental structure or "schema", learners may experience a confused state known as

"disequilibrium" or cognitive conflict. Disequilibrium motivates the "need to know" and learners will continue to assimilate more information in the attempt to understand their experiences. When students resolve their disequilibrium, they experience cognitive relief, or the "aha" moment, known as *accommodation*. This state leads to mental equilibration. Together, the experiences of assimilation and accommodation are known as adaptation. After learners have experienced accommodation or new understanding, they must fit this new understanding or schema into their existing mental structure; connecting it to what they already know and/or expanding their structure, called *organization.*

Piaget also posed that learning occurs in stages of intellectual development toward formal reasoning, which is defined by the achievement of very specific abstract reasoning skills including, as examples, proportional reasoning, combinatorial reasoning, probability, controlling variables. Other constructivist theories that inform instruction were developed in a similar timeframe as Piaget, including Ausubel's (1963) meaningful learning theory, and Vygotsky's (1979) social constructivist theory. Ausubel's meaningful learning espouses that in order for meaningful learning to occur, the student must incorporate new knowledge using existing knowledge. Research has shown meaningful learning, as opposed to rote memorization, occurs when a student is actively engaged with the material [31, 53, 54]. In meaningful learning, the learner is continually constructing new understandings and connecting new information with what is known. The student is able to construct schema that integrates the new knowledge creating a complex neural network.

Vygotsky's social constructivist theory poses a different model for development. Rather than a series of distinct stages, Vygotsky describes "actual" and "potential" developmental levels. Actual developmental level is what learners are able to accomplish, know, or do on their own without assistance. Potential developmental level is

what learners can do with the help of more capable peers, teachers, or others who are already at this level. Thus developmental progress is socially constructed, and requires assistance of others, which is called, scaffolding. The amount or type of scaffolding needed for students to reach the potential developmental level may be different for each learner. Once the learner has accomplished the potential development level and can perform the tasks or shows understanding on their own, this level becomes the new actual developmental level, and new potential level is set. Accordingly, scaffolding is applied within the zone of proximal development (ZPD), known as "the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance, or in collaboration with more capable peers."[55]

In the absence of other active learning methodologies, as is often the case in chemistry lecture halls, it is important that students are provided experiences and opportunities that allow them construct understandings and support their learning. This study examined the use of online e-learning tools to provide supplemental, constructivist-based instruction in stoichiometry alongside the traditional lecture. The design, interactivity, and teaching strategy of the learning modules were investigated for their effectiveness in helping students achieve appropriate and effective ways to approach and solve stoichiometry problems.

3.3 E-Learning Tools

With the advent of the Internet and the World Wide Web, there has been a vast number of web-based instruction tools created. With wireless technology, these tools have become more widely accessible. Most on-line media involves an instructor presenting a lesson either through video or power point presentations. Unfortunately, this

mode of instruction provides little more to the learner than a traditional in-class lecture, and perhaps is even less effective. Ruth and Mayer[37] describe in their book, *e-learning and the Science of Instruction*, the promise, the challenge, and the pitfalls for creating and using e-learning tools. The challenge in creating e-learning tools is to build learning modules in ways that are compatible with human learning processes. To be effective, instructional strategies must support these processes. That is, instruction must actively and interactively foster the psychological events necessary for learning.

3.4 Problem Solving and Stoichiometry

The problem solving heuristics used in the creation of such modules can follow a pattern commonly used in solving any problem. In his book "The Chemistry Classroom", Herron explains there is a general process in problem solving which includes: a) analyzing and understanding the problem; b) representing the problem and developing a strategy to solve the problem; c) executing said strategy; and d) verifying the answer. One of the aspects of understanding the problem is identifying the goal and conditions. Once the goal is realized, a number of mental steps must be overcome to arrive at the goal. In other words, a cognitive roadmap or "schemata" must be created in order to solve the problem. After the problem has been visualized, the student then must execute the strategy using set procedures. In stoichiometry, the use of dimensional analysis is one such procedure. By setting up the dimensional analysis properly, a student can use the factor labeled approach to correctly determine an answer. Dimensional Analysis is a popular technique to solve stoichiometry problems, but there is continuing research into other methods, including ratio and proportions [40]. This study provides opportunity to present those varying strategies and examine effectiveness in helping students learn how to solve stoichiometry problems. Once students have arrived at a solution, they must

verify the answer. Using dimensional analysis, the student appropriately cancels the correct units and the unit that is left should be the desired solution. Another procedure is the operational method. The operational method is characterized by a series of operational statements to arrive at an answer. For example, if one needs to solve for the moles a particular item, given the mass of that item, one would only need to divide by the molar mass of that item.

Teaching students through constructivist methods has been shown to be more effective than direct, expository instruction[56]. However, the constraints of having large numbers of students in typical college chemistry courses often make constructivist theory difficult to implement. Problem solving stoichiometry is a particularly difficult topic for students to master in college chemistry. Direct, expository instruction is minimally effective as it provides little opportunity for students to construct and practice working through problems and arriving through solutions on their own. Thus students may struggle with Piaget's assimilation, accommodation and organization. In addition, the students may learn by memorization rather than forming interconnections between concepts and ideas, which occurs when students work through problems and content on their own. Lecture instruction is an individual, solitary learning experience, thus students are also not experiencing the necessary scaffolding that allows them to advance to new levels in their skills and intellectual development. It is proposed in this study that electronic learning (e-learning) designed with constructivist-teaching practices would provide an opportunity for students to develop higher level cognitive skills, supporting their learning compared to only that accomplished in a passive lecture-based learning environment. Little is yet known as to the effectiveness of utilizing e-learning in a constructivist learning manner to supplement lecture on students' success in problem solving, specifically in stoichiometry. This study will specifically explore two e-learning

based constructivist treatment methods in comparison with a control method: 1) dimensional analysis, and 2) operational method. A pilot study revealed a third method, ratio and proportions, was ineffective in promoting student learning of stoichiometry and therefore was not used in the current research. The purposes of this study are:

1. To explore possible differential shifts in novice students' scores over time (from pre-test to post-test and pre-test to final stoichiometry test), according to treatment/control groups, and possible interactions between time and treatment/control groups.

2. To determine the frequency of students choosing to solve stoichiometry problems using or not using the particular E-learning method that was experienced (dimensional analysis, operational method).

3. To examine differences in achievement on based on pre-, post-test and a stoichiometry based examination among students who used the problem solving method they experienced in their E-learning module (dimensional analysis, operational method).

4. To examine patterns in student's open-ended responses on the online E-learning modules they experienced in dimensional analysis and operational method in solving stoichiometry problems.

3.5 Method

3.5.1 Student Sample

The sample of this study consisted of all students enrolled in three consecutive semesters of general chemistry at a large university in the southwest United States. The demographics of the student sample are shown in Table 3-1. The study was conducted over three semesters, spring 2012, fall 2012, and spring 2013 which consisted of 8 total class sections and 4 different professors: 3 full-time professors, and 1 adjunct instructor. Every student enrolled in General Chemistry 1 was presented IRB consent form if they were 18 years of age or older. Of the students who gave their consent, 474 completed the activities presented. All students received instruction in stoichiometry during the course through regular lecture; the primary method of instruction was dimensional

analysis in the lectures. The students were notified in their syllabus that the research project was assigned as homework.

Table 3-1 IRB consented student demographic data for the spring 2012 to spring 2013 general chemistry students.

	Spring 2012	Fall 2012	Spring 2013	N	%
Gender					
Male	42	101	51	193	40.7
Female	77	128	77	281	59.3
Year					
Freshman	50	107	61	218	46.0
Sophomore	43	62	42	147	31.0
Other	24	60	25	109	23.0
Ethnicity**					
White	52	100	48	210	32.9
Black	18	38	10	146	22.9
Asian	34	71	55	114	17.9
Hispanic	20	43	23	100	15.7
Other	15	27	17	68	10.6
HS Math Level					
Calculus	43	84	55	182	40.3
Pre-Calculus	44	87	59	190	38.1
Algebra	13	25	3	41	8.8
Trigonometry	6	8	2	16	4.3
Geometry	3	3	1	7	1.4
Other	8	22	8	38	7.2
Major					
Biology	60	90	68	218	44.0
Chemistry	7	36	9	52	10.1
Math	1	4	2	7	1.4
Physics	2	6	1	9	2.2
Engineering	6	35	10	51	9.9
Other	33	38	28	99	21.9
Undeclared	8	20	10	38	10.5
Parent Education					
Not Finished College	104	230	103	437	46.1
College Grad	66	145	96	307	32.4
Graduate	64	83	57	204	21.5

** Students were allow to pick more than one ethnicity

3.5.2 Research Design

This research was conducted separately from regular class lecture as an on-line homework assignment. The design of this study is schematized in Figure 2-2. The research utilized a treatment-control design. Although 474 students completed the activities, the focus of this study was on novice students. Therefore for the purpose of this study the student sample was further parsed down to 350 *novice* students. Novice students were identified as those having no measureable prior knowledge of stoichiometry as determined by a pre-test. Table 3-2 shows the novice student distribution to their randomly assigned treatment groups. Group A was given lecture supplemented with dimensional analysis (DA). Group B was given lecture supplemented with operational method (OM) instruction. Group C was the control group; students in this group were still given a module to complete, but relied solely on what they had learned in lecture. The dimensional analysis and operational methodology as applied to stoichiometry modules is shown in Figure 3-1.

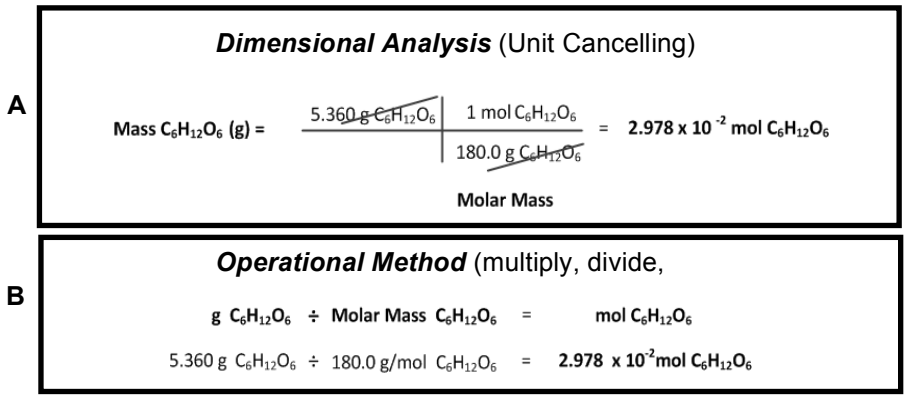


Figure 3-1 A typical stoichiometry problem and three different ways to solve it, the effectiveness of which were assed in this study: A) Dimensional Analysis (DA) B) Operational method (OM)

Table 3-2 Number of novice students assigned to each treatment group

Treatment	N
Dimensional Analysis	117
Operational Method	133
Control	100
Total	350

Refer to Chapter 2.4 for technology, statistical analysis and continued methods.

3.6 Results

The first purpose of the study was to explore possible differential shifts in novice students' scores over time (from pre-test to post-test and pre-test to final stoichiometry test), according to treatment/control groups, and possible interactions between time and treatment/control groups. The descriptive data is shown in Table 3-3. Levene's Test for equality of variance was conducted, and results show no significant differences for any of the groups ($p>0.05$), thus the assumption of homogeneity of variance was not violated.

Table 3-3 Pre-, Post-, Stoichiometry test means by treatment group

Treatment	N	Pre-Test	SD	Post-Test	SD	Δ	Stoich. Test	SD
Dimensional Analysis	117	23.6	18.1	54.35	29.0	30.7	69.8	19.9
Operational Method	133	20.0	17.0	61.0	28.7	41.0	66.5	28.7
Control	100	25.3	21.2	54.1	27.2	28.8	64.7	21.4
Total	350	22.7	18.8	56.8	28.5	34.1	67.1	21.2

Descriptively, examining the pre- and post- test scores shows students' pre-test scores range from 20.0-25.3 the treatments. Figure 3-5 descriptively shows a positive level increase in average means pre- and post-test over the treatment. Post treatment, students who received either treatment scored higher on the post-test than who received no scaffolding in the control needed to solve the same problems. Although students in

the operational method group had the greatest difference in pre- and post-test scores (avg. mean ~41.0)

To determine if observe descriptive level differences were statistically significant, a 2x3 repeated measures analysis was performed to determine possible shifts over time (pre to post), according to treatment, and possible interactions between time and treatment. Levene's Test for equality of variance was first conducted and the results, shown in Table 3-5, show no significant differences ($p > 0.05$) for both pre- and post-test scores based on treatment, thus the assumption of homogeneity of variance was not violated. The results of the 2x3 repeated measures analysis are shown in Table 3-4. Results revealed that over the course of the treatment, pre- and post-test scores were statistically significantly different ($p < 0.001$) showing an increase in scores over time as shown in Tables 3.3 and 3.4. The type of treatment did not yield statistically significant difference in pre- and post-test scores ($p = 0.75$). There was a trend level increase between pre- and post-test scores, however there was not a significant interaction between time and treatment ($p = .07$). These finding represented graphically in Figure 3-2.

Table 3-4 Repeated measures analysis on time (pre- to post), treatment/control, and the interaction of time and treatment.

	Mean^2	F	Sig.
Time	193749.5	457.0	0.000
Treatment	1306.4	1.759	0.754
Time*Treatment	2278.5	2.678	0.069

Table 3-5 Levene's Test of Homogeneity for pre- and post-test scores based on treatment

	F	Sig
Pre-Test	1.031	0.358
Post-Test	0.517	0.597

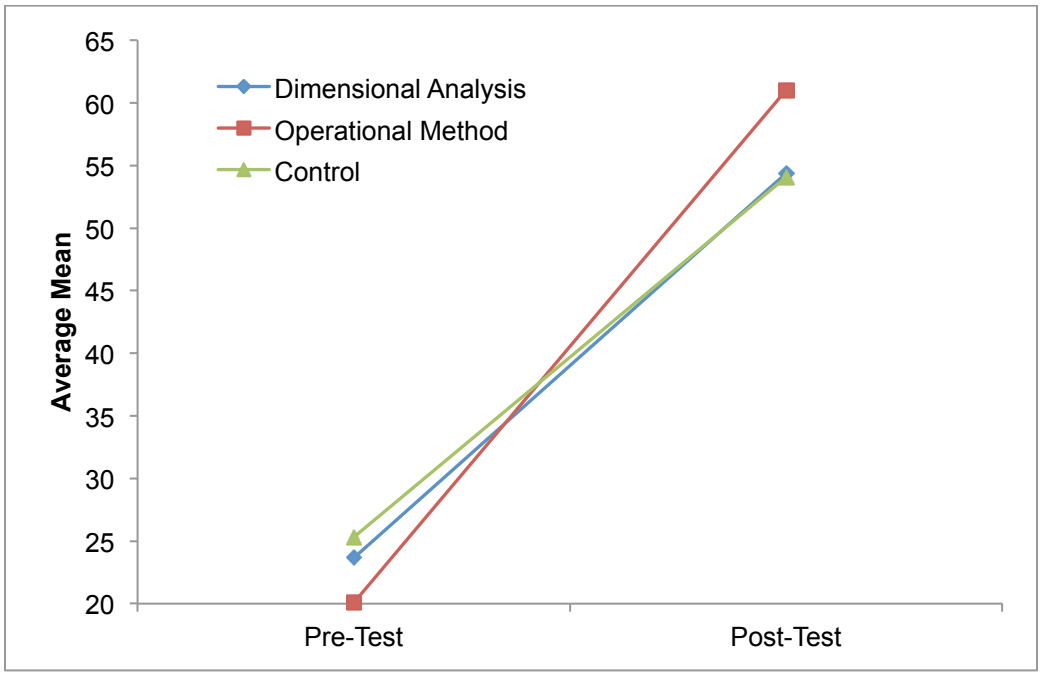


Figure 3-2 Representation of trend level interaction between pre- and post-test scores by treatment group over the course of the treatment

The second purpose of this study was to determine the frequency of students choosing to solve stoichiometry problems using or not using the particular E-learning method that was experienced (dimensional analysis, operational method). To respond to this research question a frequency table was generated to examine the match and/or mismatch between the problem solving method students used (dimensional analysis, operational method) and the treatment they experienced. These results are shown in Table 3-6. The number of novice students who successfully answered the stoichiometry

question post-test and used the method that matched their treatment is shown in Figure 3-3.

Table 3-6 Frequency of problem solving method used by students as matched or mismatched with treatment

Treatment		Answered Using Dimensional Analysis	Answered Using Operational Method	Total
Dimensional Analysis	Count	25	7	32
	Expected Count	14.2	17.8	32
	% With Treatment	78.1	21.9	100
	% Match	50	11.1	61.1
	% Total	22.1	6.2	28.3
Operational Method	Count	15	47	62
	Expected Count	27.4	34.6	62
	% With Treatment	24.2	75.8	100
	% Match	29.4	74.6	100
	% Total	13.3	41.6	54.9
Control	Count	10	9	19
	Expected Count	8.4	10.6	19
	% With Treatment	52.6	47.4	100
	% Match	20	14.3	34.3
	% Total	8.8	8	16.8
Total	Count	50	63	113
	% Total	44.2	55.8	100

The frequency analysis shown in Table 3-6 indicates a greater number of novice students (N=47) from the operational method treatment who were able to successfully apply the language used to the question presented consistently semester to semester. This population represents 41.6 % of those novice students in the operational method treatment group. There were nine students in the control group who that did not receive scaffolding but developed the operational method language. In comparison to the dimensional analysis treatment group, there were fewer students (N=25) who were able to successfully apply dimensional analysis to the given test questions. These students only represented 22.1 % of the population in the dimensional analysis treatment group. To determine if the observed frequency distribution showed significantly different patterns

than expected, a Chi-square analysis was conducted. The results of the Chi-square revealed this result to be statistically significant ($X^2 = 25.536$, $p < 0.001$), indicating these frequency patterns resulted from chance is statistically unlikely.

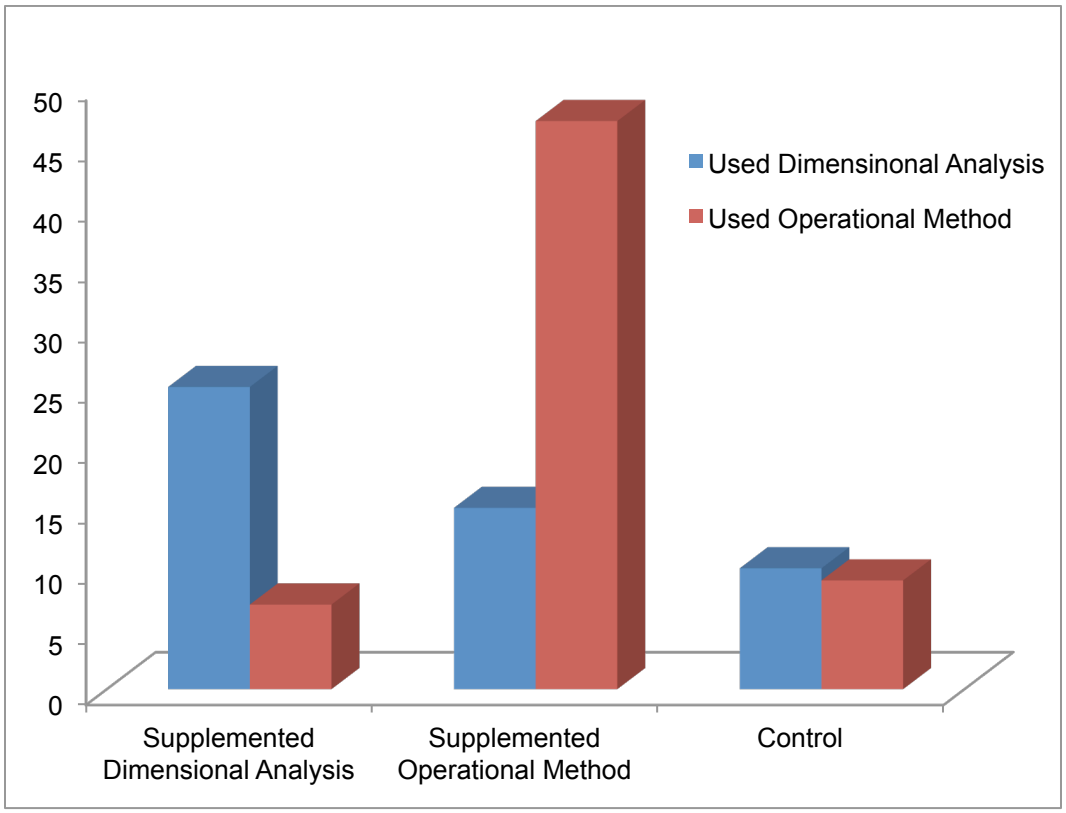


Figure 3-3 Frequency of response types in each treatment group compared to the control group which received no scaffolding.

The third research purpose of this study was to examine differences in achievement based on pre-, post-test and a stoichiometry based examination among students who used the problem solving method they experienced in their E-learning module (dimensional analysis, operational method). In response to this purpose, an analysis was conducted to determine those students whose problem solving method

matched the treatment they experienced. Next students' pre-, post- and stoichiometry test scores were examined to determine possible differences over time based on their utilization of problem solving methods that matched (or where students applied the learning used in) the treatment they received (DA or OM). Thus, the analyses corresponding to this third research purpose was conducted on only students who utilized the same problem solving method learned within their treatment (treatment and problem solving method used matched). Descriptive data is shown in Table 3-7. A representation of these data showing distinctions between pre- to post test and pre- to stoichiometry test based on student problem solving responses matching the treatment they experienced is shown in Figure 3-4 and Figure 3-5, respectively.

Table 3-7 Pre-, Post-, Stoichiometry Test means based on student problem solving response matching the treatment they experienced as Dimensional Analysis or Operational Method

	Student Response Type	N	Mean	Std. Deviation
Pre-Test Score	Dimensional Analysis	25	29.33	17.76
	Operational Method	47	24.42	17.67
Post-Test Score	Dimensional Analysis	25	72.19	27.50
	Operational Method	47	80.39	18.19
Stoich. Test	Dimensional Analysis	25	69.97	17.34
	Operational Method	47	76.88	16.41

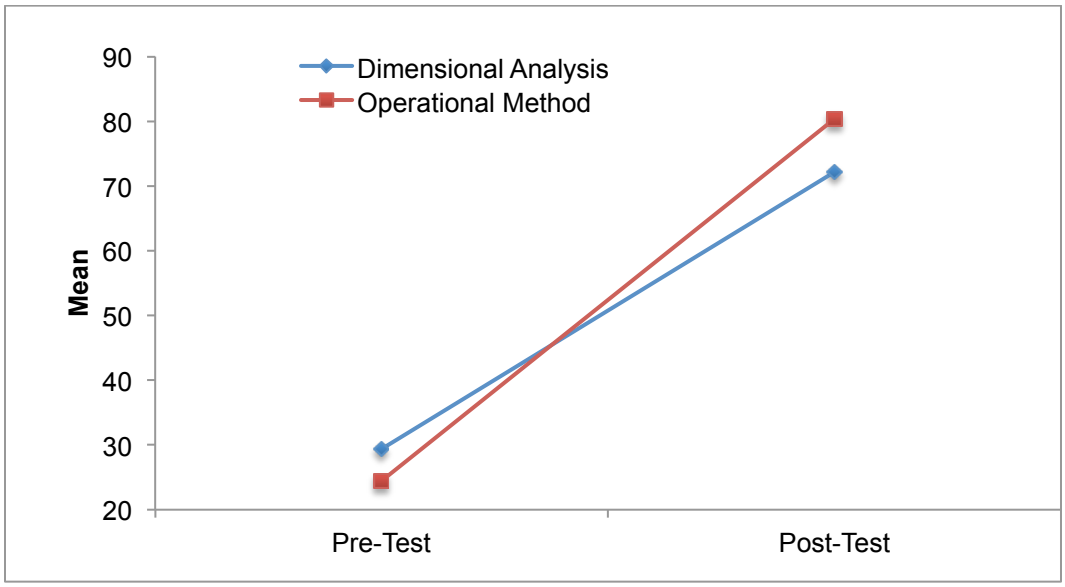


Figure 3-4 Representation of trend level interaction between pre- and post-test scores by achieved by students that utilized the scaffolding technique within their treatment group

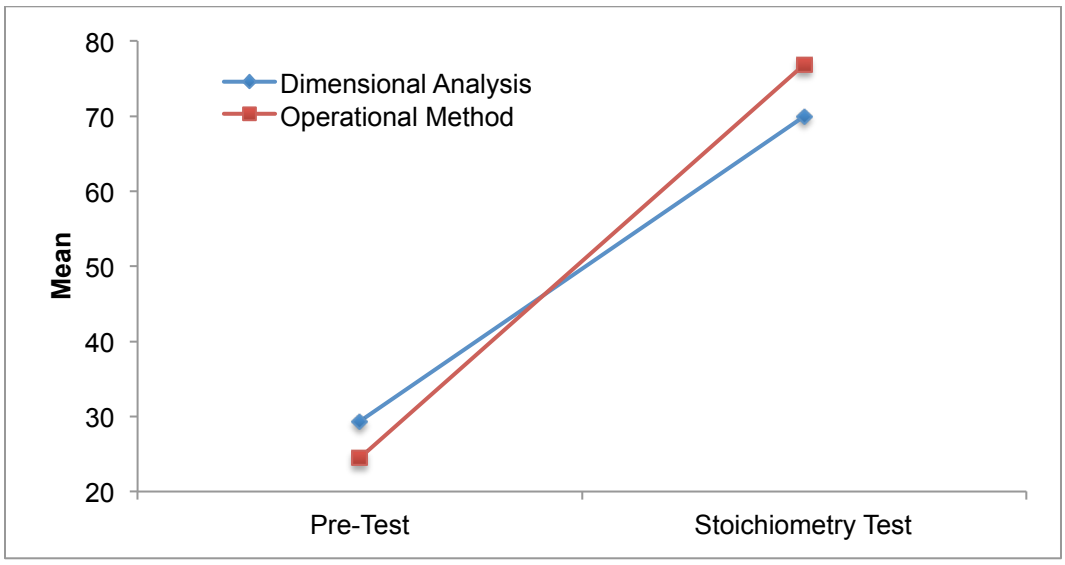


Figure 3-5 Difference in pre-test and stoichiometry test score over time between the students that utilized the scaffolding technique within their treatment group.

To determine if the observed descriptive level differences in means shown in Table 3-7, and Figures 3.4 and 3.5 were significant, 2 x 3 repeated measures analysis were conducted. Prior to analysis, Levene's Test for equality of variance was conducted for student achievement based on pre- to post-test and pre- to stoichiometry test. The results, shown in Table 3-9, show no significant differences for pre-test ($p=0.98$) and stoichiometry test ($p=0.68$) scores achieved by students who answers matched the treatment they were exposed to, thus the assumption of homogeneity of variance was not violated. But, the results also show a significant difference ($p > 0.02$) for post-test scores, thus the assumption of homogeneity of variance was violated. Therefore interpretation of this point should be done with caution. Table 3-8 shows the 2 x 3 repeated measures analysis on students whose problem solving methods matched their treatment on time (pre-test, post-test), treatment/problem solving match, and time x treatment/problem solving match. Table 3-8 also shows the same analyses with final stoichiometry test in place of the post-test scores. Results shown in Table 3-8, reveal a significant difference in pre- to post-test score and in pre- to stoichiometry test scores over time. In pre-to post test and pre-test to stoichiometry test, the type of treatment students received was statistically significant different, $p < 0.05$. As represented in Figures 3.7 and 3.8 students instructed in the operational method group scored higher in either on both the post-test and stoichiometry test compared to the dimensional analysis students. Examining the time over treatment effect, the difference in pre- and post-test scores was statistically significantly higher among students given the operational method and who used the operational method versus the dimensional analysis group. The difference in scores between the pre-test and the stoichiometry-based examination were also descriptively higher, but although a positive trend level, it was not statistically significant ($p = 0.05$).

Table 3-8 Repeated measures analysis to determine any significant difference in student utilization of treatment over time based on scores achieved pre-, post- and stoichiometry tests

Pre- to Post-Test	Mean^2	F	Sig.
Time	79700.1	255.7	< 0.001
Treatment_Match	1404.2	0.184	0.669
Time*Treatment_Match	1141.0	3.833	0.040
Pre to Stoichiometry Test			
Time	70728.3	255.7	< 0.001
Treatment_Match	1404.2	1.759	0.003
Time*Treatment_Match	1141.0	3.833	0.050

Table 3-9 Levene's Test for Equality of variance for pre-, post- and stoichiometry test scores achieved by students based student utilization of treatment

Pre- to Post-Test	**F**	**Sig.**
Pre-Test	0.001	0.982
Post-Test	6.142	0.016

Pre- to Stoichiometry Test	**F**	**Sig.**
Pre-Test	0.001	0.982
Stoichiometry Test	0.177	0.675

The fourth research purpose of this study was to examine patterns in students open-ended responses on the online modules they experienced in dimensional analysis and operational method in solving stoichiometry problems. Open-ended responses were also analyzed from students whose method of problem solving matched their treatment. In this phase of the study, 46 of 47 students in the matched groups provided written feedback. Accordingly it was found that 80% of these students agreed or strongly agreed that using the OM made solving stoichiometry problems easier. The same sets of students were also in agreement that the problem solving steps provided within the learning modules helped them better solve stoichiometry problems. Thirty-eight students left positive comments; a majority (N=30) stated that they appreciated how the modules dissected the problem solving into basic parts, which they could follow. Three students

liked the examples presented in the modules, pre- and post-test, and the examples given in the modules. Two students liked both the presented strategies and the examples. Finally, three students liked the stoichiometry map, which was presented. Of the negative comments (N = 3), one student was dissatisfied with the on-line format. The two remaining students noted that they already knew most of the information, so the modules just added to their work. The remaining 5 students added comments that had no value (e.g., “stoichiometry” or “n/a”). In both student groups that used dimensional analysis and operational method, the students responded most favorably to the layout of the modules rather than the conceptual nature of different models presented. The students appreciated that the problem solving strategies were presented in a step-by-step fashion, and included explanations for each step and why it was necessary.

3.7 Discussion of Results

Solving stoichiometry problems is a series of problems solving steps and in this research the methodology the student used to answer the problem; either dimensional analysis or operational method was closely examined. In a pilot study, there was evidence indicating that the operational method seemed to scaffold the ability to solve stoichiometry problems compared to the dimensional analysis method and with greater frequency. The evidence in this paper seems to further the initial findings.

The initial research question includes an all-inclusive examination of 348 novice student’s responses. As shown in Figure 3-5, from a descriptive level, the trend indicates that students in the control group achievement scores increased less markedly than either of the treatment groups. This finding may imply that scaffolding of either form (dimensional analysis or operational method) may have been more effective than no scaffolding. Future research would be needed to clarify this finding.

Since this experiment was conducted as a supplement to the student's in class instruction, which focused primarily on the use of dimensional analysis, students had the freedom to apply whatever methodology they saw fit. The results of the frequency analysis descriptively shown in Table 3-6 reaffirms that not all students used the methodology in their particular treatment group. First, there is evidence that those novice students will develop and use either dimensional analysis or operational method towards stoichiometry problems in the absence of scaffolding as shown in Figure 3-6. As a measurement of student involvement with their particular treatment, the frequency analysis also revealed there were a greater number of students whose problem solving response matched the treatment they experienced, whether it be dimensional analysis or operational method, to the given stoichiometry problem. Even more telling was that there were nearly twice as many students in the operational method group that applied the matching treatment compared to the students who were supplemented with dimensional analysis learning experiences. The data does show that the distribution of these types of students between the treatment groups, compared to the control group did not happen by chance. According to the Unified Learning Model (ULM) and other resources, incorporating new knowledge, especially among novice students, takes effort,[57] but if learning is a matter of survival, would not a simplification of the learning process for stoichiometry provide a better understanding of the material? In other words, learning most often occurs more easily down the path of lease resistance. The operational method, a less rigorous method, mathematically, would resonate better with students with less mathematical anxiety. In a recent paper by Saitta and co-workers, it was discussed how students have difficulties in chemistry due to the transfer of pure mathematics into the science domain.[58] These difficulties have been seen and documented by others,[59] especially when a student's understanding of stoichiometry was assessed. A student's

mathematical foundation is an important component of success or failure in chemistry. Not only for stoichiometry, but also throughout the chemistry curriculum, the student must be comfortable manipulating units and numbers. A future study would include an examination of student's mathematical aptitude as it relates to a students response type.

From a descriptive level, the achievement trends indicates that there was a greater increase in students achievement scores whose problems solving response matched the operational method pre- to post- test and pre to stoichiometry test, as was shown in Figure 3-6 and 3-7. These comparative experiments were done assuming, that since the post test and the stoichiometry test took place nearly at the same time, whatever methodology the students chose to apply was the same in either test. The results do strongly suggest the operational method is a better scaffolding tool for novice students than dimensional analysis based on pre- to post- test. Although there was a greater increase in achievement scores pre- to stoichiometry test for students whose problem solving matched the operational there is no conclusive evidence that operational method or dimensional analysis was a better scaffolding tool. This could be due to the fact that the stoichiometry test has a greater variety of stoichiometry related questions, with varying degrees of difficulty. Future studies would need to clarify this finding.

Since there were nearly twice the numbers of students whose problem solving matched the operational method compared to the dimensional students is important, as it implies that the language of the operational method better resonated with the students. The open inquiry in the post survey seems to support this implications a majority of those students reported that the method made it easier for them to solve stoichiometry problems. In addition, the layout of how the problems were presented was cited as important. If most students agree that it was important to visually see the layout for the steps needed to solve the problem and the reasons behind each step, perhaps in that

process, they could better accommodate and assimilate how to solve stoichiometry problems and incorporate this new knowledge into their own mental schema. Using step-by-step procedures, with practice, students can solve problems making fewer mistakes. Pedagogically speaking, DA is usually taught as a series of connected steps (e.g., “railroad tracks”). Cognitively, this places a larger cognitive load on students, which may lead to mistakes if students are not aware. Many students appreciated the stoichiometry map presented in the modules. The stoichiometry map shown in Figure 3-4 is a slide that was given to every student as part of the learning modules. If most students agree that it was important to visually see and mentally internalize the layout for the steps needed to solve the problem and the reasons behind each step, maybe in that process, they could better assimilate and accommodate how to solve stoichiometry problems into their own mental schema in ways that are meaningful and that make sense to them. Future studies should investigate if there are any predictors among the problem solving steps would lead to better success in solving stoichiometry problems.

3.8 Implications for Teaching

As this study was conducted at the university level, most students would have already experienced learning stoichiometry in their high school coursework. Depending on their level of comfort with the method they were originally taught, they may continue to use it at the university level. Unfortunately, college professors often lack the time to teach the myriad of ways stoichiometry can be taught and often resort to teaching via expository lecture. However, with supplemental online instruction sessions, as presented here, different models can be experienced by the student, with students choosing to use the method that makes the most sense to them. Importantly, the concept of stoichiometry is at the core of basic manipulations of chemical equations, as the

chemistry student progresses on to higher-level courses (e.g., organic chemistry and quantitative analysis). It is critical that the concept and operations involved in such problems are well understood by students, as the complexity of problems build upon earlier skills and knowledge and may positively impact their future success in chemistry.

Chapter 4

An Investigation into the Predictive Influeces on How Students Solve Stoichiometry Problems

4.1 Introduction

Throughout history, technological advancement has always had a direct impact on the on the enhancement of education, by being able to distribute content knowledge to a larger audience. In one of the earliest articles posted by the Journal of Chemical Education, Killeiffer[60] wrote, there are two distinct kinds of education. The first is the education of the classroom and the second is represented by our newspapers, magazines and most recently by wireless telephone. Some of you readers might have thought for a second if the author meant cell phones, but this article was written in 1921 and Killeiffer was talking about the radio.

Throughout the 20th century the advancement of technology exploded as well as the exploration of its use to improve education. In the 1940-50's, a number of education short movies were made used during WWII on a number of topics, like proper etiquette for teenagers, safe sexual activity practices, and even how to plan a good party. The late 1950's also saw the use of closed circuit television at a number of universities for educational purposes.[61] Although computers have also been around since the mid 1940's non-commercial use, the 1980's saw the birth of the personal computer and computer aided instruction. One of the most important changes of the 20th century was the commercial expansion of the Internet in the 1990's and the birth of the World Wide Web (www). The internet has now become the largest database of information, graphics and steaming videos, which is an important resource for educators.

With the almost unlimited access to the internet and access to Wi-Fi from anywhere, technology has become very pervasive. In education, pervasive technology can be described as borderless technology. Technology without borders has made students' lives connected to technology in ways that we could have never imagined without the Internet. In an informal study done by studyblue.com detailing "The learning life" of 2 million students lists the top pieces of hardware student's own. Top 4 on the list include laptops, smart phones, and tablets. The list also included the pencil, which is only non-electronic device. The study also showed that 59 % of the students that took part in the study use their mobile phones to study and 93 % of those students use apps.

It is not uncommon these days to find students studying using online homework. Online homework, in general, is defined to be a complete system of computerized homework problems that are available online. Online-homework may or may not correlate closely with a particular text, are most often automatically graded to provide immediate feedback regarding the correctness of answers, and may be accompanied by varying degrees of diagnostic instructional hints and/or tutorial assistance.[62] This university and many like it have used several online homework systems like, Mastering Chemistry (by Pearson), OWL (by Cengage), WebAssign, and Sapling Learning. There are many others a quick online search reveals many online homework systems and study tools; the only limitation is the key word search of whatever topic one is searching for. Many of these groups claim that each of the programs can improve student achievement. But with any sales pitched, the claims are coming from a place of bias. On-line homework provides a great alternative to paper-based homework for a number of reasons, but research has shown there is no significant difference in student achievement between the two. [63]

4.2 The Use of On-Line Homework to Enhance Learning

There is substantial research that describes the benefits of using on-line homework. From an instructors point of view, providing online homework is a time saver and they no longer have to "collect, grade and return papers".[63] Instructors can interact more usefully with students since they can tell what a student was thinking just by viewing the answer they submitted most recently and what the problem might have been, i.e. conceptual, syntax, or a technical error.[64] From a student perspective, students can practice and engage in the material more which may lead to increased knowledge and skills.[65] Immediate feedback on whether or not a student's answer is correct is a benefit of online homework systems compared to waiting a few days or more with the traditional paper-and-pencil option.[66] Some con's include, online homework systems tend to put emphasis on the final answer rather than the process students use to obtain their solution[67] The issue of cheating amongst classmates can be a problem since there is no way to determine who is actually completing the online homework assignment[65]

In this study, we created a module to scaffold the learning of one of the most challenging topics in a first semester general chemistry course. That topic is stoichiometry. The modules were created using a constructivist framework and distributed using online resources, as described in the methods section. In the creation of the e-learning modules, the author had to ensure that the learning process within the modules was compatible with the human learning experience.[37] In other words, the modules had to take every opportunity to promote active learning in the absence of social interaction.

4.3 Creation of the E-learning Tool Using a Constructivist Framework

What exactly is a constructivist framework? Constructivism asserts that "knowledge is not passively received but is actively built up by the cognizing [learner].[68] Constructivists holds that knowledge exists only in our heads where it is constructed by each of us in our own way.[69] Therefore whenever creating an education tool, one has to keep in mind that however we transmit the information, the student will process it however they learn. A lot of early work that describes this phenomenon was done by Piaget.[35] Piaget asserted that children construct their knowledge in the form of schemas. A "schema" can be described as a cognitive framework or concept that helps organize and interpret information. The children then process that information through assimilation and acommodaation.[13] The constructivist ideas and much Piaget's work and how it is applied to learning, provided the foundation by which the modules were created.

One of the most familiar models for applying the work done by Piaget's ideas to teaching is the learning cycle, which is shown in Figure 4-1. Much of the early work done with the learning cycle was introduced by Atkin and Karplus.[70] The learning cycle consists of three phases: 1) an exploration phase (learning) 2) a concept invention phase and 3) the application phase, which was originally called the discovery phase. During the exploration phase the learner is introduced to the problem which his to be learned. In other words, the student will try to assimilate the information into their cognitive schema. Following the exploration phase is the concept invention phase. In this phase, terms are introduced and clarified which will help studies discover theories, laws, or ideas, which provide the scaffolding necessary to solve the given problem. The idea of scaffolding is a term that is associated with Vygotsky's Zone of Proximal Development.[55] The idea is that students need help in learning a new concepts and idea. An instructor or someone with more knowledge can guide the student a solution, by asking more manageable

questions. These questions should be within the students' abilities to answer, without the instructor directly communicating the answer. During the scaffolding phase, or between the assimilation and accommodation phase, the student might experience cognitive dissonance and disequilibrium. This process can be described as the process by which they try to incorporate knowledge into their cognitive structure at the same time changing or removing previous held ideas or beliefs. At the end of this phase, students should achieve and experience the phenomenon called accommodation. This process describes the integration of new knowledge into the learners' complex neural network. Following the concept invention state is the application stage. During the application phase, the student applies what he or she has learned to a variety of problems and situations and achieving what Ausbel[71] described as "meaningful learning". To learn meaningfully, the learner must relate new knowledge to relevant prior knowledge. In doing so, the student will be able to store this new information into their long term memory and if the situation arises, that information can be recalled at.

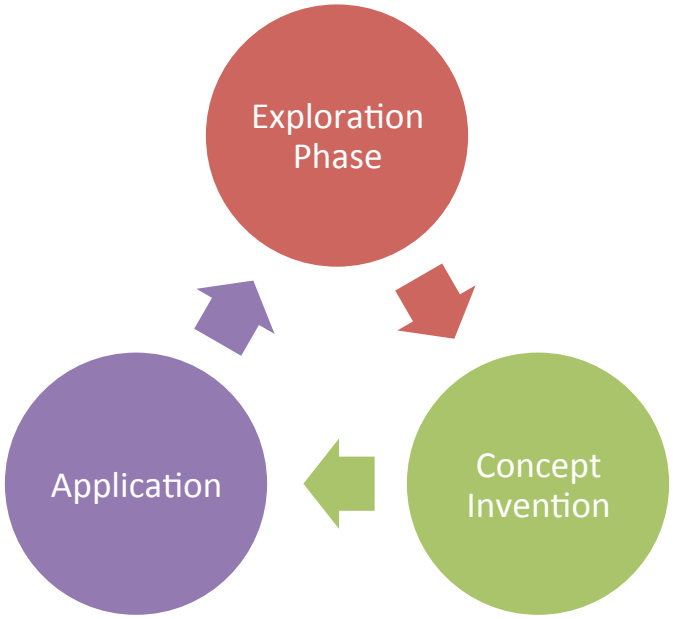


Figure 4-1 The learning cycle

4.4 Using E-Learning Tools to Scaffold the Process of Problem Solving as it's Applied to the Learning Cycle.

How is the learning cycle incorporated into the e-learning modules created? The modules were divided into three similar phases of the learning cycle. The first phase the stoichiometry question is introduced. Quickly following this phases beings the problem-solving phase. For any problem solving process (which is described in the following sections), students must first analyze and eventually understand what the question is asking: this is the concept intervention phase. Second that student must come up with a strategy to solve the problem. To scaffold this part of the problem solving process and at the same time actively engage the student, the learning modules featured "points of learning". These "points of learning" included questions or fill in the blank statements that were strategically placed to allow the student to become cognizant of the fact that there is a thought process that must be completed before moving onto the next step in the

problem solving process. These questions provided the student the appropriate level of "scaffolding" to make the problem solving easier; at the same the amount of frustration that might be associated with the overall process could be mitigated. Lastly, the student must be able to verify his or her answer. Once the problem has been scaffold the student will be introduce to a different problem and apply what he or she has learned to a different problem with the same scaffolding questions, without the scaffolding support. This is then followed by several different examples. This is the application phase.

4.4.1 Analysis and Understanding: Use of Scaffolding Techniques

The first step in the problem solving process, being able to decipher what the question is asking, is often the most difficult. The screenshots in Figure 4-2 demonstrate one of the first points of learning used by the learning modules. Students were required to stop, read the problem, and pick out the necessary information needed to solve the problem. Part of being able to read the problem is to filter out any unnecessary pieces of information and focus on certain key aspects (i.e., "What is given?" "What is wanted?" If a reaction is given, "is the reaction balanced?").

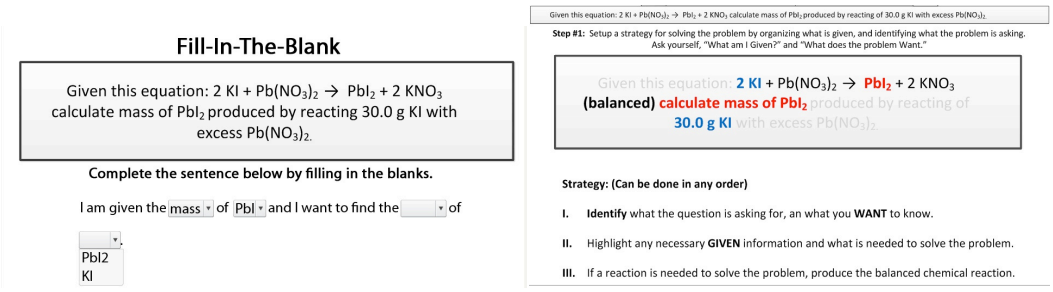


Figure 4-2 Side-by-side screenshots of one of the “points of learning” first step in problem solving, analyzing the problem, followed by scaffolding support contained within the learning modules.

These points of learning are questions that are used as scaffolding tools, to be able to gauge the learner’s level of understanding and to help shape the student’s perception how to solve stoichiometry problems. If a problem is outside the learner’s ZPD, anxiety and frustration sets and the learner will be unable to perform the given task. The scaffolding support is followed to point out the finer details if the student is unable accomplish the “point learning” task.

4.4.2 Strategy: Stoichiometry Map

Once the student understands what the problem is asking, the next step in the problem solving process is devising a strategy to solve the problem. The student must recognize what steps are needed and how multiple steps fit together in the proper sequence. A general mass-to-mass stoichiometry problem has three essential steps. Those steps include, converting mass A to moles A, then convert moles A to moles B, and finally convert moles B to mass B. This strategy is brought to practice by having the students create a version of a “stoichiometry map”. Each module explains and displays the steps necessary to create a visual schema about how to break down a complex stoichiometry problem into manageable steps. Figure 4-3 provides an example of a stoichiometry map presented in one of the learning modules.

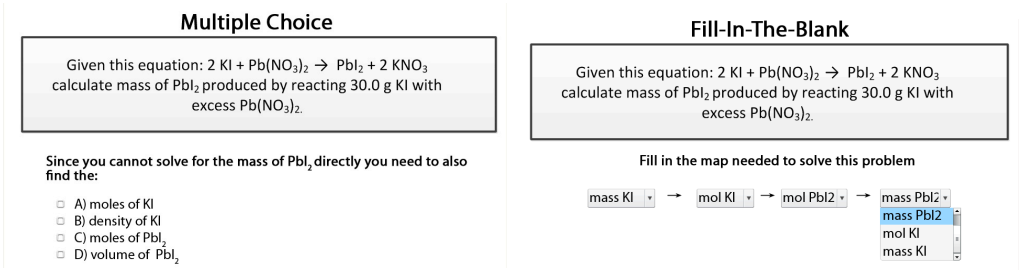


Figure 4-3 Side-by-side screenshots of the creation of visual schema (i.e. stoichiometry map) needed to solve the stoichiometry problem

Once a strategy has been devised, the student can apply it. In this study, students were randomly assigned one of three different methodologies to help them carry out their strategy. The methodologies were taken from science education literature and included: Dimensional analysis; ratio and proportions; and an operational method.[14, 72, 73] One goal of this study was to explore whether one these methods was more effective as a scaffolding tool to support the process of solving a stoichiometry problem. These methodologies are shown in Figure 4-4.

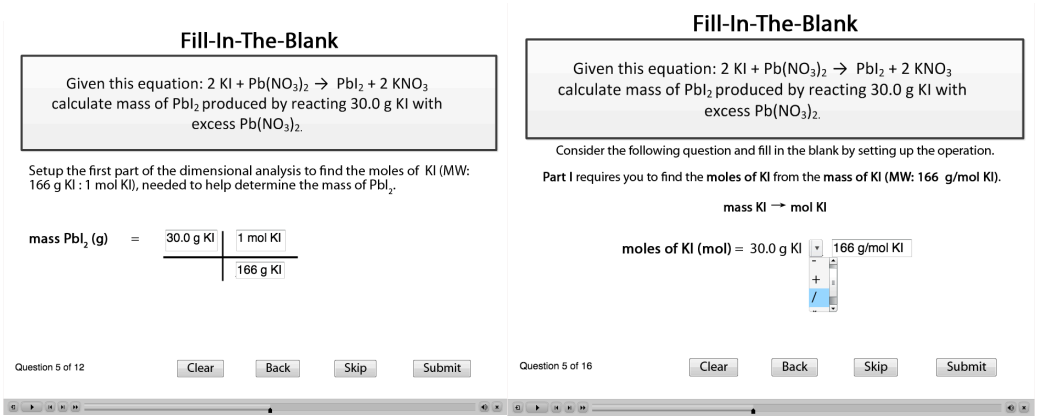


Figure 4-4 Side-by-side screenshot of the use of Dimensional Analysis versus Operational method

4.4.3 Novice vs. Expert Language: Dimensional Analysis vs. Operational Method

There are certain pedagogical differences between the two methodologies used in this study. The first, dimensional analysis (DA), is a factor labeled approach that involves the use of conversion factors and unit cancelling to arrive at an answer. The second, termed the operational method, is a formulaic approach. For example, the quantity molar mass can be written as a formula (molar mass = mass/moles). To solve for moles of a particular substance the formula can be rearranged to moles = mass/molar mass. Arguments can be made that dimensional analysis and the operational method are too similar to be distinguished and studied. For example, if one knows dimensional analysis then one knows the operations necessary to solve a mass-to-mass stoichiometry problem.

From an expert's point of view there is no difference between dimensional analysis and the operational method. As an expert, the process of solving stoichiometry problems can be distilled to a series of formalized procedures, which can easily be communicated from one expert to another. These procedures have been developed from hours of deliberate practice using DA. If we consider the pedagogical content knowledge of the two instructional methods, dimensional analysis includes conversion factors, where appropriate numbers with the appropriate units are used to systematically manipulate the units of a given number to eventually arrive at a correct answer. Proper choice, manipulation, and use of conversion factors places a significant cognitive load on the novice. The number of steps needed to solve a typical stoichiometry problem amplifies the amount of burden placed on the student's cognitive load. The situation is further exacerbated by the fact that students are usually called to perform these tasks during a timed examination. In contrast, instruction using formal operations removes those more complex considerations and replaces them with simpler operational statements. The

amount of cognitive load is thus diminished; the appropriate operations can be memorized or devised from an appropriate schema (e.g., a stoichiometry map). Although the learning modules were written in an expert's voice, the author realizes the intended audience for the learning modules is not experts but primarily novices. Therefore the construction and the language used must reflect that with great consideration.

4.4.4 Verification (Strength and Weaknesses)

Once the student has executed the strategy, the final step in the problem solving process is verifying the answer. This is a strength in dimensional analysis. If the student is able to successfully apply conversion factors, then they can verify the appropriate units cancel to leave the final desired unit. Inherently, this is also a weakness of DA. If the novice does not apply or incorrectly applies the correct conversion factors, or they do not make sure that the appropriate units cancel, then mistakes will occur. Incidentally, this problem is somewhat abated by the use of ratios and proportions. Since both ratios are set in equality and the proportions are similar, solving for a certain quantity and its implied unit, usually using cross multiplication, the chance of error is diminished. Unfortunately, with the operational method this is a little less straightforward. Although the use of defined formulas in the operational method relieves the cognitive burden placed on students, verification of the answer is not as straight forward. Consider the conversion from mass to moles. The operational method instructs the student to divide by the molar mass. If one recalls what division is, it is nothing more than the multiplication of the reciprocal (i.e., a/b = a x 1/b). Therefore the formula mol= mass (g)/molar mass of (g/mol) transforms to mol = g * (1 mol/g). The formulaic approach is verbally very simple, but mathematically written out, it is a little more complicated. The modules attempt to shoulder that burden by reminding the students of this fact.

After being exposed to the points of learning, which is applied to both the learning and concept invention phase of the learning cycle, is then ask to apply what he or she has learned a different problem. Similar "points of learning" questions are asked to the student without the scaffolding support. The purpose of this is to promote the construction of the "schema" necessary to whatever stoichiometry problem they are working on and hopefully in the end the student will have an "ah ha!" moment.

4.5 Previous Results

The results of an earlier study found that the neither operational method or dimensional analysis method provided better support in scaffolding the problem solving process of solving stoichiometry problems. The descriptive evidence did show that the students that were supported by the operational method and had correctly applied the method upon examination had higher achievement scores on pre-, post- and stoichiometry test examination. An additional finding from the qualitative evidence showed that a majority of the students agreed that they liked how the problems were scaffolded in a step by step fashion and not much was said on the particular methodology. More importantly, of the 350 students that took part in the study, there was evidence that the 146 students who had post-test clarity. These included students that were able to provide a descriptive the process how they solved given stoichiometry problem (N=33), use dimensional analysis (N=50) or operational method (N=63). These students also had to the question correctly. The study contained descriptive evidence that alluded to the fact that these students scored higher than those that did not have clarity. Therefore the purposes of this study are:

1. To determine possible differences on student performance on the stoichiometry test according to how they answered the stoichiometry post-test question (Dimensional Analysis, Operational Method, None) and level of clarity (yes, no) on a post-test related question.

2. To explore possible interrelationships and predictive influences of post-test answer type and level of post-test clarity on the stoichiometry test.

It was assumed that the way students answered on the post-test would be similar, or the same, as the way they would answer questions on the stoichiometry test. This is based on the fact that the post-test was given during the same period of time as the stoichiometry test.

4.6 Methods

Refer to Chapter 3.5

4.7 Results

The first part of the first research question was to determine any possible differences on student performance on a stoichiometry test according to how they answered the stoichiometry post-test question (Dimensional Analysis, Operational Method, None). The descriptive means for the student achievement on the stoichiometry test based on their responses type to the post-question is shown in table 4-1. Levene's test for equality of variances reveals a significant difference ($F= 4.415$, $p = 0.01$) between the stoichiometry test means based on the student answer type. Thus, the assumption of homogeneity of variance was violated. Therefore, the interpretation is to be done with caution. An ANOVA (Analysis of Variance) was done to determine homogeneity of variance between the three variables. The ANOVA results are shown in Table 4-2.

Table 4-1 Student means on a stoichiometry test based on post-test question answer type.

Post-Test Question Answer Type	N	Mean	SD
None	237	64.3	21.9
Dimensional Analysis	50	67.2	18.9
Operational Method	63	77.6	16.8
Total	350	67.1	21.2

Table 4-2 ANOVA analyzing the variance in means based on student post-test question answer type (Dimensional Analysis, Operational Method, or None)

Stoichiometry Test	F	Sig.
Post -Test Question Answer Type	10.4	< 0.001

The results show that there is a significant difference ($p < 0.001$) between the student-achieved means. Descriptively the students who answered the post-test question using the operational method (N=63, avg. mean 77.6) scored higher than the students who used dimensional analysis (N=50, avg. mean 67.2) and those students who were unable to answer the question at all (N=237, av.g mean 64.3).

A follow up post hoc test was used to determine where the differences in patterns occurred. The results are shown in Table 4-3 and Figure 4-4. The post hoc analysis showed the difference between students who used operational method versus those students who used dimensional analysis was statistically significant ($p = 0.02$). Also there was a larger difference between the operational method students and the students that were not able to answer the post-test question was statistically significant ($p < 0.001$). These differences are descriptively shown in Figure 4-4.

Table 4-3 Post Hoc mean comparison achieved by students on the stoichiometry test based on post-test question answer type

Post Question Answer Type	**Post Question Answer Type**	**Mean Difference**	**Std. dev.**	**Sig.**
Operational Method	Dimensional Analysis	10.4	3.9	0.022
	None	13.4	2.9	< 0.001

		Subset for alpha – 0.05	
Post-Test Question Answer Type	**N**	**1**	**2**
None	237	64.3	
Dimensional Analysis	50	67.2	
Operational Method	63		77.6
Sig.		0.67	1.000

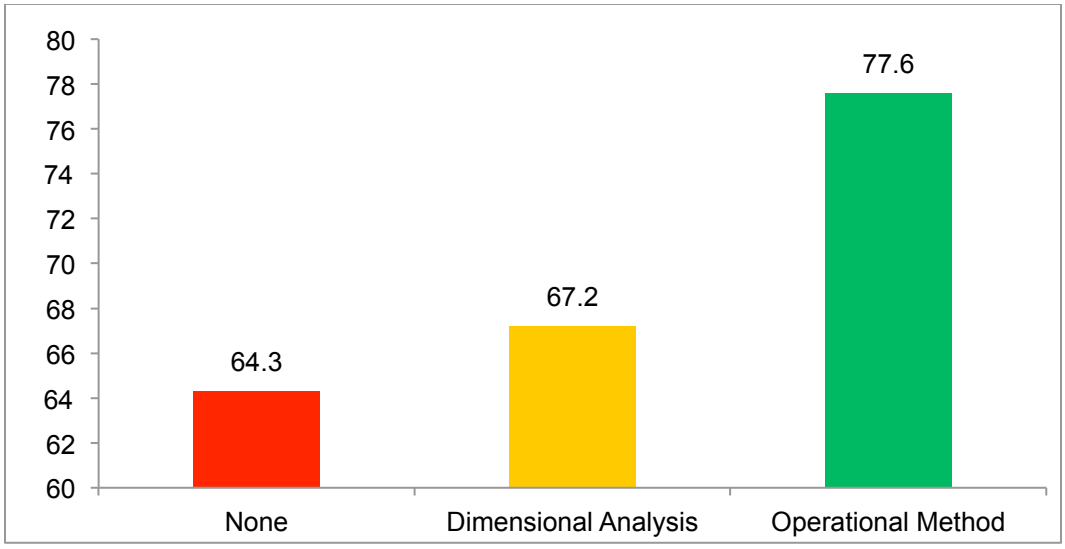


Figure 4-5 Stoichiometry test means based on post-test question answer type

The second part of the first research question was to determine any possible differences on student performance on stoichiometry test according to a student's level of clarity (yes, no) on a related post-test stoichiometry question. The descriptive means, based on student's level of clarity, is shown in Table 4-5. Levene's test for equality of variances analyzing the variances means between the two levels of clarity was not significantly different. Thus the assumption of homogeneity of variance was not violated. The results in response to the research question on possible differences show that the students who had clarity (N=146, avg. mean 73.6) scored higher on the stoichiometry exam than those students that did not. (N=204, 62.4). An independent samples t-test was run to determine if there possible difference in means between these two student groups. The results of the t-test are shown in Table 4-5. Presuming equal variance in means between the two groups of students, the t-test also showed that the average means of the two students groups was significantly different ($p < 0.001$).

Table 4-4 Descriptive means of achieved by novice students on a stoichiometry test based on their level of clarity on a post-test question.

Level of Clarity	N	Mean	SD
No	204	62.4	21.0
Yes	146	73.6	19.6
Total	350	67.1	21.2

Table 4-5 Independent samples t-test analyzing the difference in means achieved on a stoichiometry test based students level of clarity on a post-test question

Stoichiometry Test	Levene's Test for Equality of Variance		t-test Equality of Means			
Level of Clarity	F	Sig.	t	Sig. (2-tail)	Mean Diff.	Std. Dev.
	2.348	0.126	-5.054	< 0.001	-11.24	2.22

The second research question was to explore possible interrelationships and predictive influences of post-test question answer type and level of clarity based on a post-test related question, on the stoichiometry test. A regression analysis was completed using the post-test question answer type and the student's level of clarity as the model. The correlation results for the regression analysis are shown in Table 4-5. The Pearson correlation coefficient, which describes the level of association among independent variables (Level of clarity, post-test answer type) has on the dependent variable (stoichiometry test), shows that both the students level of clarity and the students response type have a weak but positive relationship. (Coefficient: 0.261, 0.231 respectively). These results are statistically significant ($p < 0.001$)

Table 4-6 Correlations of student performance on the stoichiometry test based on post question answer type and the student level of clarity on post-test question

Stoichiometry Test	Level of Clarity	Post-Test Question Ans. Type
Pearson Correlation	0.261	0.230
	1.000	0.687
Sig. (1-tailed)	< 0.001	<0.001

The results for the linear regression to determine the prediction of stoichiometry test scores are shown in Table 4-7. The results revealed an R^2 value of 0.07. This means that 7 % of the variance in the student achieved means on the stoichiometry test is predicted by level of clarity and post-test question answer type ($p < 0.001$). An ANOVA was done to determine whether or not the correlation effects happened by chance. The results of the ANOVA revealed that it did not and the result was statistically significant ($F = 13.9$, $p < 0.001$).

Table 4-7 Linear Regression analyzing students level of clarity and post-test question answer type as it relates to student performance on the stoichiometry test

Stoichiometry Test				**Change Statistics**		
Model	**R**	**R^2**	**Adjusted R^2**	**ΔR^2**	**ΔF**	**ΔSig. ΔF**
Post-Test Question Answer Type Level of Clarity	0.270	0.073	0.068	0.073	13.67	< 0.001

Model		**Mean^2**	**F**	**Sig.**
Post-Test Question Answer Type Post-Test Question Clarity	**Regression**	5752.528	13.696	< 0.001

To further elucidate how much of an effect each variable, post-test question answer type and level of clarity had an effect on student achievement on the stoichiometry test, an examination of the standardized and unstandardized coefficients was done. The descriptive results are shown Table 4-9. The results show that student achievement scores correlated more strongly with student's level of clarity ($b = 0.299$, $p < 0.001$) and this result was statistically significant. However, how the student answered on the post-test question does not significantly contribute to the prediction of student stoichiometry test achievement (0.061, $p = 0.358$).

Table 4-8 Unstandardized and Standardized coefficients for the regression model

Model	Unstandardized Coefficients		Standardized Coefficients	Sig.
	B	Std, Error		
Stoichiometry Test	57.27	5.75		
Level of Clarity	12.85	2.83	0.299	< 0.001
Post-Test Question Answer Type	1.757	1.91	0.061	0.358

4.8 Discussion of Results

In response to the first research question, which was to determine if there were differences in student achievement on a stoichiometry test based on their post-test question answer type (dimensional analysis, operational method, or none) it seems the operational method, a less rigorous mathematical model compared to the dimensional analysis, seems to relieve some of the anxiety and complexities of solving a stoichiometry problem. In the current study, enhanced performance on examinations, post-test and the stoichiometry test, was found for those who used operational method. In this context, the operational method appears to be superior. More importantly, of the students that answered operational method (N=60), 47 (~78%) students were novice students that were supplemented with the operation method module.

The results from the second part of the first research question, which was to determine if there were any differences in student achievement on a stoichiometry test based on their level of clarity on a post-test question revealed that students performed better on the stoichiometry test. This result is not surprising. If a student could correctly describe the proper procedure on how to solve the stoichiometry problem, they should potentially do better on a stoichiometry based examination than those that cannot.

Even though the students who used operational method scored significantly higher on the stoichiometry test, the methodology wasn't the sole predictor on student performance on the stoichiometry test according to the findings from the second research question. The second research question was to explore possible interrelationships and predictive influences of post-test question answer type and level of clarity based on a post-test related stoichiometry question. The finding did show that methodology was a predictor, however more important was the students' level of clarity. Even though the results showed a weak but positive prediction of stoichiometry test achievement by level of clarity, the association explained 7% of this achievement. In education, any factor that contribute to improving achievement by any significant amount is valuable information, especially given the myriad of factors that are likely involved, most of which instructors cannot impact or control, such as past experiences with the subject. This 7% is something instructors can work to improve among their student – level of clarity – and so have some impact on improving understanding, even if only by a small amount.

Both of these results are supported by work that was done by Gabel and Sherwood.[41] They found instruction that employs strategies such as diagrams and analogies as opposed to multiple examples using dimensional analysis is significantly more effective for students with high math anxiety probably because such an approach efficiently makes use of both the visual and verbal components of their memory structure. Further research would need to explore the fact amongst the students at this university.

4.9 Implications for Teaching

Clearly today's college students spend substantial time connected to their electronic technologies and as a result they may find appeal and interest in learning utilizing on-line tools. The results of this study have shown that when teaching

stoichiometry, the methodology by which to solve a stoichiometry problem may be important, but helping students create mental schema on how to solve the problem is just as important. Therefore in addition to helping students learn dimensional analysis, much deeper level learning should be applied in chemistry instruction. E-learning modules as described in this study should continually be developed to help students identify the type of stoichiometry problem he or she is facing and most importantly provide scaffolding support into creating the appropriate schema necessary to solve that problem.

Chapter 5

A Reflective Look Into the Creation of a Chemical Education Research Program at an Urban-Based Research Institition

5.1 Introduction

I first started as a traditional PhD student at the University of Texas at Arlington (UTA) back in 2008. My original intent was to study ruthenium polypyridyl complexes and their potential use as anti-cancer agents. After the first couple of years, I was given the opportunity to take part in a couple of education initiatives that were started as a joint venture between the College of Science and the College of Engineering. Part of my role, within these initiatives, was to tackle the issue of student retention in our general chemistry courses. It became readily apparent to my advisors that I had more passion working with students than working in the lab. It was decided that my research focus would transition from inorganic chemistry to chemical education. There was funding available, but there were also a number challenges I had to overcome to make this transition, including coming up with a novel chemical education research question that we wanted to study. A second challenge I had to overcome was to fill in gaps in personal knowledge to be able to do scholarly research in chemical education. The purpose of this article is to discuss the potential creation of a post-secondary Chemistry Education or Chemical Education Research program at The University of Texas at Arlington and reflect on my experiences related to steps in that direction over the past few years.

5.2 Chemical Education Research

5.2.1 What is Chemistry Education Research?

What is Chemical Education Research? CER is the systematic investigation of learning grounded in a theoretical foundation that focuses on understanding and improving learning of chemistry.[74] Diane Bunce explains in her introduction to the "Nuts and Bolts of Chemical Education Research" that CER if often misunderstood within the field of chemistry and as such the expectations from outside of CER of what chemical education research should be addressing, how it should operate, and what it should produce are often at odds with reality.[75]

There is currently a national crisis in education, where we need to examine the current efficacy of our education standards. Many people (citizens, educators, policy makers, administrators, etc.) want answers about how we can better educate our populace. These people don't want handed down wisdom educators have learned when they were in school; they want hard and impartial evidence of what works. They want decisions that rest on reasonable, rigorous, and scientific deliberation.[76] In the case of CER and other discipline-based education research programs, Bunce further points out, and it is my shared belief, that CER can provide answers to questions that have plagued many chemistry faculty such as "What is the best way to teach?" or "Why don't students learn?". Unfortunately, there does not always seem to a clear connection between CER outcomes and the implementation of best practices in the chemistry classroom.

5.2.2 What Would a Chemistry Education Research Program Look Like at this University?

Chemical Education Research (CER) is inherently multi-disciplinary and therefore does not necessarily fit under a single college. At UT Arlington, the Department

of Chemistry and Biochemistry in the College of Science and the Department of Instruction and Curriculum in the College of Education and Health Professions provide for a possible joint foundation for such a program. In the absence of a formalized program, there are two potential degree routes a student could take if interested in CER. The first path could be a traditional M.S. or Ph.D. in Science Education with a focus on Chemistry curricula, and the second could be a traditional M.S. or Ph.D. in Chemistry with a focus on CER. Unfortunately, the American Chemical Society does not recognize a degree in Chemistry with a focus in CER. To obtain a degree in Chemistry, a student would specialize in one of the traditional chemistry fields (i.e., organic, inorganic, biochemistry, physical, or analytical) and then some part of the dissertation should be dedicated to a valid laboratory-based chemistry research proposal. At the same time, a significant portion of that student's dissertation could also focus primarily on a CER project. For example, as I near the completion of my own dissertation, it is likely to consist of two chapters of inorganic chemistry research and three chapters of CER.

5.2.3 What Educational Paths Would a Student Take to Part in Chemistry Education Research?

Although I can expound on the importance of what CER has to offer, there are other questions that have to be answered before considering the beginning of a new formalized program. For example, how does the proposed program support the Colleges' and the University's mission? UT Arlington, like many universities, follows a model of discovery, learning, and engagement. This effort requires attracting and retaining scholars who promote a culture of intellectual curiosity, rigorous inquiry, and high academic standards among their fellow faculty and students they teach.

(http://www.uta.edu/uta/about/administration/mission.php). The College of Curriculum and Instruction, whose focus is on teacher preparation, is dedicated to creating and supporting effective professional educators who can meet students' diverse academic, social, and personal needs. The faculty also generate and disseminate high-quality research, develop innovative programs to meet education needs, and provide meaningful professional service. (http://www.uta.edu/coehp/curricandinstruct/about/index.php).

Creation of a CER program is synonymous with Scholarship of Teaching and Learning (STL). STL is a reflective practice where faculty examine student learning. STL involves traditional educational research and improvement of teaching through peer review and dissemination of research to the public. This type of activity reaffirms the Colleges' and university's mission to create a diverse and comprehensive research program. Each college provides an environment where undergraduate and graduate students can learn to be independent scientists as well as educators, so they learn and communicate intelligently what they have learned.

5.2.4 Are There Any Other Institutions That Have Programs in Chemistry Education Research?

There are several institutions in Texas that have postgraduate programs in Chemical Education (e.g., Texas Tech University, University of North Texas, Texas A&M University, and The University of Texas at Austin). Nationally, Chemical Education programs can be found at institutions such as Purdue University, University of California - San Diego, Iowa State University, and several others. Although there are relatively few institutions that officially have Chemical Education programs, there are a large number of universities that try to incorporate CER in their Chemistry Departments. Their research and findings are usually reported at national conferences, such as the Biennial

Conference in Chemical Education conference, the American Chemical Society National Meeting, or Gordon Research Conferences. There are a number of journals that specialize in the dissemination of CER. These include *Journal of Chemical Education* (American Chemical Society), *Chemical Education Research and Practice* (CERP) (Royal Society of Chemistry), and *Education in Chemistry* (Royal Society of Chemistry). There are also a number of educational journals not focused on chemistry, but rather in the broader field of science education. These include the *Journal of Research and Science Teaching* and the *Journal of Science Education and Technology*, which are both published by Wiley, and the *Journal of Science Teaching*, the official publication of the National Association for Research in Science teaching ASTE.

Academic institutions are not the only ones interested in the findings that come out of CER. There are a number of agencies that are willing to fund research involving CER, most notably the National Science Foundation. One of the active open grants that the NSF has towards science education is the Improving Undergraduate STEM Education, or IUSE Grants which seeks to improve the quality of science, technology, engineering, and mathematics (STEM) education (http://www.nsf.gov – under the division of undergraduate education). The purpose of this grant is to fund research leading to dissemination of findings that provide improvement in STEM education for all undergraduate students.

5.3 A Snapshot of the University of Texas at Arlington

UT Arlington is located in Arlington, Texas, which is part of the Dallas-Fort Worth Metroplex. The university has a student population of more than 35,000. Students come from every state as well as 123 countries. Recently, US News and World Report ranked UT Arlington as a university with the one of the top 5 most diverse student populations.

Ten percent of the student population register for classes in the College of science and about 1200 enroll in first semester General Chemistry every year. Demographic data shows that 55% of those students are female, 65% are considered minorities, and 60% are first generation college students. With such a diverse group of students, providing the best education possible for the student population is a decided challenge.

5.4 Institutional Challenges

One of the challenges that the Department of Chemistry and Biochemistry is facing is attrition rate in introductory courses. The attrition rate is reflective of the department's, as well as the unverity's, ability to retain it's students and acts as an important indictor to their commitment to fostering a stable, and more importantly, a stable educational enviorment.

5.4.1 The Issue of Retention

Currently the DFW (D's, F's and Withdrawal) rate for students taking General Chemistry within this department is 45-55%. This DFW rate has the potential to severely impact this University's ability to become a Tier 1 institution of learning. The grades the chemistry students have achieved in the fall 2012 semester are shown in Figure 5-1. In fact, these results have remained consistent over the past 3 years and because of this there has been a call by the Department to find ways to improve retention.

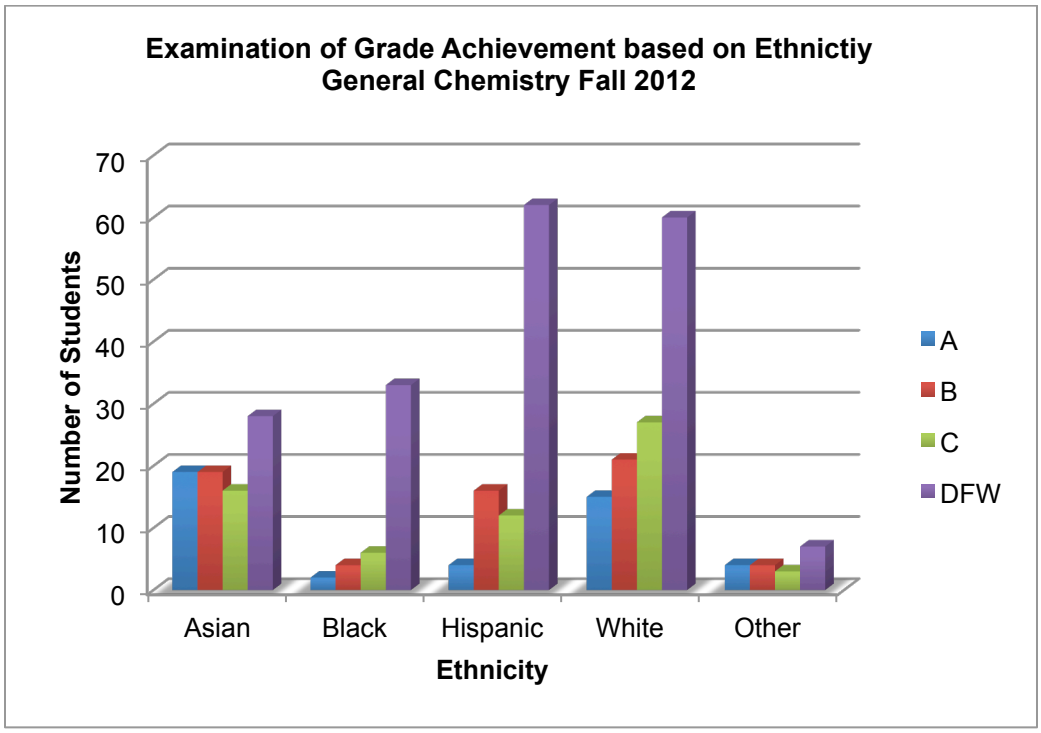


Figure 5-1 Fall 2012 General Chemistry I student final course grades achieved based on ethnicity.

5.4.2 Predictors to Student Success in General Chemistry

Correlations of students' success in general chemistry have been studied extensively by a number of groups. [77-79] One of the predictors of student success is student performance on standardized exams such as the Scholastic Aptitude Test (SAT). Students usually take the SAT in their final year in high school. The test measures, in part, their reading comprehension and mathematical aptitude. A recent study looking at the past 3 years at this University revealed that Math SAT is a strong predictor of passing General Chemistry. Examining the SAT Math scores achieved by the different ethnic groups as they relate to success in chemistry, we have found that ethnicity has basically no effect. The differences found across ethnicities simply appear to reflect different

levels of math proficiency. The better prepared a student is mathematically, the better the student will fare in General Chemistry.

Even so, researchers say that SAT scores should not be used as a sole predictor of student success.[80, 81] Instead, a better predictor may be the rigor of the student's pre-college curriculum. One can argue that using this information and the information found in Figure 5-1, that the Department is not properly identifying and targeting the most "at-risk students" with programming to improve their success. However, quantifying a measure of pre-college academic rigor is very difficult. In the past couple of years, the department has been actively pursuing avenues to better identify at-risk students. This has included larger efforts, such as the evaluation of data provided from a STEM Talent Expansion Program (STEP) grant to U.T. Arlington (a major focus of which is chemistry). More on this will be discussed later. The Department has also tried to put in place an appropriate diagnostic exam to determine whether students are ready to enroll in General Chemistry, or if they should first take a pre-chemistry course. This is also not simple. There are many such diagnostic exam models that can be used for this purpose, and ultimately, one would need to be evaluated for success with the population of students at U.T. Arlington.

The California Chemistry Diagnostic Test whose history[82] is chronicled in an article published by the Journal of Chemical Education has been used by a number of universities. The ACS Division of Chemical Examination Institute also led a discussion into formally including the examination in its exam Distribution list back in 1992. In 2006, the ACS Exams instituted its most recent version of the California Chemistry Diagnostic Test (CCDT). There are a number of institutions, other than the ones located in California, such as the Unversity of Nevada and Winthrop University located South Carolina. Since the CCDT has been used and vetted by a number of insititutions, it can

be used by this university as a diagnostic to determine whether or not students are ready to take General Chemistry. If not those students could be placed into the appropriate class.

5.5 Difficulties Students Experienced in a Typical General Chemistry Course

General Chemistry is considered a gateway course. It is specified in many STEM degree plans as necessary for a student to progress in their chosen major. Knowledge of chemistry is important as it can touch or contribute heavily to a great many other fields. Yet, there are many reasons why students might find chemistry difficult. Chemistry, more specifically general chemistry, is a not so much hard as it is challenging. There are many topics that are covered in general chemistry, including stoichiometry as it relates to the “mole”, writing chemical equations and reactions, manipulating chemical equilibria, and thermodynamics, that may be very conceptual or difficult for a student to visualize and incorporate into their cognitive structure.

CER sheds light on some underlying factors that make chemistry difficult to master. Several studies reported by Johnstone[24-26] have found that students are unable to transition between the three conceptual levels of chemistry - the macroscopic, the sub-microscopic, and the representational level of chemistry, as depicted in Figure 5-2. Often, professors give lectures that are communicated through these cognitive domains, masterfully and simultaneously. At the same time, professors lose sight of the fact that their students are just beginning their chemistry careers, and cannot process the same information the same way. As a result, this can potentially lose a number of novice students due to their inability to translate what the professor is saying.

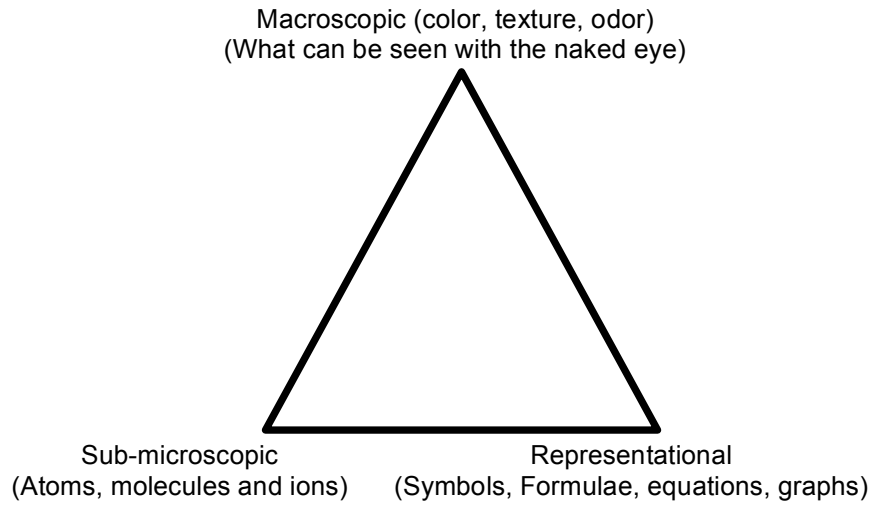


Figure 5-2 The three conceptual levels of chemistry

This is not to say we have bad lectures at this university. It is quite the contrary, according to the numerous positive end of the semester surveys each professor receives. What can be said is that there are argument that can be made that lectures in their current form are not as effective for communicating the topics that are covered in general chemistry. It is our responsibility as scientists and educators to continually improve the way we communicate these topics to our students. We need to be aware of the challenges students face, and this awareness can be gained in large part through CER. And even though we can rely a great deal on what is currently in the literature, ultimately, one has to validate that best practices are also valid for achieving success in our own learning environments, with our own student populations.

5.6 Examples of NSF Funded Programs to Promote Student Retention

5.6.1 Emerging Scholars Program

A number of chemistry education research projects have been created and whose results have been utilized to enhance the learning of chemistry. One well-known example that has been integrated into a number of institutions across the nation are the NSF-funded Emerging Scholars Programs (ESP). Emerging Scholars Program (ESP) central features are a problem-based approach to learning with a focus on high-level work rather than remediation (remediation is handled within the context of challenging work); a welcoming community with shared academic interests; collaborative learning and small group interactions; an underlying goal of increasing diversity by increasing minority student successes.

Philip Uri Treisman, a mathematics professor at the University of Texas Austin and the executive director of he University's Charles A. Dana Center, an organized research unit of the College of Natural Sciences is the person credited for the creation of the first ESP program. The first ESP program was first installed at the University of California Berkeley, during the 1970's. There, Treisman studied the academic and soclal lives of minority groups, ie African Americans, Latinos, and Chinese Americans taking calculus. What he saw was that 60% of African American and Latino who had enrolled in calculus failed. Treisman found that the source of the problem was not due to poor motivation, poor academic preparation, or lack of family support, but more and issue of social and academic isolation.[83-85] This is in contrast to the Chinese American student who first studied by themselves and then studied in group. These students performed better. Ultimately, they benefitted from the sense of community and collaboration. It is with these results that provide the foundation for various Emerging Scholars Programs. Once such program, dubbed the AURAS program, was created at this university. The

goal of the AURAS program is to recruit and retain more students in engineering and science majors by providing support for them in challenging freshman courses.

5.6.2 AURAS

Three years ago, UT Arlington was successful in winning a National Science Foundation STEP grant. Through this support was created a program to support high loss courses in the calculus sequence, primarily through the creation of an Emerging Scholars Program (ESP). The Arlington Undergraduate Research-based Achievement in STEM (AURAS) is a combined initiative between the College of Science and the College of Engineering to implement best practices that will lead to an increase in the number of students obtaining STEM degrees, especially amongst "at-risk" students. AURAS has several objectives. The first is to create pedagogical reform in high loss courses to provide intensive intervention to target students. Second, AURAS attempts to provide authentic learning experiences to increase STEM interest and offer financial support to early-career college students. Lastly, researchers in the program utilize discipline-based research, in our case CER, to evaluate the effectiveness of programming, to investigate other best practices in teaching, to verify results, and to foster long-term change.

AURAS students in the ESP portion of the program are exposed to a content-intensive collaborative learning experience. The theoretical framework behind this experience borrows from the ideas of social constructivism. Social constructivism is the sociological theory of knowledge, wherein groups construct knowledge for one another, by working in small collaborative groups and working on whatever problem the instructor has prepared for them.[86] The role of the instructor is not to teach, which is the purpose of the lecture and the professor, but rather to be a facilitator of learning. As a facilitator, he or she is compelled to find ways to appropriately scaffold the lesson.

Table 5-1 University of Texas at Arlington Composite results fall 2010 - spring 2012

Course		A	B	C	Pass	DFW	Fail	Total
CHEM 1441	ESP	19	23	24	**63%**	39	**37%**	105
CHEM 1441	non-ESP (all sections)	257	308	349	**48%**	971	**52%**	1885
CHEM 1441	target ESP	16	17	20	**65%**	28	**35%**	81
CHEM 1441	target non-ESP	36	52	64	**53%**	134	**47%**	286
CHEM 1465	ESP	23	28	37	**75%**	29	**25%**	117
CHEM 1465	non-ESP (all sections)	38	108	157	**52%**	279	**48%**	582
CHEM 1465	target ESP	22	27	35	**76%**	26	**24%**	110
CHEM1465	target non-ESP	36	97	148	**56%**	219	**44%**	500

Has the AURAS program been successful? The composite results for student achievement in the chemistry classes from the fall 2010 through spring 2012 are shown in Table 5-1. From semester to semester, the program has shown marked improvement and retention of AURAS students (ESP sections) compared to the students that were not enrolled (non-ESP sections). Similar results were also shown in MATH AURAS classrooms. Qualitative feedback also revealed that a large majority of students who took advantage of program resources appreciated the relationships they formed in the AURAS classroom, which in turn helped them form study groups and succeed in the courses.

5.7 Challenges Facing the AURAS Program

There have been a number of challenges facing the program. One is space. Although the university is growing and new buildings are being created, space is still at a premium and even if a space were to exist, would the space be functional and appropriate for a content-intensive collaborative learning program? One particular semester, students experienced the moving classroom. Although printed on their

syllabus, the need to be in different room on different weeks was a real detractor for student enthusiasm and attendance. Also the classrooms were large conference rooms which provided a lot of board availability for board work, but the group tables were large and supported groups up to 8 members. In a group size that large, there will be students that participate and those that do not. As a result some students were able to "hide" within their groups and not fully participate in the activities. Another semester, the classroom was placed in the campus activities center on campus, right next to a ZUMBA room. That was a particularly disastrous semester, grade and retention wise.

Besides the learning space, another challenge is creating activities that are student learning centric rather than instructor centric. In other words, learning activities should place the responsibility of learning on the student rather that providing instruction in the form of a lecture. In a typical supplemental instruction session, a worksheet is created by a peer academic leader (PAL), usually by someone that has taken the class before; maybe some group work is involved and in the end the PAL goes over the worksheet. This is where the focus of the AURAS classroom diverges from a supplemental instruction classroom. Although worksheets are created, they are designed to make use of a guided inquiry process, or learning through investigation. The investigative interactivity of activities is crafted by faculty, graduate students, and PALs with the idea to help better improve a student's metacognitive abilities. Most importantly, all of these worksheets and activities are crafted and backed using current (chemical) education research.

A simple question we investigated was whether or not student attendance, a measure of motivation and participation, had any effect on student outcomes. An examination of th ESP student's performance on exams based attendance was done. The attendance of the ESP students were separated based on >75% or < 75%

attendance (N=29 and 17, respectively). These grades were then compared to grades student achieved in the non-esp class. The students in the ESP section out performed those students in the non-ESP section and more importantly those students that attended ESP sessions greater than 75% of the time further out performed those students who attended less than 75% of the time. What also can be said is that those students that attended less than 75% scored similarly with those students not enrolled in ESP section, essentially negating any positive effect of AURAS classroom support. Similar results were shown in a previous study by a group of students in the ESP section of a General Chemistry for Engineers course. While it is not surprising, it is simply another strong indication that attendance matters. Students who want to do well must first go to class and participate in programs provided, in order to reap the benefits.

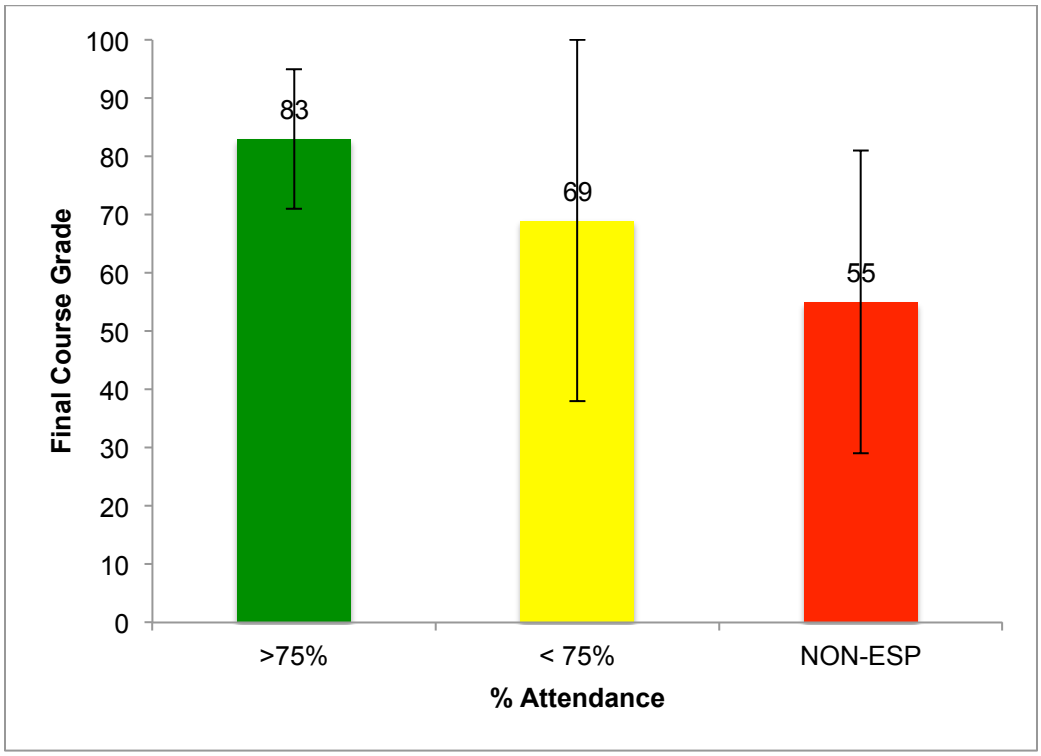


Figure 5-3 Student achievement based on attendance comparing ESP versus non-ESP classes.

Chemical education research at UT Arlington is not confined to that associated with the AURAS program. In fact, growing interest amongst the faculty has prompted some to investigate how they can use CER within their own programs. Recently, some chemistry faculty have been investigating the use of technology to further enhance the student learning experience in the classroom. One example is use of clickers in the classroom to see whether or not student participation in this form increases student outcomes. There has also recently been an examination into the effectiveness of different online homework systems to see if any provided better student gains in performance over another. Although investigations into these areas of study are relatively new at this institution, one can find in the education journals, other universities that have asked similar questions. As we have said, just because a finding is reported in the literature at one university, it does not mean the answers to similar questions will be identical when asked at another university. This supports the notion of having dedicated discipline-based educational researchers at different universities. In this way, best practices can be confirmed viable, or altered as necessary to meet the needs of a particular student population.

Another challenge the program is facing is the expansion to increase the number of AURAS classrooms. In this day and age with dwindling budget sizes, one has to do more with less. Each AURAS classroom has to be renovated in such a way to maximize interactivity amongst the students. Things like furniture have to be installed, which could potentially mean ripping out old outdated desks and blackboards. New technology may need to be installed as well. All these things are not cheap and neither is the labor to carry out remodeling. We are currently in a fortunate situation; as stated previously,

some room renovations to transform traditional classroom space into collaborative learning space are currently being pursued.

However, room and space is not the major cost-limiting factor. The program will continue to need more and trained personnel to support the AURAS classrooms. Currently, there are graduate students leading and facilitating the various sessions. Graduate students are not cheap; not to mention each has one or more undergraduate PALs supporting them. Many of the graduate students are already assigned to teaching duties in undergraduate laboratories. A program like this would cause the department to reallocate and replace graduate teaching assistants in the laboratories with undergraduate teaching assistants, or further resources would be needed to increase the graduate student pool.

This leads to another problem the program would face if it expanded and added additional graduate students. It is imperative to ensure that those leading the sessions are adequately trained to implement best practices towards facilitating, not teaching, the sections for which they are responsible. The AURAS group has recently begun a workshop series to help train new TAs and PALs how to facilitate student collaborative learning experiences. But workshops like these take a graduate student away from research they could potentially be doing. Time is money. There is currently discussion about incorporating some of the already existing programs that the university already has installed. An idea that has been discussed is to utilize the chemistry learning center and its staff to support an increase in the number of undergraduate PALs which would be trained by the existing facilitators, reducing the need for high priced graduate students. There can be many solutions to the problem, but finding the best solution may take some trial and error.

5.8 How Would a Graduate Student Benefit From Having a Chemical Education Research Program?

Through the AURAS program, I have been granted the funding to not only perform inorganic chemistry research, but also to explore ways to improve the quality of teaching I can provide to students through chemical education research. Originally starting as an inorganic chemistry PhD candidate, I did not have the background or tools necessary to begin and develop a chemical education research project. Luckily, I was afforded an opportunity through my interaction with the AURAS program. Even so, U.T. Arlington has recently begun a special program designed to give students like me more opportunities to explore scholarly teaching and to improve student learning. The program is called the Organizational Network for Teaching as Research Advancement and Collaboration (ON-TRAC) (http://grad.uta.edu/ontrac), and it was created as part of joining the nationwide Center for Integration of Research Teaching and Learning (CIRTL) (www.cirtl.net), founded at the University of Wisconsin – Madision.[87-89]

5.8.1 The CIRTL Network

The ON-TRAC program is a local learning community at U.T. Arlington, and part of the larger 22 university CIRTL network. The mission of the network is to develop a national STEM faculty committed to implementing and advancing teaching and learning best practices for diverse undergraduate student audiences as part of their professional careers. The CIRTL network initially started out as an NSF funded research program with principal investigators from several well-known universities. U.T. Arlington competed for a spot and was invited to join the program along with 19 other new university partners in 2011. The CIRTL network was created with the idea of addressing several national issues such as the increasing demand for a scientifically literate workforce especially in

STEM related fields; the increased demand for career-long success in both research and teaching, with different balances in different institutions; and the perception that current undergraduate instruction is neither effective nor motivating. The network is predicated on three simple ideas: 1) Teaching-as-research (or scholarly teaching); 2) creation of learning communities; and 3) learning through diversity. CIRTL is designed to train participants (generally graduate students and post-doctoral fellows who are future faculty) to use research best practices in the classroom and the scientific method to advance teaching and learning. Finally, it is a central tenant of CIRTL that learning is enhanced through diversity since everyone brings an array of experiences and skills that can be shared.

How does the ON-TRAC program benefit a graduate student like myself? In the near term, the program has allowed me to be able to dedicate a major portion of my dissertation to chemistry-related teaching as a research project, which was a challenge in itself. When the project was initially presented to me, I had very little time and resources to come up with a valid research proposal, which would be acceptable to my committee and more importantly, develop the tools needed to quantifiably measure results. My advisors also wanted to make sure that the research question was broad enough to be able to collect a significant amount of data so that future questions could continue to be asked. Another challenge was to make sure that the project was appropriate and acceptable to current faculty. It was important that faculty teaching the courses be fully on board so that they could “sell” the idea to the students who would be taking part in the experiment. Without their support, there would be little motivation for any of the students to complete any given task. Fortunately, we had a very supportive faculty and the proposed question I asked was something they were interested in examining.

5.8.2 Teaching as Research (TAR) Project – The Use of E-Learning Tools to Enhance Learning

An e-learning tool was created to supplement students learning of stoichiometry, a major topic of importance covered in general chemistry. In order for the e-learning tool to be effective, it was decided that it must be compatible with the human learning experience and that the instruction must actively and interactively foster the psychological events necessary for learning. Therefore the e-learning tool was meticulously designed to scaffold the problem solving process to better help the student learn to solve stoichiometry problems. When the project was completed and data analyzed, our initial foray into trying to get the work published was met with rejection. Although this was disappointing, some reviewers were very positive in their feedback stating that the paper was too broad and should be broken up into several different papers. This is the strategy we are now pursuing, and we expect the first of two papers to be accepted into the literature in the very near future.

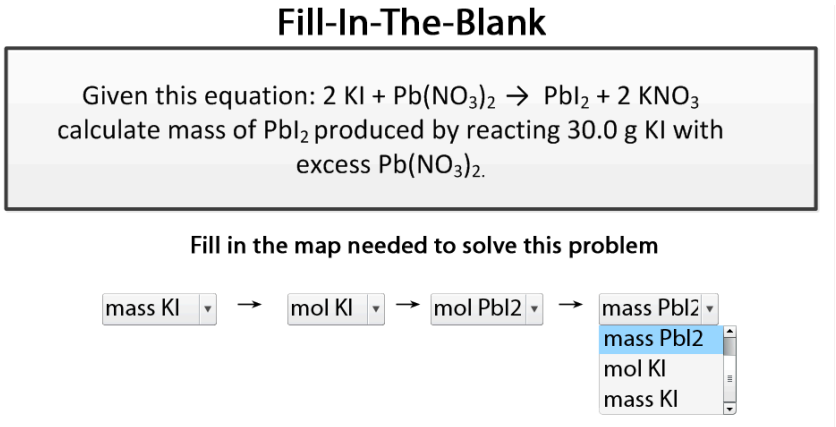


Figure 5-4 Screenshot of the e-learning tool attempting to scaffold the learning process of solving a stoichiometry problem.

As I progress through my chemistry education research project, the courses, lectures, and discussions with other like-minded individuals available through the CIRTL network have given me enough exposure and information to create a framework to practice teaching-as-research. Through CIRTL and AURAS, these programs have helped me become a better and more effective teacher and hopefully, CIRTL has given me the right exposure to have a competitive advantage for obtaining a faculty position when I complete my degree.

5.9 Final Thoughts

As I reflect back on my experiences in the past 5 ½ years here at UTA, I started out expecting to be a full-fledged inorganic research chemist. But sometimes in life we are given opportunities, sometimes subtle and sometimes not so subtle, that can transform us. In this case, I was given a choice - continue on path to becoming an inorganic chemist, at which point the committee had to light a fire under me to get going. Alternatively, I could explore an untested area of chemical education research. Either way they were all in support of me getting my PhD. And to quote line from the movie "The Matrix", I took the red pill to see "how deep the rabbit hole goes". The adventure was full of ups and downs. I've wanted to quit on a number of occasions, but in the end there was a light at the end of the tunnel.

I had been teaching for 12 years before coming to this university. If I had continued on the inorganic chemistry path, I would have considered my teaching good enough. I may have altered a few things here and there, but overall my teaching would have been stagnant. As I write my final thoughts on this, I can say for certain that my teaching is not "good enough". It's better than most of my colleagues, but it is only going to get better given the tools and resources I've been given with the help of my advisors, and most importantly the funding from U.T. Arlington's programs.

Coming full circle as I end my tenure at this university, I will leave behind a mountain of collected demographics and data for any future graduate students to examine and to continue the work I have started. As for the AURAS program and the sections I have thought, I have the sincerest pleasure of witnessing the one of my original AURAS students - formerly an engineering major, but converted to chemistry based on his experiences - become a graduate student at this institution working with two very notable analytical chemists. Coming full circle, he will also be continuing in my footsteps creating, examining, questioning and researching the things we have started at this institution.

Section II

INVESTIGATION INTO THE MECHANISM OF TWO BIOLOGICALLY ACTIVE, RUTHENIUM POLYPYRIDYL COMPLEXES

Chapter 6

Oxygen Dependant Mechanistic Study of a Biologically Redox Active Ruthenium Polypyridal Complex with DNA

6.1 Cancer Statistics

According to the American Cancer Society, cancer is the second leading cause of death in the U.S.. Half of all men and one-third of all women developing some form of cancer during their lifetimes. The most common type of cancer is prostate cancer, with more than 238,000 new cases expected in the United States in 2013. The next most common cancers are breast cancer and lung cancer.

In an annual report to the nation of the status of Cancer between 1975-2009 provided by the American Cancer Society (ACS), the Centers for Disease Control and Prevention (CDC), the National Cancer Institute (NCI), and the North American Association of Central Cancer Registries (NAACCR) showed death rates continuing to decline for all cancers combined for men and women of all major racial and ethnic groups. Rates for both sexes combined decreased by 1.5% per year from 2000 to 2009. Although, the incidence rates have increased for two HPV-associated cancers (oropharynx, anus) and some cancers not associated with HPV (eg, liver, kidney, thyroid)

6.2 What is Cancer?

Cancer is a word that describes a group of diseases that arise from the abnormal reproduction of cells in the body. To fully understand what cancer is, one has to realize it originates from cells. There are trillions of cells in the body, which have many different functions. Normal cells are created, replicate, become “old” and “die”. The replication process helps create new cells to keep the body functioning properly. Sometimes the genetic material within the cells, called deoxyribonucleic acids (DNA) can become

damaged. Most of the time this damage can be repaired by normal cellular functions. Or the cell can undergo apoptosis or “cell death”. But sometimes this damage can affect the normal process of cell growth and division and the cells can replicate at an abnormal rate. This abnormal growth of cells can form tumors. Not all tumors are cancerous. There are two types of tumors and those are benign and malignant. Benign tumors are not cancerous and can often be removed. Malignant tumors are cancerous and can undergo metastasis. This is where the cancerous cells can invade near-by tissue and spread to other parts of the body.

In the event of uncontrolled carcinogenesis, or cancer, treatment usually involves a variety of methods depending on how early it is detected. If the cancer is small and localized, surgery can be an option. But for more advance cancers, a mixture of surgery, radiation and chemotherapy is utilized.

6.3 Chemotherapy

Chemotherapy, or anticancer therapy, is a word often used to describe the drugs used in cancer treatment. Chemotherapy differs from other conventional treatments such as surgery or radiation as it is a systemic treatment. In systemic treatment, the whole body is treated with the drugs, regardless of where the cancer is located. In other words, chemotherapy is indiscriminate and will kill healthy and cancer cells alike.

The drugs used in chemotherapy are sometimes called chemotherapeutic agents. There are many types of chemotherapeutic agents. Chemotherapeutic agents are divided into groups depending on how they affect chemical substances within the cancer cell, which activity or process in the cell the drug interferes, and what part of the cell cycle the drug affects. Below is list of several types of anti-cancer.[90]

I. Alkylating Agents

These anti-cancer agents are distinguishable by their ability to attach an alkyl group to DNA. This damage often prevents the DNA from replicating. (i.e. Nitrogen mustards: mechloroethamin, Nitrosoureas: streptozocin, etc.

II. Anti-Metabolites

Anti-metabolites masquerade as a purine (azathioprine, mercaptopurine) or a pyrimidine,) chemicals and can interference with the enzymes responsible for the replication of DNA. By doing so they stop normal cell development and division.[91] (i.e. 5-fluorouacil, hydroxyurea)

III. Topoisomerase inhibitors

These drugs were designed to interfere with the enzymes topoisomerase (I and II) by blocking the ligation step of the cell cycle. They do this by generating single and double strand nicks along the DNA backbone. These breaks subsequently lead to cell to die. (Topo I inhibitor: irinotecan, Topo II inhibitor: amsacrine)

There is a group of "alkylating-like" agents that don't alkylate the DNA but bind to DNA similarly to alkylating agents, thereby damaging the DNA and interfering with DNA repair. These are the platinum-based chemotherapy drugs. One such drug that is often used into cancer treatment is cisplatin or *cis*-Diamminedichloridoplatinum (CDDP) CDDP is shown in Figure 6-1.

6.4 Cisplatin

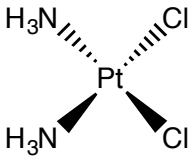


Figure 6-1 Structure of cis-diamminedichloridoplatinum (II), cisplatin™

Michel Peyrone first synthesized CDDP in 1845. Through the work of Barnett Rosenburg, in the 1960's, he found that certain platinum salts, like CDDP, could potentially be used as an anti-cancer agent.[92] To that end, he experimented with CDDP, Pt(IV) cis-diamminetetrachloridoplatinum and other similar metal complexes. What he found was that when he introduced the CDDP and CDTP complexes white mice that had Sarcoma 180 tumors, the complexes demonstrated potent activity, shrinking large solid tumors. More importantly the mice were not dead, but were alive and healthy.[93] As it turned out, CDDP was more effective than CDTP. First clinical trials for CDDP were set in 1972 and finally received FDA approval for human use against testicular and ovarian cancer in 1978.

Ever since it's approval, CDDP has been used for treatment of the lung, head-and-neck, stomach, colon, uterus cancer. CDDP is also being used as a second-line treatment against most other advanced cancers such as cancers of the breast, pancreas, liver, kidney, prostate as well as against glioblastomas, metastatic melanomas, and peritoneal or pleural mesotheliomas.[94] The mechanism, by which CDDP damages DNA, has been extensively investigated, discussed and reviewed by many.[95-100] It is generally agreed that the reaction between cisplatin and the N^7 atoms of the imidazole rings of guanine and adenine base pairs in DNA leads to several different types of adducts.[101] Several adducts are shown in Figure 6-2. Initially, monofunctional DNA adducts are formed, but most of them further react to produce interstrand or intrastrand cross-links, which then block replication and/or prevent transcription.[102]

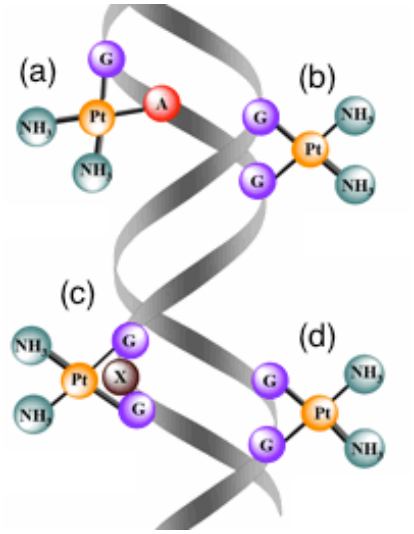


Figure 6-2 DNA adduct formation with cisplatin (a)intrastrand 1,2-d(GpA) cross link 0-25% (b) interstrand d(GpG) cross link (c) intrastrand 1,3-d(GpXpG) cross link (d) intrastrand 1,2-d(GpG) cross link 60-65%

One of the major drawbacks of the use of cisplatin is the development of drug resistant tumors. Some tumors such as colorectal and non-small cell lung cancers have intrinsic resistance to cisplatin, while others such as ovarian or small cell lung cancers develop acquired resistance after the initial treatment.[103] Other severe side effects include renal toxicity, gastrointestinal toxicity (emetogenesis), peripheral neuropathy, asthenia, and ototoxicity. To address these issues, thousand of cisplatin-like complexes have been synthesized an studied. Only two platinum (II) complexes have successful been approved by the FDA and those are carboplatin and oxoplatin shown in Figure 6-3. Carboplatin, broadly speaking, is just as effective as cisplatin, but has a more acceptable side-effect profile. The FDA is currently considering satraplatin for approval and picoplatin is in phase III trials.[104]

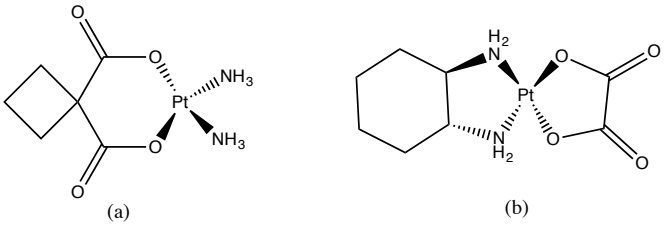


Figure 6-3 Structures of (a) Carboplatin and (b) Oxoplatin

6.5 Metal Based Anti-Cancer Agents

To this day, cisplatin, carboplatin and oxoplatin are currently the gold standard when it comes to chemotherapeutic treatments. A cancer patient is more than likely going to be exposed to one of these three cancer drugs as part of their regiment when receiving chemotherapy. Unfortunately, these complexes are only effective against a limited range of cancers and some tumors are just inherently resistant to it. Therefore there is wide interest to looking to other metals, especially transition metals that can be the "next" metal-based anti cancer drug. When developing metal-based drugs, there are certain aspects developers should be aware of. One of the reasons why using transition metals are extremely attractive is because each metal can exist in a variety of oxidations states depending on what it is coordinated with. Also, the coordination sphere for each metal is highly diverse, thereby potentially creating a large library of unique compounds. Unfortunately when using metals especially heavy metals, one has to keep in mind the acute toxicity that comes along with their use. Thus bio-distribution and clearance of the metal complexes as well as its pharmacological specificity are to be considered.[105]

6.6 Ruthenium Based Anti-Cancer Drugs

One of the transition metals that has gained a lot of notoriety in the field of anti-cancer research recently is ruthenium. The interest is due to two ruthenium-based drugs

that are currently in clinical trials. Those two ruthenium complexes are NAMI-A and KP1019.

Before the discussion of these two complexes, it must be asked first, “Why ruthenium?” Ruthenium was look at closely because of several factors. Ruthenium can easily reach several oxidation states (II, III, and IV) under physiological conditions.[106] Also, many ruthenium complexes are very stable complexes and undergo very slow ligand exchange rates, especially in aqueous media. The exchange rates of ruthenium complexes are very similar to Pt(II) complexes like, CDDP. The ligand exchange rates for several metals are shown in Figure 6-4**.** Unlike the 4-coordinate platinum drugs, ruthenium complexes can form octahedral geometry, which allows it to have even greater ligand diversity.

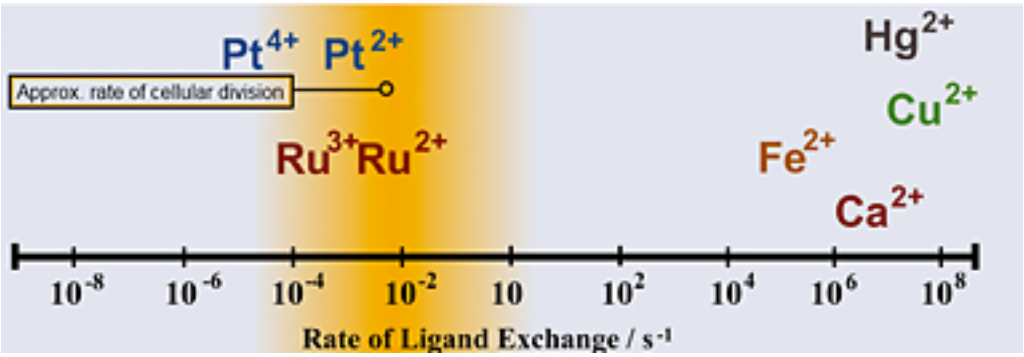
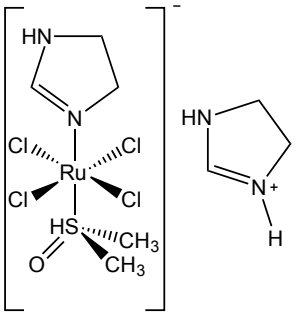


Figure 6-4 The ligand exchange rates of platinum group metals are considerably slower than those of other metals[107]

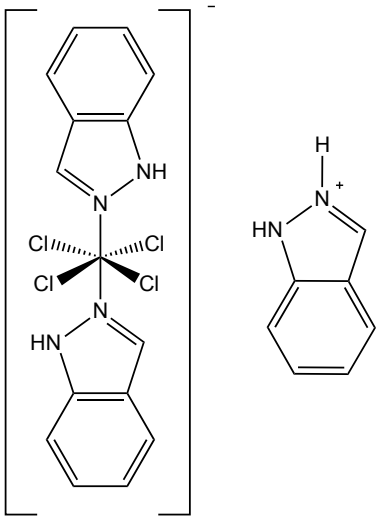
As mentioned earlier, the two ruthenium complexes that have made it successfully to clinical trials are ImH[*trans*-Ru(Cl)$_4$(DMSO)Im], NAMI-A, and KP1019 (indazolium trans-[tetrachlorobis(1H-indazole)ruthenate(III), sturctures for these complexes are shown in Figure. NAMI is an acronym for "New Anti-tumour Metastasis Inhibitor", while the -A suffix indicates that this is the first of a potential series. NAMI-A

has shown to selectively reduce the formation and growth of lung metastases of malignant tumors such as mammary carcinoma, Lewis lung carcinoma (LLC) and adenocarcinoma. In a study comparing the effects of NAMI-A and CDDP, patients that were exposed to cisplatin experience reduced body weight gain and increased spleen weight and greater toxicity towards liver, kidney and lung.[108] Overall, NAMI-A was less toxic and has less severe side effects. Even though the mechanism of action has been extensively investigated by Sava et al. it has yet to be fully elucidated.[109, 110]

KP1019, belongs to a set of "Keppler-type" complexes synthesized by Keppler et al. KP1019 is an anionic ruthenium (III) complex with indazole ligands. KP1019 was reported to be effective in inhibiting platinum resistant colorectal carcinoma's in rats.[111] Recently, work done by Singh found that KP1019 targets histone proteins, which has important consequences for DNA damage response and epigenetics.[112]



(a) NAMI-A; ImH[trans-$RuCl_4$(DMSO)Im]



(b) KP1019;
indazolium trans-[tetrachlorobis(1H-indazole)ruthenate(III)]

Figure 6-5 Structures of (a) NAMI-A; ImH[trans-$RuCl_4$(DMSO)Im] (Im=Imidazole; DMSO: Dimethylsulfoxide) and (b) InH trans[terachlorobis(1H-In) rutheniate (III) (In = Indazole)

6.7 Ruthenium Polypyridyl Complexes as Potential Anticancer Agents.

Another set of ruthenium complexes that set the stage for much of the work done by the MacDonnell group are a class of ruthenium (II) cationic complexes known as ruthenium polypyridyl complexes (RPC's). These complexes usually involve multidentate polypyridyl ligands, such as 2',2'-bypyridine, 1,10-phenanthroline, etc. bound to a ruthenium center. Two structures of some well-known RPC's are shown in Figure 6-6. These complexes, like most ruthenium complexes, are chemically inert, under physiological conditions, have well-developed substitution chemistry, and possess many attractive photo physical properties. [113]

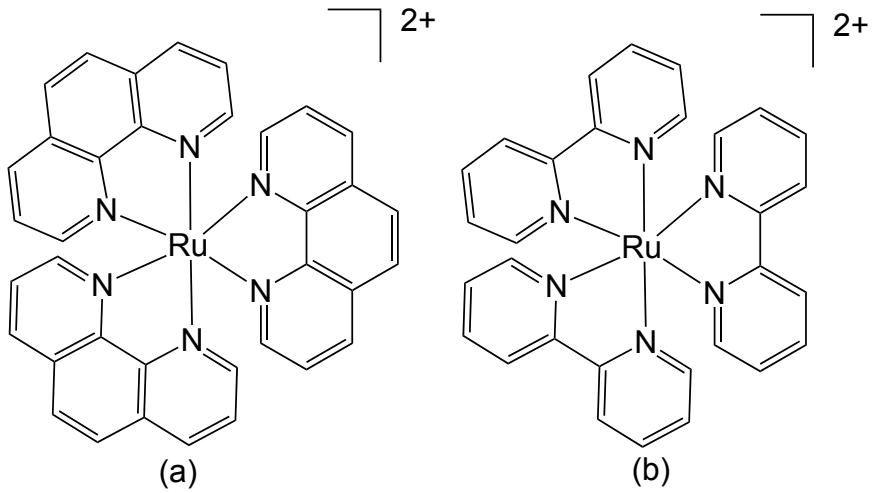


Figure 6-6 Structures of $[Ru(phen)_3]^{2+}$ and $[Ru(bpy)_3]^{2+}$ (phen = 1,10 phenanthroline; bpy = 2',2' bypyridine)

6.8 Historical Context: Dwyer Work with RPC's

Francis Dwyer did some of the earliest work with RPC's and investigating their biological activity. Two cationic RPC's Dwyer worked with are $[Ru^{II}(phen)_3](ClO_4)_2$ and $[Ru^{II(}byp)_3](ClO_4)_2$. In the 1950's, Dwyer showed that these RPC's had bacteriostatic and

anti-viral activities.[114] More importantly, he found in that these complexes were very toxic to mice at very low doses. Some of the toxicity results are shown in Figure 6-7. When Dwyer injected mice with five times the maximum tolerable dose, the mice died within 15 minutes. Prior to the death the mice experienced labored breathing and seizures. Death appeared to be cause by respiratory failure. Following this experiment Dwyer began examining the complexes mechanism of action. He found that the RPC's had neuromuscular blocking activity on rat diaphragm nerve-muscle at the nerve junction.[115] This suggested that the complexes interacted with the acetylcholine and acted as a potent acetylcholinesterase inhibitor. Examination of the enantiopure complexes revealed that the delta form of the complexes is 1.5-2 time more potent than their corresponding lambda forms. Because of the overall toxicity of these complexes, it was believed that these complexes had very limited biological applications.

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Racemates	LD_{50} mg/kg
$[Ru(bpy)_3]^{2+}$	18
$[Ru(phen)_3]^{2+}$	27

Enantiomer	Toxic Dose mg Ru complex/kg mouse	
	Δ	Λ
$[Ru(phen)_3]^{2+}$	9.2	18.2

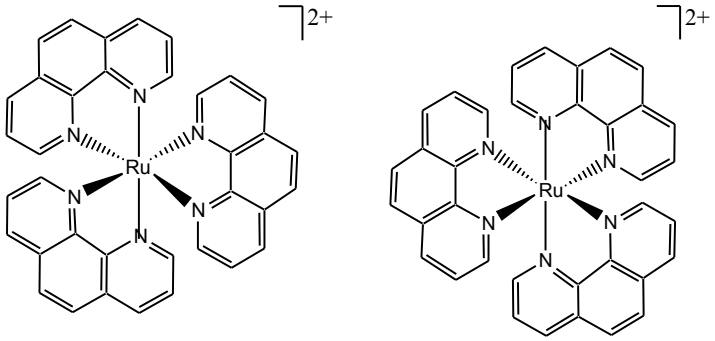
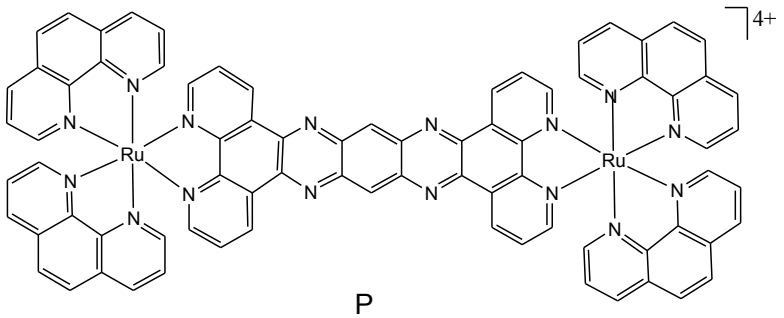


Figure 6-7 The effects of chirality of two ruthenium polypyridyl complex on toxicity in mice.

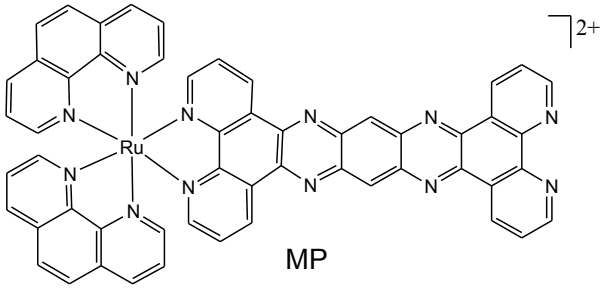
Dwyer performed another experiment examining the metabolic fate of radiolabelled $[^{106}Ru(phen_3)](ClO_4)_2$ within mice.[116] Like in his previous experiment, mice were given an intraperitoneal injection containing the radio labeled complex. Dwyer found that a majority of the complexes remained intact and was not processed by the body. Instead, higher concentrations of the complex were excreted through urine. Autopsy on the mice also revealed the complexes had primarily accumulated in the kidney and liver and very little amount were found in other tissues.

In 1965, Schulman and Dwyer reported on two RPC's, tris(3,4,7,8-tetramethyl-1,10-phenanthroline) ruthenium(II) dichloride and acetylacetonatobis(3,4,7,8-tetramethyl-1,10-phenanthroline) ruthenium(II) dichloride and their effects on Landschuz ascite tumor. They found that these complexes inhibited the growth of the Landshuz ascite tumor. Examination of the tumors on mice that were treated with tris(3,4,7,8-tetramethyl-1,10-phenanthroline) ruthenium(II) dichloride showed that the tumors grew to a greater extent compared to the tumors on the mice that were treated acetylacetonatobis(3,4,7,8-tetramethyl-1,10-phenanthroline) ruthenium(II) dichloride.[117] These results have given inspiration for the current studies being done in the MacDonnell Lab with two RPC's that have been synthesized by the group. Those complexes are shown in Figure 6-9.

6.9 Previous Research Work in the MacDonnell Group



P



MP

Figure 6-8 Structure of $[(phen)_2Ru(tatpp)Ru(phen)_2]^{4+}$ (P^{4+}), and $[(phen)_2Ru(tatpp)]^{2+}$ (MP^{2+}).

The MacDonnell group synthesized two RPC's, which has shown to have some interesting biological properties. Those complexes are the dinuclear ruthenium (II) cationic polypyridyl complex $[(phen)_2Ru(tatpp)Ru(phen)_2]^{4+}$ $[P^{4+}]$ (where tatpp = 9,11,20,22-tetraazatetrapyrido[3,2-a:2',3'-c:3'',2''-l:2''',3'''-n) and the corresponding mononuclear ruthenium(II) cationic complex $[(phen)_2Ru(tatpp)]^{2+}$ $[MP^{2+}]$. A mice toxicity study was completed by by Yadev. The results for the cytotoxicity and animal toxicity study are shown in Figure. 6-9. The experiment showed that $[P^{4+}]$ has relatively high cytotoxicity against NSCLC cells H538 and low animal toxicity compared to $Ru^{II}(phen)_3$ and $[Ru(phen)_2tpphzRu(phen)_2]^{4+}$ where tpphz is tetrapyrido[3,2-a:2',3'-c:3' ',2' '-h:2' ',3']phenazine.

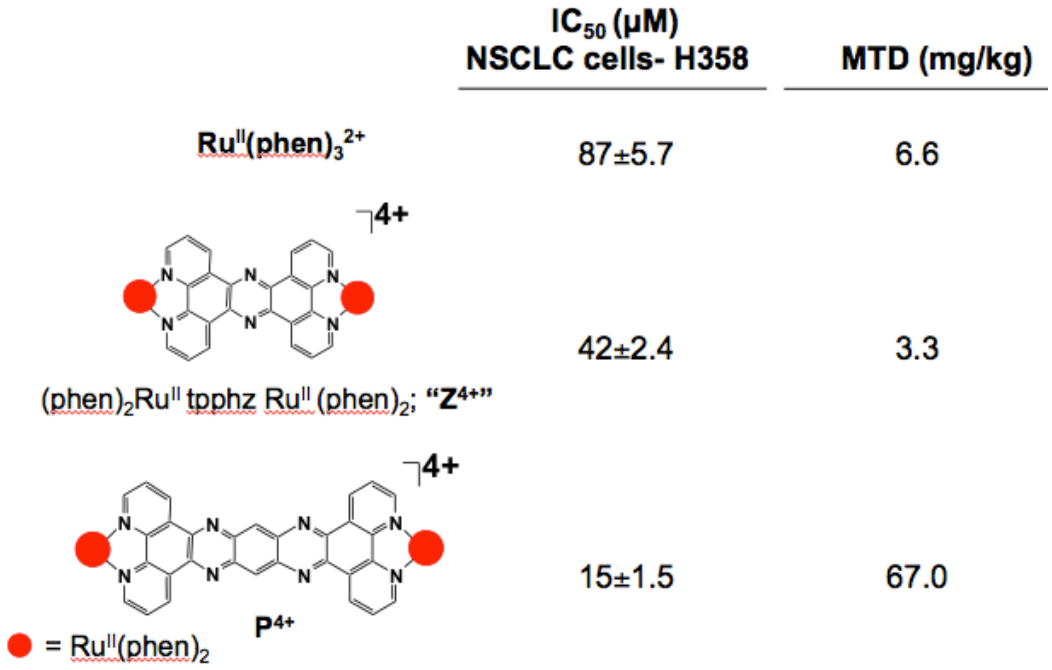


Figure 6-9 Toxicity screen of some ruthenium polypyridyl complexes

6.9.1 Tumor Regression Study

Yadev also performed a tumor regression study, where 9 mice were injected with NSCLC-H358 lung cancer cells subcutaneously and tumors were allowed to grow to a size of 35mm[118] approximately 14 days. 3 mice served as the control, 3 mice were treated with P^{4+} and 3 were treated with MP^{2+}. The control group was given 200 uL of Tris Buffer 2 days per week; the other mice were 1mg of each complex dissolved in 200 ul of Tris Buffer 2 days per week. The duration of the experiment was 21 days and total dosage per rat was 6 mg. These results of the experiment are shown in Figure 6-10.

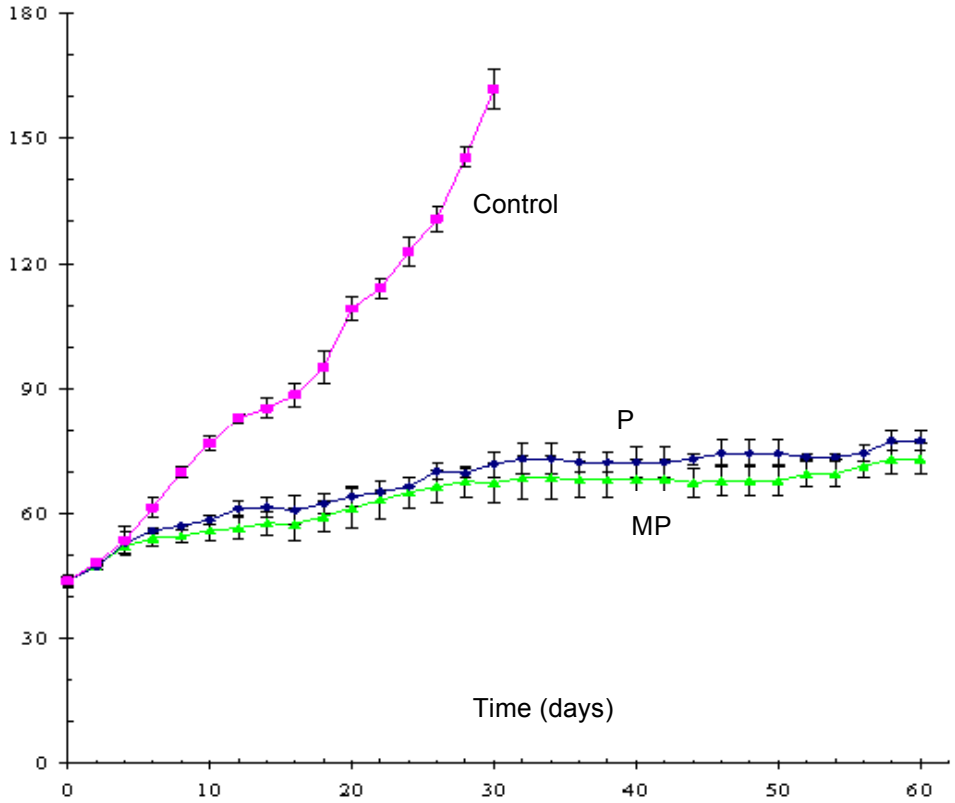


Figure 6-10 Change in a tumor volume after injecting NSCLC-H358 lung cancer cells

The tumors in the rats in the control group grew out of control and the rats died 30 days into the experiment. The rats that were treated with complexes lived.

Additionally, the tumors did not grow to an appreciable size over the course of the experiment. The treated mice were also alive at the end of the experiment and were summarily sacrificed. These results laid the initial motivation for detailing the mechanism [P^{4+}] and [MP^{2+}] work. In determining a suitable mechanism for how these complexes inhibit tumor growth, certain assumptions have to be made. The first assumption is that the Ru(II) complexes interact directly with the DNA

.

6.9.2 Ruthenium Polypyridyl Complexes Binding with DNA

The biological activities of numerous RPC's have been reported in literature and been the subject of many reviews.[119] it is generally accepted the RPC's reversibly bind to DNA. RPC's can interact with DNA through electrostatic interactions, intercalation, groove-binding and binding to non-canonical DNA. Three of the four binding modes are shown in Figure 6-11.

The most simple ruthenium polypyridyl complex, $[Ru(byp)_3]^{2+}$, predominantly binds with DNA through electrostatics and has a relatively low binding affinity. As the planarity of one of the ligands is extened (ie. $[Ru(phen)_2dppz]^{2+}$: dppz = dipyrido[3,2-a:2',3'-c]phenazine) these Ru(II) complexes bind not only through electrostatics but also through intercalation. Intercalation occurs when the planar aromatic ligand is inserted between adjacent base pair located in DNA.

In 1990, Barton and Sauvage reported the binding constants of $[(byp)_2Rudppz]^{2+}$ and $[(phen)_2Rudppz]^{2+}$ with DNA (binding constant Kb ~ 10^6).[120, 121] Examination of the enantiopure versions of these complexes revealed that the binding constants of Δ-$[(phen)_2Ru(dppz)]^{2+}$ was 1.5-2 times ($3.2x10^6$ M^{-1}) stronger than Λ-$[(phen)_2Ru(dppz)]^{2+}$ [122] In reference to the complex [P^{4+}], work done by Erikkson revealed that the

enantiopure complexes of complex Δ Δ **–** and Λ Λ **P** binds with DNA by intercalation[123]. Rajput work in 2006 reports that the binding constant for complex P is ~ 1.1 x 10^8 M^{-1}.[124]

One of the more interesting results of these (metallo)intercallators binding with DNA is a phenomenon, more commonly known as the DNA "light switch" effect. Basically these complexes become luminescent when bound to DNA. Because of this, many have used RPC's as probe when examining the structure of DNA.

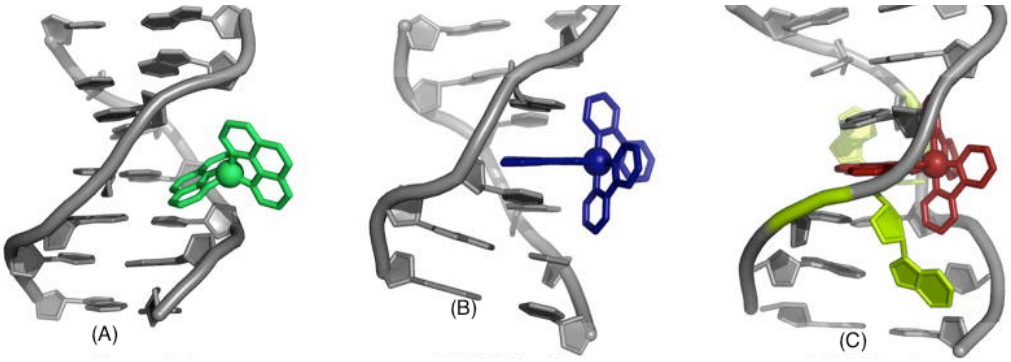


Figure 6-11 The three binding modes of metal complexes with DNA: (a) groove binding, (b) intercalation, and (c) insertion.[125]

6.9.3 Ruthenium Polypyridyl Complexes: Mechanistic Pathways for Causing DNA Damage.

Given that complex P^{4+} and MP^{2+} binds with DNA, it can be assumed that these two complexes interact with the DNA itself. There are two common mechanisms in which metal complexes can cause DNA damage. Those two mechanisms are hydrolytic cleavage and oxidative cleavage. Since P^{4+} and MP^{2+} are both cationic species, they can electrostatically interact with the negatively charged backbone of DNA. Through this interaction P^{4+} and MP^{2+} could potentially cause hydrolytic lesions. Deshpande reported of a ruthenium polypyridyl complex, $[Ru(bpy)_2(BPG)]Cl_2$ (where BPG = bipyridine-glycoluril) that has the ability to hydrolytically cleave DNA.[126] Although, most metal

complexes, including RPC's undergo damage to DNA through an oxidative cleavage pathway. This pathway often exhibits the creation of a strong oxidant, usually a ROS or reactive oxygen species such as, OH•, O_2^-•, HOO•, H_2O_2. These ROS interact with DNA through Fenton-like chemistry, which describes the abstraction of an H atom from the deoxyribose sugar or base moiety. With that, this study will focus on the oxidative pathway.

6.9.4 DNA Cleavage Assay

A simple DNA cleavage assay is performed to quickly screen whether or not the RPC's can cause damage the DNA. Often plasmid DNA (pUC18, pBR322) is used. There are primarily 3 different topological conformations of pUC18. Those conformations are: Super coiled DNA (form I), circular DNA (form II) and linear DNA (form III). These forms can be separated by agarose gel electrophoresis and visualized under UV light after staining the gel with ethidium bromide as shown in Figure 6-12.

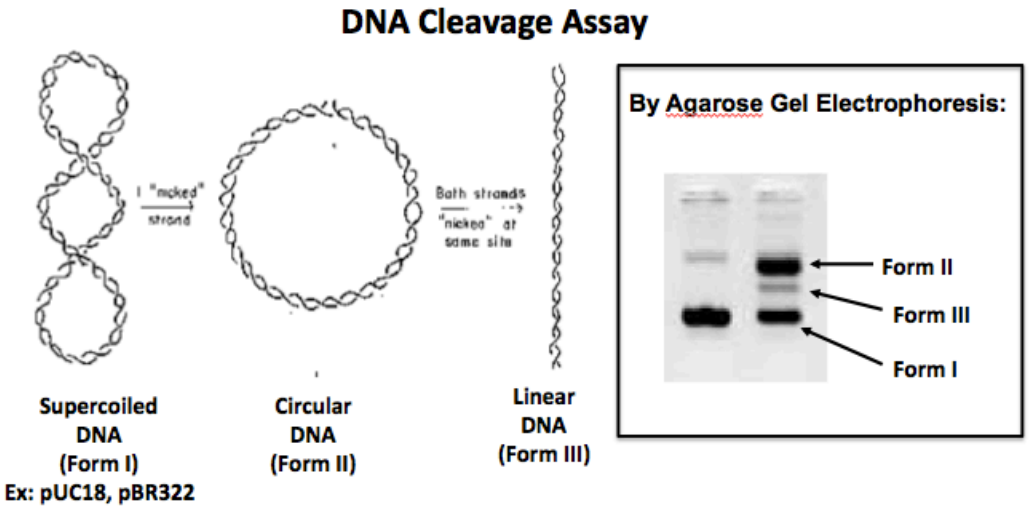


Figure 6-12 Topological conformation (pUC18, pBR322): Super coiled DNA (form I), circular DNA (form II) and linear DNA (form III)

6.9.5 DNA Cleavage Study in the Presence of Several Ruthenium Polypyridyl Complexes

Janaratne performed a cleavage assay using several RPC's. She reacted the following complexes, $[(phen)_2Ru(tpphz)Ru(phen)_2]^{4+}$ (Z^{4+}), $[(phen)_2Ru(tatpp)Ru(phen)_2]^{4+}$ (P^{4+}), $[(phen)_2Ru(tatpq)Ru(phen)_2]^{4+}$ (Q^{4+}), $(phen)_2Ru(dppz)^{2+}$, $Ru(phen)_3^{2+}$ under reducing conditions, in the presence of glutathione (GSH). The results of the cleavage assay are shown in Figure 6-13. She found that complex [P^{4+}] was the most active in being able to cleave DNA.

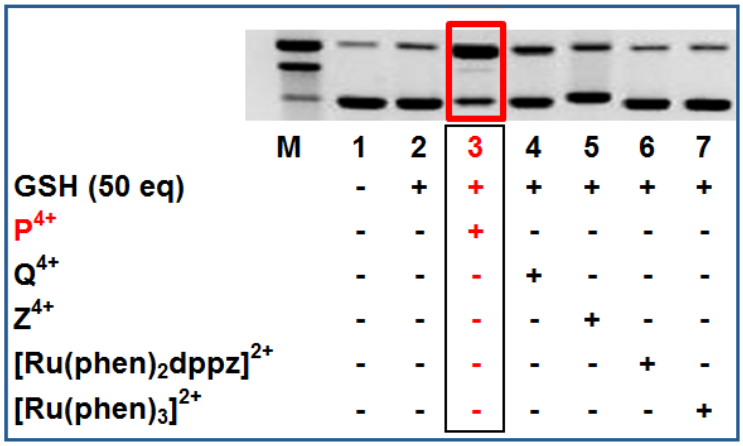


Figure 6-13 DNA cleavage assay of several RPC's in the presence of GSH.

6.9.6 Effect of Oxygen on DNA in the Presence of Several RPC's

Since the experiment was done in aerobic conditions, It was initially assumed that the DNA damage was caused by ROS. Janaratne did a follow up study to confirm if the DNA damaged cause by complex [P^{4+}] was related to the presence of oxygen in situ. The experiment was done under both aerobic and anaerobic cleavage using Fe-Blm, iron(II)-bleomycin, as a control. Anaerobic conditions were achieved by degassing the

solutions using the freeze-pump thaw method. The reaction was done in a glove box under N_2 atmosphere. Fe-Blm is a known oxygen dependent DNA cleaving agent. The experimental results are shown in Figure 6-13. It turns out that the damage caused by complex [P^{4+}] was enhanced under anaerobic conditions as opposed to Fe-Blm, whose DNA cleavage activity is diminished. A similar experiment was performed by Yadav, using complex [MP^{2+}], yielding similar results.[127]

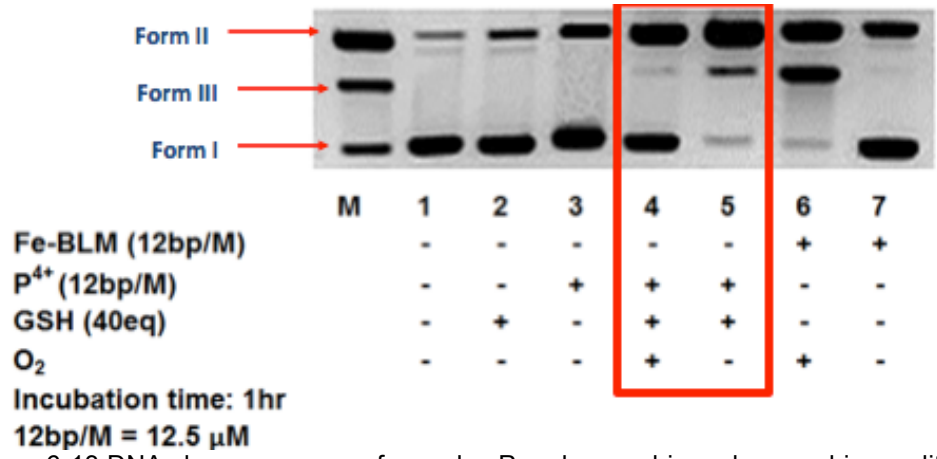


Figure 6-13 DNA cleavage assay of complex P under aerobic and anaerobic conditions

These results reveal that both complexes P^{4+} and MP^{2+} cleaves DNA under aerobic conditions and anaerobic conditions, but is enhanced under anaerobic conditions. Also, the reaction must take place under reducing conditions (in the presence of GSH) in order for DNA cleavage to occur. Because of these results several questions needed to be investigated. Those are:

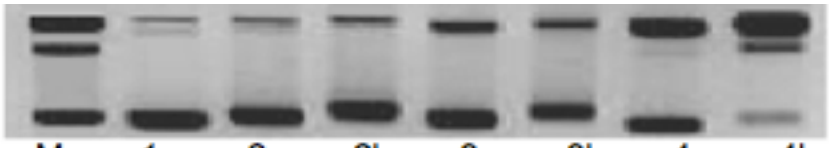
I. What species is cleaving the DNA? Is it some form of ROS species or is it some other species?

II. What exactly is the role of oxygen, what is a plausible mechanism, which takes into account our oxygen observations?

6.10 Identification of the Active Species Responsible for Damaging DNA

It has been established that complexes [P^{4+}] and [MP^{2+}] react with GSH and in the presence of DNA cause DNA damage. The species that is produced when both complexes react with GSH is the doubly protonated species $[(phen)_2Ru(H_2tatpp)Ru(phen)_2]^{4+}$ [H_2P^{4+}] and $[(phen)_2Ru(H_2tatpp)]^{2+}$ [H_2MP^{2+}]. A quick review of the literature does not reveal any evidence of any other reduced RPC's similar to these having the ability to cause damage to DNA. It was further hypothesized that possibly one of the other redox states complex between [P^{4+}] and [H_2P^{4+}], maybe a radical species, is responsible for doing the DNA damage.

The redox states of complex [P^{4+}] has been extensively student and has been show to have several oxidations states between [P^{4+}] and [H_2P^{4+}]. Spectroelectrochemistry done by Janaratne[128] revealed of one possible redox state of the complex, [P^{3+}], which is a radical, maybe the culprit responsible for doing the DNA damage. A DNA cleavage assay was performed using the complexes [P^{4+}], [P^{3+}], and [H_2P^{4+}], under anaerobic conditions, and the results are shown in Figure 6-15.



	M	1	2	2'	3	3'	4	4'
P^{4+}		-	+	+	-	-	-	-
P^{3+}		-	-	-	+	+	-	-
H_2P^{4+}		-	-	-	-	-	+	+

Figure 6-14 DNA cleavage assay using P_{4+}, P^{3+}, H_2P^{4+}

The results showed that the most active species casing the damage is [H_2P^{4+}] and the least active is [P^{4+}]. The radical complex [P^{3+}] was barely active at all. pKa study

also done by Janaratne, revealed that the major species present under physiological conditions are [HP^{3+}] and [H_2P^{4+}]. Therefore, the only other radical species present that can possibly be responsible for the damage [$HP\bullet^{4+}$]. Unfortunately, this species quickly undergoes a disproportionation reaction to produce [P^{4+}] and [H_2P^{4+}].

Yadev[128] completed a DNA cleavage experiment using radical scavengers to determine if a radical was present during the reaction between the complex and DNA. The results revealed that DNA cleavage activity was quenched in the presences of TEMPO, a known carbon radical scavenger. The results also showed that DNA cleavage continued in the presence of DMSO. This evidence strongly suggests that a ROS is not responsible for the DNA damage, but an organic radical is.

Yadev[127] performed a follow up EPR experiment to determine if indeed a radical exist. The experiment revealed that the complex H_2P^{4+} in solution by itself did not show an EPR signal. But when DNA was incubated with complex [H_2P^{4+}], a g signal characteristic to carbon-based radical was observed. The same EPR experiment was conducted with complex H_2MP^{2+} and showed similar results.

With these result it was further hypothesized that the redox state of [$HP\bullet^{3+}$] and [$HMP\bullet^{1+}$], which are both radicals, are accessible, when bound and intercalated into DNA in situ, and exist long enough to do damage. It was further hypothesized that in order to access these redox states, oxygen has to be present but in limiting amounts. This means even though in previous experiments, the solutions were degassed, that process did not completely remove all the oxygen.

6.11 The Proposed Mechanism for Complex H_2MP^{2+}

Given the results from previous experiments, the following mechanism is postulated: (DNAH is written explicitly with a hydrogen for clarity purposes.)

H_2MP^{2+} + DNAH → H_2MP^{2+} — DNAH (rxn 1)

H_2MP^{2+}—DNAH + ¼ O_2 → $HMP^{+\bullet}$—DNAH+ ½ H_2O (rxn2)

$HMP^{+\bullet}$—DNAH —DNAH → H_2MP^{2+}— $DNA^{\bullet}$ (rxn 3)

H_2MP^{2+} — $DNA^{\bullet}$ → H_2MP^{2+} + $DNA^{\bullet}$ (rxn 4)

$DNA^{\bullet}$ → DNA cleavage products (rxn 5)

A similar mechanism can be written for complex H_2P^{4+}

The intercalation of [H_2MP^{2+}] with DNA is shown in reaction 1. Once H_2MP^{2+} is intercalated, [H_2MP^{2+}] is oxidized to a radical species, in the presence of limiting oxygen. That radical species we hypothesize is $HMP^{+\bullet}$. Since the complex is bound to DNA, is unable to undergo disproportion. Reaction 3-5 shows the subsequent fate $HMP^{+\bullet}$, causing oxidative DNA cleavage. In order for this mechanism to be plausible, there has to be some oxygen present in the situ. This would mean that previous assumption of an anaerobic system is incorrect. If that is so, then how much oxygen is in the system?

6.12 Oxygen Dependent DNA Cleavage Study using [H_2MP^{2+}]

To determine the extent of DNA cleavage caused [H_2MP^{2+}], as a function of oxygen concentration, an experiment was proposed to use an enzyme that would “scrub” a solution of oxygen. That enzyme is 3.4-protocatechuate dioxygenase. The enzyme catalyzes the reaction between oxygen and 3,4-dihydoxybenzoate to 3-carboxy-cis,cis mucanoate. There would be two possible outcomes from this experiment, either the DNA cleavage would remain unchanged and the mechanism as written is incorrect or DNA cleavage is attenuated, meaning the cleavage is accentuated by the presence of oxygen.

6.12.1 Experimental

All reagents were purchased commercially and used without purification unless noted. Millipore water was used to prepare all buffers. Supercoiled plasmid pUC18 DNA was purchased from Bayou Biolabs (New England). agarose, ethidium bromide, glutathione (GSH), TRIZMA base, 3,4 dihydroxybeonzoate ethyl ester (DHB) and protocatechuate 3, 4-dioxygenase (PCD) were purchased from Sigma and used without any further purification. The complexes $[P^{4+}]Cl_4$ and $[MP^{2+}]Cl_2$ were synthesized as described in the literature.[129]

6.12.2 Instrumentation

Plasmid cleavage products were analyzed using an AlphaImage™ 2200 gel analysis system and quantitated using a UVPGDS 8000 complete gel documentation and analysis system. Oxygen concentrations were measured using an oxygen sensitive electrode and analyzed using the Oxygraph system.

6.12.3 DNA Cleavage Assay using 3,4 Protocatechuate Dioxygenase and H_2MP^{2+}

The DNA cleavage experiment was carried out in a total volume of 40 **µ**L of Tris-Cl buffer (pH 7) containing 4 **µ**L of supercoiled pUC18 DNA (1 **µ**g/1 **µ**L, 0.154 mM DNA base pairs). The concentration of and nature of the complex added are given in Figure 6-15 as well as the conditions and time of reaction. The reaction was quenched by addition of 3-µL sodium acetate at pH 6.2 and 80 **µ**L ethanol, which precipitated the DNA. The sample was allowed to sit for overnight at –20°C to complete the precipitation. The DNA was pelleted by centrifugation at 13000 rpm for 20 minutes. The supernatant was removed by decanting and the samples air-dried for 30 minutes before the DNA was suspended in a mixture of 80 **µ**L deionized water, 40 **µ**L of buffer I (40 mM Tris-Cl, 1 mM

EDTA at pH 8.0) and 8 **μ**L of a loading buffer (18% Ficol, 2 % glycerol with 0.1% w/v bromophenol blue). Eight microliters of this solution was then loaded into a well on a 1 % agarose gel (horizontal slab configuration) immersed in TAE buffer (40 mM Tris-acetate, 1 mM EDTA, pH 8). The gel was made previously by dissolving 1 g agarose into 100 mL of hot TAE buffer contained ethidium bromide (0.2 mM). The gel was electrophoresed at 80 V for 40 minutes. The DNA products were visualized by irradiation with ultra-violet light and the image recorded using AlphaImage™ 2200 gel analysis system.

Anaerobic conditions was achieved by the degassing of all the reagent solutions including the DNA stock, which was done using three freeze-pump-thaw cycles under N_2. The degassed reagents were taken into a N_2 glove box and all the solutions were prepared inside it to minimize further contamination with oxygen. The assays were completed in the glove box and the reactions quenched by precipitating the DNA using 2 **μ**L of degassed sodium acetate at pH 5.2 and 80 **μ**L degassed ethanol under N_2 inside the glove box. The oxygen concentrations for each prepared solution was measured using an oxygen sensitive electrode. Aerobic measurements were done on the bench top and anaerobic measurements were conducted in glove box.

	Lane 1	Lane 2	Lane 3	Lane 4	Lane 5
DNA:	+	+	+	+	+
H_2MP^{2+}: 12.8 bp/M	-	+	+	+	+
DHB: 30.6 μM	-	-	-	+	+
Enyzme:	-	-	-	-	+
O_2 (conc μM):	**4.0**	**200.0**	**4.0**	**4 .0**	**0.0**

Incubation Time: 2hr
12.8 bp/M = 12.8 μM

Figure 6-15 1% Agarose gel of super coiled pUC18 DNA (0.154 mM) in the presence of H_2MP^{2+}. All incubations were performed with an incubation time of 2 h at 25 °C with Tris-Cl buffer at pH=7. Lane 1, DNA control; lane 2, DNA + H_2MP^{2+} (0.0308 mM) on the bench; lane 3, DNA + H_2MP^{2+} (0.0308 mM) in the glove box under N_2, lane 4, DNA + H_2MP^{2+} (0.0308 mM) + DHB (0.0308 mM) in the glove box under N_2; lane 5, DNA + H_2MP^{2+} (0.0308 mM) + DHB + PCD.

To determine the amount of DNA cleavage was present the intensities (*I*) of each DNA band were quantified using UVPGDS 8000 complete gel documentation and analysis system. The percentages of Form II and Form III were calculated using equations:

$$\%\ Cleavage\ Form\ II = \frac{I^*_{Form\ II}}{I_{Form\ I}+I^*_{Form\ II}+I_{Form\ III}} * 100\% \qquad \text{(eq a)}$$

$$\%\ Cleavage\ Form\ III = \frac{I_{Form\ III}}{I_{Form\ I}+I^*_{Form\ II}+I_{Form\ III}} * 100\% \qquad \text{(eq b)}$$

$$I^*_{Form\ II} = I_{Form\ II} - I^{Control}_{Form\ II} \qquad \text{(eq c)}$$

The stock solution of DNA usually contains a spurious amount of Form II. That initial background intensity $I_{Form\ II}^{Control}$ was subtracted from each proceeding lane as shown in eq c. The average intensities for Form II and Form III were measured from 5 experiments. The means were calculated, along with standard error, and plotted results is shown in Figure 6-16.

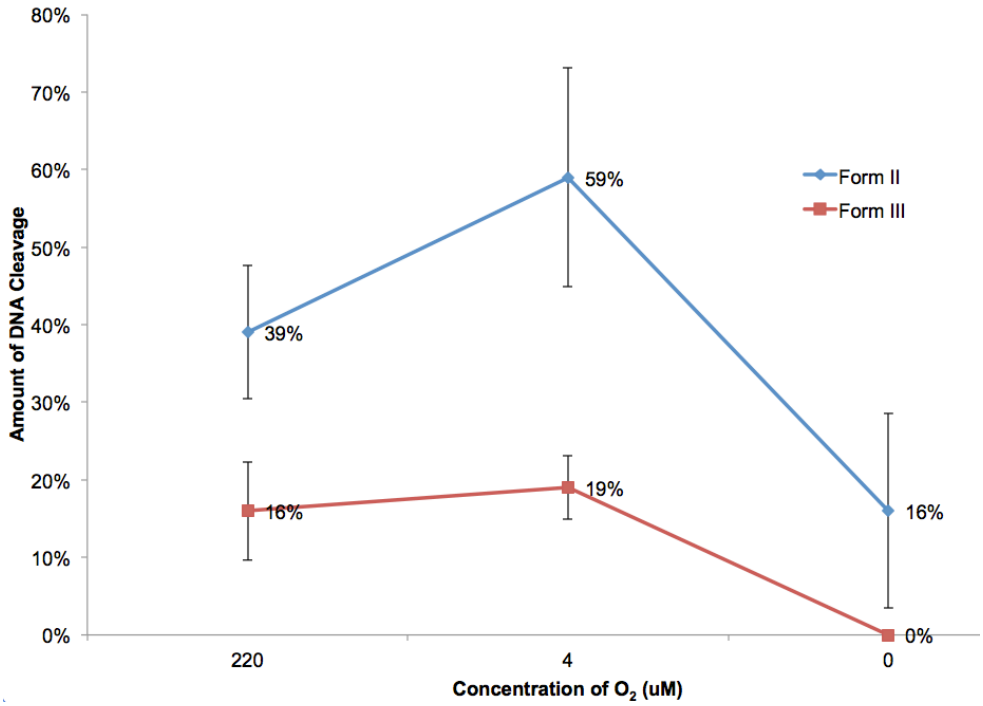


Figure 6-16 DNA cleavage activity as a function of oxygen concentration

6.13 Discussion and Conclusion

Previous work by Janaratne and Yadev revealed that both complex [P^{4+}] and [MP^{2+}] cleave DNA, under reducing conditions in the presence of GSH. DNA cleavage activity was examined under both aerobic and anaerobic conditions. It was found that this activyt was enhanced under anaerobic conditions. This current study shows that the description of anaerobic which implies oxygen free, in not correct. The cleavage assay

completed in this study showed the degassed solution to have an oxygen concentration of ~4 uM. After using the enzyme along with the DHB catalyst, the oxygen concentration was undetectable, effectively "scrubbing" out the system. Maximum cleavage activity was achieved under condition of minimal oxygen. But when the system was "scrubbed of any remaining oxygen, cleavage activity was almost completely stopped. This evidence further supports a mechanism in which a limiting amount of oxygen is needed.

EPR evidence suggests the presence a carbon based radical, when $[H_2P^{4+}]$or $[H_2MP^{2+}]$ is bound to DNA. These radicals we postulate is responsible for doing the DNA damage**.** The driving force for the abstraction of the H-atom from the DNA by the $[MP\bullet^{+}]$ or $[P\bullet^{3+}]$ is likely to be very small, or even endergonic, suggesting that the reaction is slow and only occurs because the radical is "docked" into the DNA via intercalation and this places it in an optimal position to eventually attack the DNA. Chapter 7 will attempt to paint a scenario, where thermodynamically this maybe possible.

Chapter 7

The Theorectical Thermodynamics Behind the Proton-Coupled Electron Transfer Reaction Between DNA and a Biologically Redox Active Ruthenium Polypyridal Complex

7.1 Introduction

As described in the previous chapter, both complexes P^{4+} and MP^{2+} intercalate with DNA and show potentiated DNA cleavage under hypoxic and reducing conditions.[130, 131] Both complexes contain the redox-active tatpp ligand, which is thought to be the essential component for the observed biological activity. For the sake of clarity in this chapter, complex P^{4+} and MP^{2+} will have their redox active ligand explicity expressed as $[(phen)_2Ru(tatpp)Ru(phen)_2]^{4+}$ and $[(phen)_2Ru(tatpp)]^{2+}$ respectively.

It was proposed in the Chapter 6, that one of the redox states, most likely a radical of $[(phen)_2Ru(tatpp)Ru(phen)_2]^{4+}$ or $[(phen)_2Ru\ (tatpp)]^{2+}$ is responsible causing damage to DNA. Experimental evidence shows that this is possible. The purpose of this study is to examine the thermodynamics between one of the possible radical redox states of $[(phen)_2Ru\ (tatpp)]^{2+}$ and DNA. What exactly is the driving force behind this reaction? How can such a relatively weak radical cause DNA lesions. As discussed previously there are two main mechanistic pathways that metal complexes can cause DNA cleavage, and that is either through hydrolytic or oxidative cleavage pathways. The focus of this discussion will be on the thermodynamics of he oxidative pathway.

7.2 H-Atom Transfer

There are two common ways in which DNA oxidation can be expressed. The first is H-atom abstraction (HAT). Meyer et al. proposed to restrict HAT reactions where a proton and electron come from the same bond.[132, 133] To put it simply, a radical reacts with one hydrogen atom (1 proton, electron) in one concerted step, hence the naming

convention. To elucidate this point using the current study with DNA, an H atom from the deoxyribose sugar is broken and is transferred to the radical containing tatpp bridge forming a N-H bond, in one concerted step. Thermodynamically this is an uphill battle. The typical homolytic bond dissociation energy of a C-H bond is approximately 414 kJ versus the bond dissociation energy of an N-H bond 389 kJ. Using Hess Law, the process is unfavorable due to the overall positive enthalpy change.

7.3 Proton Coupled Electron Transfer (PCET)

In more recent decades, the thermodynamics of the H-atom transfer has been described as a separate 1 H^+, 1 e^- process or a proton electron transfer process (PET). Thermodynamically speaking, HAT and PET are energetically similar, the only difference is where the H+/e- come from and where they are going to. Proton electron transfer can be a stepwise or concerted chemical reaction where in the HAT example 1 H^+, and 1 e^- are transferred in a single kinetic step. In the PET mechanism, the species' pKa is a description of the specie's H^+ transfer ability and the e^- transfer process can be described by its' redox potential. Each of these processes can further be described by each individual free energy and relationships can be made from the thermodynamic square show in Figure 7-1. With this, one can discuss the bond dissociation free energy (BDFE) of the overall PET process in either a stepwise proton coupled electron transfer process PCET or concerted proton electron transfer (CPET). Work done by the Mayer group has found that it is more appropriate to discuss PET processes in terms of BDFE rather than BDE's because they can be quite different and more importantly for metal complexes there can be a large entropic contribution.[134-136]

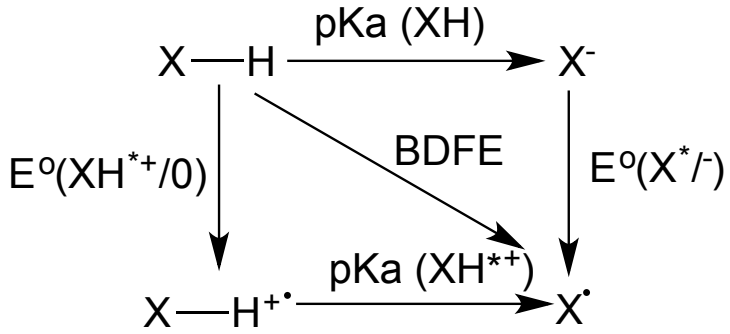


Figure 7-1 Thermodynamic square for proton coupled electron transfer processes.

7.4 Examination of the PCET Mechanism Between $[(phen)_2Ru(H_2tatpp)]^{2+}$ and DNA

It has been revealed from previous experiments, under reducing conditions the species is the doubly reduced doubly protonated species i.e. $[(phen)_2Ru(H_2tatpp)]^{2+}$. Also, it has been shown that in order for this reaction to occur there must be some oxygen present, but in the presence of excess oxygen, maximum damage to DNA cannot occur. Therefore, the following mechanistic steps of the oxidative cleavage of deoxyribose sugar under hypoxic conditions is presented by the reactions below. First, $[(phen)_2Ru(H_2tatpp)]^{2+}$ quickly intercalates into the DNA. Once intercalated into the DNA under hypoxic conditions, $[(phen)_2Ru(H_2tatpp)]^{2+}$ oxides to $[(phen)_2Ru(tatpp^{\bullet})]^{1+}$. We further postulate that $[(phen)_2Ru(tatpp^{\bullet})]^{1+}$ will undergo a proton coupled electron transfer reaction with the deoxyribose sugar shown as shown rxn 3.

$[(phen)_2Ru(H_2tatpp)]^{2+}$ + DNAH → $[(phen)_2Ru(H_2tatpp)]^{2+}$ — DNAH (rxn 1)

$[(phen)_2Ru(H_2tatpp)]^{2+}$—DNAH + ¼ O_2 → $[(phen)_2Ru(tatpp^{\bullet})]^{1+}$—DNAH+ ½ H_2O + H^+ (rxn2)

$[(phen)_2Ru(tatpp^{\bullet})]^{1+}$—DNAH → $[(phen)_2Ru(H_2tatpp)]^{2+}$—DNA$^{\bullet}$ (rxn 3)

$[(phen)_2Ru(H_2tatpp)]^{2+}$—DNA$^{\bullet}$ → $[(phen)_2Ru(H_2tatpp)]^{2+}$ + DNA$^{\bullet}$ (rxn 4)

DNA$^{\bullet}$ → DNA cleavage products (rxn 5)

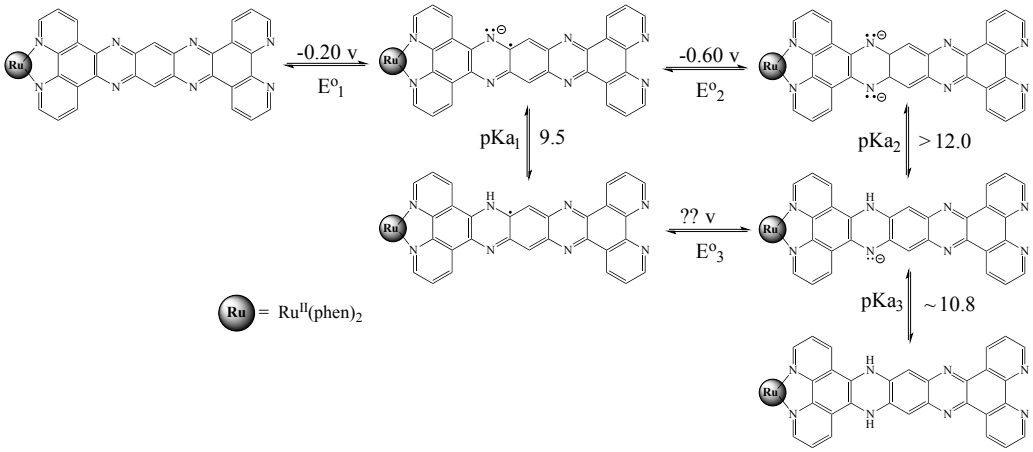


Figure 7-2 Redox potentials, in CH_3CN, and pKa's, in water, of the series of oxidations states between $[(phen)_2Ru(tatpp)]^{2+}$ and $[(phen)_2Ru(H_2tatpp)]^{2+}$

7.5 Redox Ladder of $[(phen)_2Ru(tatpp)]^{2+}$

The redox chemistry of $[(phen)_2Ru(tatpp)Ru(phen)_2]^{4+}$ and $[(phen)_2Ru(tatpp)]^{2+}$ is well known and it was found that the tatpp ligand can undergo multiple reductions.[137-140] The redox ladder for $[(phen)_2Ru(tatpp)]^{2+}$ are shown in Figure 7-2. The redox potential of $[(phen)_2Ru\ (Htatpp^{\bullet})]^{2+}$ is difficult to obtain because the complex undergoes rapid disproportionation, at relevan pH of 7.2, and forms $[(phen)_2Ru(H_2tatpp)]^{2+}$ and $[(phen)_2Ru(tatpp)]^{2+}$

7.6 PCET Transfer Reaction Between $[(phen)_2Ru(tatpp^{\bullet})]^{1+}$ and DNAH

The main system of interest for the abstraction of a hydrogen atom from DNA is the proton coupled electron transfer reaction between $[(phen)_2Ru(tatpp^{\bullet})]^{1+}$ and DNAH, where DNAH is DNA with an explicity labeled hydrogen. Thermodynamic squares can be created, describing the proton coupled electron transfer reactions as shown in Figure 7-3[141]. Using these thermodynamics squares, the BDFE's (bond dissociation free energies) can be determined for each system.

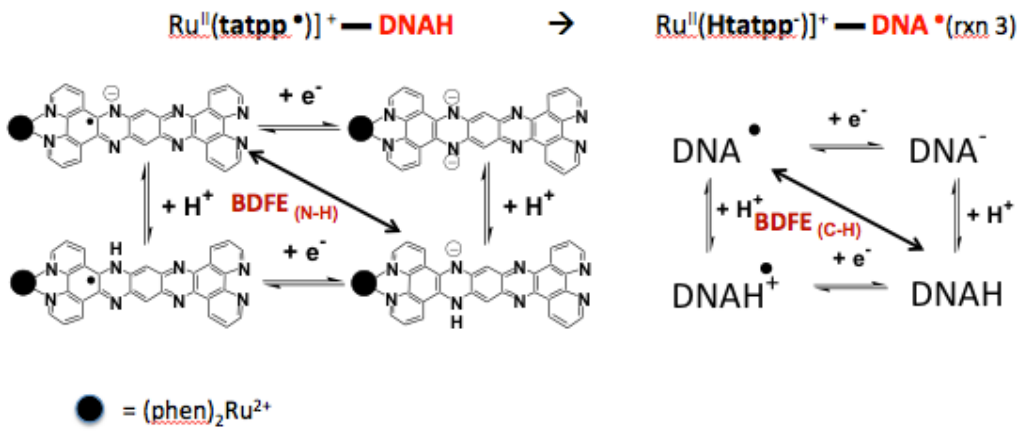


Figure 7-3 Thermodynamic squares of $[(phen)_2Ru\ (tatpp^{\bullet})]^{1+}$ and DNAH

When considering which pKa's and redox potentials to use in determining BDFE's, it is important try use values that closely resemble the system being examined. In this case, the reaction is taking place in an aqueous environment buffered at pH~7.0. The BDFE of the describing the thermodynamic steps between $[(phen)_2Ru(tatpp^{\bullet})]^{1+}$ and $[(phen)_2Ru(Htatpp^{-})]^{1+}$ complexes can be calculated as the sum of free energies of the corresponding to the electron and proton transfer steps contained in the thermodynamic square. The electron transfer reaction can be described by the redox potential between $[(phen)_2Ru(tatpp^{\bullet})]^{1+}$ and $[(phen)_2Ru(tatpp^{-})]$. The proton transfer reaction can be described as the pKa of $[(phen)_2Ru(Htatpp^{-})]^{1+}$. Similarly, the pKa for $[(phen)_2Ru(Htatpp^{\bullet})]^{2+}$ and the redox potential between $[(phen)_2Ru(Htatpp^{\bullet})]^{2+}$ and $[(phen)_2Ru(Htatpp^{-})]^{1+}$ can be used.

7.7 Thermodynamic Determination of E^{o}_{3} for $[(phen)_2Ru(Htatpp^{\bullet})]^{2+}$ and $[(phen)_2Ru(Htatpp^{-})]^{1+}$

The only redox potential that is currently not known is E^{o}_{3}, shown in Figure 7-2, which represents electron transfer between $[(phen)_2Ru(Htatpp^{\bullet})]^{2+}$ and

$[(phen)_2Ru(Htatpp^{-})]^{1+}$. This is due to the rapid disproportion reaction that $[(phen)_2Ru(Htatpp^{\bullet})]^{2+}$ undergoes. Although, it is difficult to experimentally determine the redox potential, it can be estimated using the fact that for any cyclic, closed system the sum of the individual free energies is 0. This system is illustrated in Figure 7-4.

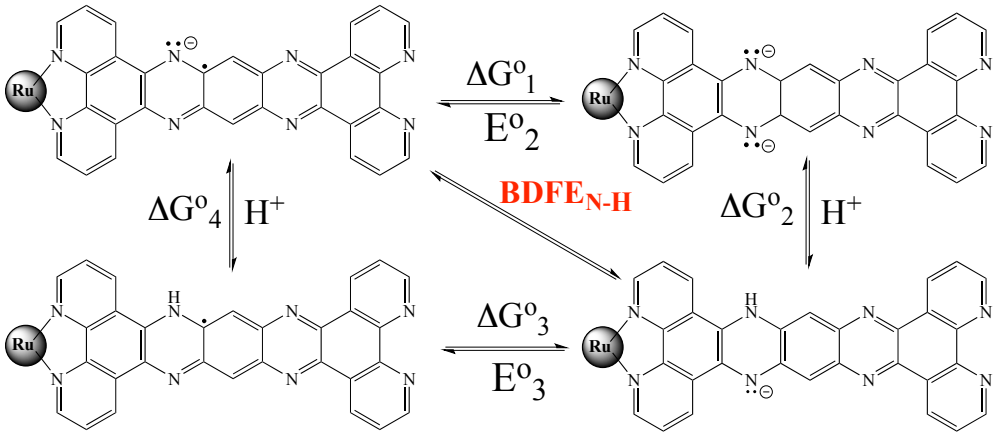


Figure 7-4 Thermodynamic square representing the $BDFE_{(N-H)}$ bond formation between $(phen)_2Rutatpp^{*-}$ and $(phen)_2RuHtatpp^{-}$

$$\Delta G^{\circ}{}_1 + \Delta G^{\circ}{}_2 + \Delta G^{\circ}{}_3 + \Delta G^{\circ}{}_4 = 0$$

$$\Delta G^{\circ}{}_{redox} = -n\mathrm{F}E^{\circ}$$

$$\Delta G^{\circ}{}_{\frac{acid}{base}} = -2.303 * RT * logK_a = 2.303 * RT * pKa$$

$$-nFE^{\circ}{}_1 - 2.303 * RT * pKa_2 + nFE^{\circ}{}_3 + 2.303 * RT * pKa_4 = 0$$

$$2.303 * RT * pKa_4 - 2.303 * RT * pKa_2 = nFE^{\circ}{}_3 - nFE^{\circ}{}_1$$

Given R = 8.3145 J/K*mol and F = 96485 J/mol eV

$$\Delta pKa = 16.9 * \Delta E^{\circ}$$

Therefore, the difference in the pKa's directly proportional to the change in redox potentials. Given R = 8.3145 J/K*mol, F = 96484 J/ mol e V, and T = 298.15K, $E^{o}{}_3$ can be theoretically calculated. The redox potential for $E^{o}{}_3$ was calculated to be -0.45 v.

7.8 Determination of the $BDFE_{N-H}$ for the 1 H+/1 e- PCET Process.

Thermodynamic calculations such as these are usually done using Hess's law along side these thermodynamic squares. This was further modified by several groups included work done by Tilset.[142, 143] Tilset includes the free energy of solvation of the H-atom during the proton electron transfer process, which was termed Cg. Table 7-1 shows the Cg values for various solvents.

$$\boldsymbol{BDFE_{(solv)} = 1.37\ pKa + 2.303E^{\circ} + C_{g,solv}}$$

$$\boldsymbol{BDFE_{(solv)} = \Delta G^{\circ}_{N-H} + C_{g,solv}}$$

Table 7-1 Summary of Constants C_G and C_H in common solvents

Solvent	C_g	$T(\Delta S^o)^b$	C_H	Electrode reference
Acetonitrile	54.9	4.62	59.4	$Cp_2/Fe^{+/0}$
DMSO	71.1	4.60	75.7	$Cp_2/Fe^{+/0}$
DMF	69.7	4.56	74.3	$Cp_2/Fe^{+/0}$
Methanol	65.3	3.81	69.1	$Cp_2/Fe^{+/0}$
Water	57.6	-1.80	55.8	normal hydrogen

[a] Values in kcal mol^{-1} at 298 K from references.[136, 144] [b] $T(\Delta S^o)solv = TS^o(H^*)g + \Delta S^o_{solv\ (H_2)\ solv}$

Using a portion of the thermodynamic square shown in Figure 7-5 in reference to Figure 7-4, the $BDFE_{N-H}$ by adding the Gibbs Free Energy for the PCET, $1H^+$,$1e^-$ process and the Cg provided by Tilset. Using the redox potential reported earlier of 0.45 v and the given pKa 10.5, the corresponding free energy of proton electron transfer process for the N-H bond formation is -10.6 kJ/mol.

$$\boldsymbol{\Delta G_3^{\circ} = -nFE_3^{\circ}}$$

$$\boldsymbol{\Delta G_4^{\circ} = -2.303\ RT \log K\ ; 2.303\ RT\ pKa}$$

$$\boldsymbol{\Delta G^o_{PCET,1H+,1e-} = \Delta G_4^{\circ} + \Delta G_3^{\circ}}$$

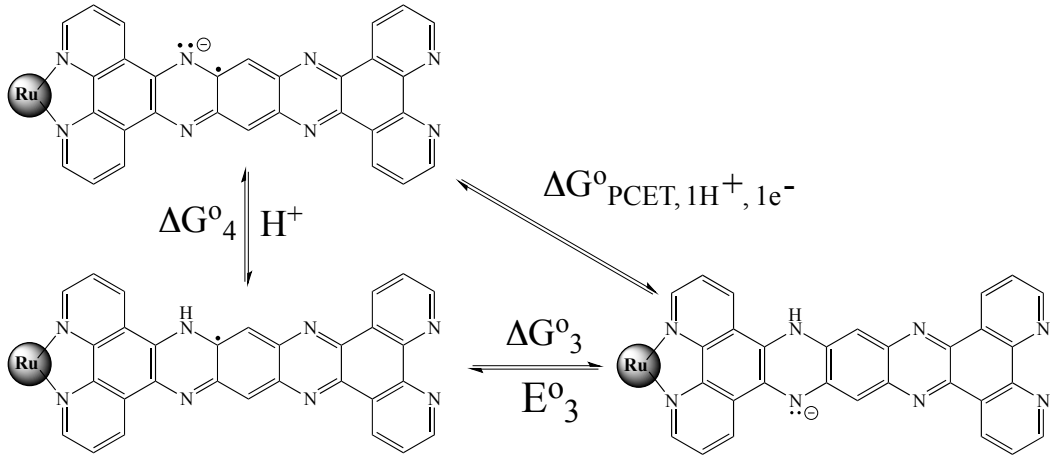


Figure 7-5 Thermodynamic quadrant used to determine the $BDFE_{N-H}$

Therefore the using the Cg provided by Tilset the $BDFE_{N-H}$ bonds can be determined. Two solvent systems are shown in Table 7-2.

Table 7-2 Determination of the $BDFE_{N-H}$ under two opposing solvent systems

Solvent	H_2O	DMSO
C_G	241	297
$\Delta G^{o}_{1H+, 1e-}$	-10.6	-10.6
$BDFE_{N-H}$	230	288

7.9 Determination of $BDFE_{C-H}$ for the Deoxyribose Sugar Using Bond Dissociation Energies Under Varying Solvent Systems.

The technique used to determine the $BDFE_{N-H}$ can be applied to the corresponding DNA/DNAH thermodynamic square, where DNAH explicitly shows a hydrogen atom, more specifically from the deoxyribose sugar. Unfortunately, the redox potentials and the pKa's of DNA C-H bonds are not known. Although, the BDE of the C-H bonds in the deoxyribose ring are well known.[145] Of the 5 C-H bonds that exist on the deoxyribose ring, the weakest bond is the C_1 hydrogen at 367 kJ/mol. The BDFE can be calculated using the BDE and the entropies of solvation. Tilset explains as long as long

as there are no significant differences in entropic effects between the solvation of species and the H-atom, the BDFE can be calculated using the C_g and C_H constants provided in Table 7-1.

Assuming $\boldsymbol{S^{\circ}_{solv}(HX) = S^{\circ}_{solv}(H^{*})}$

$$\boldsymbol{BDE(X-H)_{Solv} = BDFE_{Solv}(X-H) + (C_{H,solv} - C_{g,solv})}$$

The difference in the $BDFE_{C\text{-}H}$ the bond broken from the deoxyribose ring and the BDFE (N-H), the bond formed on the tatpp bridge of the ruthenium complex as shown in Table 7-3. Since the ruthenium complex is not completely in an aqueous environment, but intercalated between the base pairs of DNA, which can be described as a hydrophobic aprotic environment, two solvent scenarios were calculated. Calculations show that although the thermodynamics of the PCET transfer between $[(phen)_2Ru(Htatpp^{\bullet})]^{2+}$ and DNAH is more spontaneous in an aprotic environment, by 75 kJ/mol, there the reaction process is still uphill by 60 kJ/mol. Since DNA damage is occurring here must be an additional driving force pushing this reaction forward to make this mechanism

Table 7-3 BDFE difference between the N-H formation and C-H abstraction of $[(phen)_2Ru(Htatpp^{\bullet})]^{2+}$/DNAH under protic and aprotic solvent systems.

Solvent	H_2O kJ/mol	DMSO kJ/mol
BDFE (N-H)	230	288
BDFE (C-H)	375	348
ΔBDFE	135	60

7.10 Examination of the Environmental Dependence of E^o_3

As discussed in the section 7.4, the value or E^o_3, was experimentally indeterminable due to the rapid disproportionation reaction that $[(phen)_2Ru(Htatpp^{\bullet})]^{2+}$ undergoes under the conditions cited. Therefore to make calculations simple, the initial assumption was to determine E^o_3 under standard conditions. The redox potential under standard conditions was calculated to be 0.45 v. The fact that the complex, $[(phen)_2Ru(H_2tatpp)]^{2+}$, is intercalated, the environment the complex is in cannot be fairly described as being under standard conditions. To determine the redox potential under non-standard conditions, an examination of the equilibrium conditions, and the determination of which species are present must be done.

Spectroelectrochemistry[146] was performed by our group to help determine which redox species of $[(phen)_2Ru(tatpp)]^{2+}$ are present under physiological conditions while intercalated into DNA. The result to that experiment is shown in Figure 7-6. The growth of peaks at 600 and 900 nm allude to three species being present at pH = 7.2. Those species are $[(phen)_2Ru(Htatpp^{-})]^{1+}$, $[(phen)_2Ru(Htatpp^{\bullet})]^{2+}$, and $[(phen)_2Ru(H_2tatpp)]^{2+}$. Unfortunately, the amount of each species is not easily determined since the complexes $[(phen)_2Ru(Htatpp^{-})]^{1+}$ and $[(phen)_2Ru(H_2tatpp)]^{2}$ are overlapping and difficult to deconvolute from the spectra. Thermodynamically the ratio of $[(phen)_2Ru(Htatpp^{-})]^{1+}$ and $[(phen)_2Ru(Htatpp^{\bullet})]^{2+}$ can be described using the nonstandard Nernst equation shown below. The relative ratio of concentrations of can be used to infer the relative hydrophobicity within the intercalated space, where $[(phen)_2Ru(Htatpp^{-})]^{1+}$ is $Ru^{II}[Htatpp^{-}]$ and $[(phen)_2Ru(Htatpp^{\bullet})]^{2+}$ is $Ru^{II}[Htatpp^{*}]$.

$$E = E^o - 2.303 * \frac{RT}{nF} log\, Q\,, where, Q = \frac{Ru^{II}[Htatpp^{-}]}{Ru^{II}[Htatpp^{*}]}$$

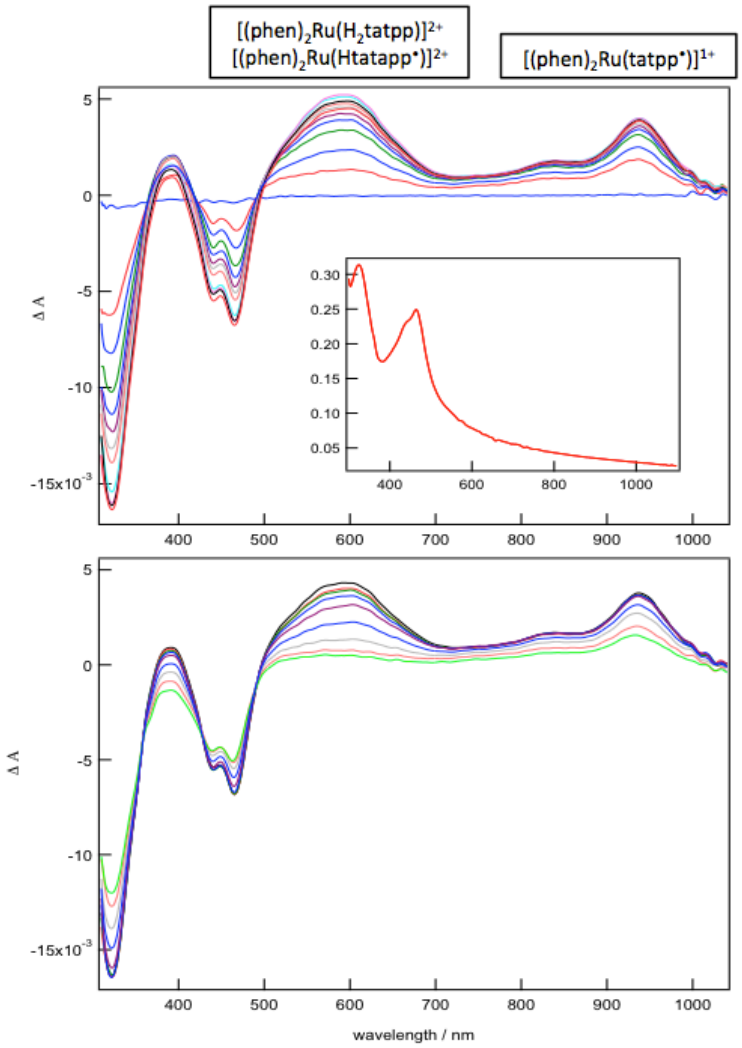


Figure 7-6 Spectroelectrochemistry of a ITO/AV/DNA $[(phen)_2Ru(tatpp)]^{2+}$ in 0.02 M phosphate buffer, pH 7.2. Spectra are shown as $\Delta A = A - A_0$ where A_0 is the absorbance of the film at open circuit potential (0.3 V). Spectra were collected during a cyclic potential scan at 5 mV/s in the 0.3 V / -0. 7 V. Top frame is for the oxidation and bottom frame for the oxidation processes. Insert in the top frame shows the A_0 spectrum that was used as reference.

Three cases can be examined given the preceding equation. Case I $[(phen)_2Ru(Htatpp^-)]^{1+} = [(phen)_2Ru(Htatpp^\bullet)]^{2+}$ Case II $[(phen)_2Ru(Htatpp^-)]^{1+} >> [(phen)_2Ru(Htatpp^\bullet)]^{2+}$ and Case III $([(phen)_2Ru(Htatpp^-)]^{1+} << [(phen)_2Ru(Htatpp^\bullet)]^{2+}$. The corresponding non-standad redox potentials, E, and Gibbs Free Energy, ΔG, are shown in Table 7-4.

Table 7-4 Case study of varying redox potential and free energies based on equilibrium concentration of species bound to DNA under non-standard conditions.

	Case I 50%/50%	Case II 99.9%/0.1%	Case III 0.1%/99.9%
E (v)	- 0.45	-0.62	-0.27
ΔG (kJ/mol)	43.4	59.8	26.2

Case III lends to a more negative redox potential, making the reaction overall more spontaneous by ~20 kJ/mol compared to Case I. Where Case II is the opposite being less spontaneous by ~20kJ/mol.

7.11 Discussion of Results

Ultimately, the overall reaction for the $1H^+/1e^-$ is still uphill by 40 kJ/mol. It is further postulated that this reaction is not a simple $1H^+/1e^-$ process. There must be an additional driving force pushing this reaction forward. Adding the third protonation step, pKa_3, into the mechanism would make plausible what has been described here potentially possible, which describes the deprotonation of $[(phen)_2Ru(H_2tatpp)]^{2+}$. This is reasonable assumption given the fact that $[(phen)_2Ru(H_2tatpp)]^{2+}$ is also present in the system at the relevant pH of 7.2. This assumption is also back up by the

spectroelectrochemistry presented earlier. As seen in Figure 2, pKa_3 is approximately 10.8. This adds an additional ΔG^o of -62 kJ/mol. Therefore, the overall $\Delta G^o_{2H+/1e-}$ process provides a description of a thermo neutral process spontaneous by - 2 kJ/mol. In conclusion, neither HAT nor the $1H^+/1e^-$ process is adequate explanation for our mechanism. Instead we surmise using a $2H^+/1e^-$ coupled process, which is supported by spectroelectrochemical evidence of the species that is present under the stated conditions.

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Chapter 8

Future Work

8.1 Section I

For future work, several limitations in this study have to be address. The first limitation in this study was student participation. Every semester only 20-30% of the entire general chemistry I population completed the student. Addressing student participation for any future studies (it doesn't have to be this one) the instructor has to be able to "sell" the idea of its importance, not just for the department or the grad student who is doing the study, but for himself or herself as well.

Also in line with instructions, by informing the instructors of the results contained in this study, a request could be made to include information of creating schema's as it is applied to the problem solving stoichiometry problems. This experiment could potentially be run again examining if there are any differences in achievement scores.

The author does recognize there is only limited time in any given lecture. This limitation could be addressed in supplemental instruction. If enough students were to take part in this sort of supplemental instruction, another experiment could be done looking at those students versus those that did not take part in those activities.

In examining the issue of student participation, this is a systemic problem. It is a measure of a student's motivation and feelings about the topic of chemistry in general. In chapter 5 of his dissertation there was a discussion of finding ways to identify at risk students. These unmotivated students could potentially be considered "at-risk". There has been work to use self-efficacy scales to correlate student's feeling about chemistry and achievement and retention in the course. In fact, a joint project between the Department of Chemistry and Biochemistry and the Department of Curriculum and

instruction, is examining the validity of three different scales, which are the Self-Efficacy for General Chemistry (SEGC) Scale, Attitude Toward Chemistry Lessons Scale (ATCLS), and General Chemistry Intentions Scale (CGI). This is hopes of identifying at-risk students" and placing students in the proper course.

8.2 Section II

The deoxyribose fragment is shown in Figure 8-1. There are 5 carbons on the fragment where potentially oxidative damage can occur. It has been shown that for every site C1-C5, if oxidative cleavage were to occur a specific scission product would be produced.[147] To further expand on the oxidative mechanism proposed in this study, a search for these scission products should be undertaken.

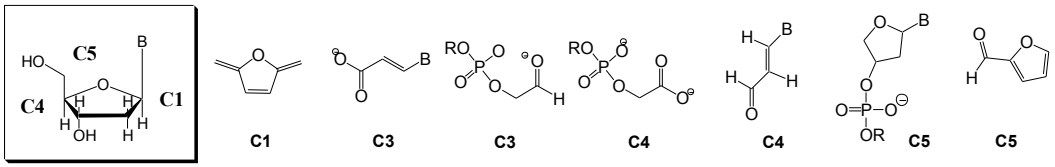


Figure 8-1 Deoxyribose fragment and related scission products.

Appendix A

IRB Consent form

THE UNIVERSITY
OF TEXAS
AT ARLINGTON

Office of Research Administration
Box 19188
202 E. Border St., Suite 214
Arlington, Texas
76019-0188

T 817.272.3723
F 817.272.1111

http://www.uta.edu/research
Expertise at UT Arlington
http://www.uta.edu/expertise

BeA Maverick™

March 2nd 2011

Dr. Lynn Peterson
College of Engineering
Box 19019

RE: Continuing Review Approval Letter

TITLE: ***Arlington Undergraduate Research Based Achievement for STEM (AURAS)***

IRB No.: 2009.1637s

The University of Texas at Arlington IRB Chair (or designee) reviewed and approved the status of '*continuing /revised' for* a period not to exceed one year, effective **February 10th 2011.** IRB approval for the research shall continue for a period not to exceed twelve months [45 CFR 46.109(e)]. In order for the research to continue, Continuing Review must be completed within the month preceding the date of approval indicated above. A reminder notice will be forwarded to the attention of the Principal Investigator (PI) at a time sufficient enough to allow for the continuation review to occur.

The IRB and investigators must plan ahead to meet required continuing review dates. If an investigator has failed to provide continuing review information to the IRB or the IRB has not reviewed and approved a research study by the continuing review date specified by the IRB, the research must stop, unless the IRB finds that it is in the best interests of individual subjects to continue participating in the research interventions or interactions. Enrollment of new subjects cannot occur after the expiration of IRB approval.

When continuing review of a research protocol does not occur prior to the end of the approval period specified by the IRB, IRB approval expires automatically. Such expiration of IRB approval does not need to be reported to OHRP as a suspension of IRB approval under HHS regulations.
http://www.hhs.gov/ohrp/humansubjects/guidance/contrev0107.htm

Important Note: The research records, including the signed consent forms must be securely maintained on the UT Arlington campus for at least three years after the completion of the research unless a longer retention period is specified by a sponsor, funding source, or regulation. The complete study record is subject to inspection and/or audit during this time period by entities including but not limited to the UT Arlington IRB, Regulatory Services staff, OHRP and by study sponsors (if the study is funded).

Please be advised that as the principal investigator, you are required to report local adverse (unanticipated) events to this office within 24 hours. In addition, pursuant to Title 45 CFR 46.103(b)(4)(iii), investigators are required to, "promptly report to the IRB ***any*** proposed changes in the research activity, and to ensure that such changes in approved research, during the period for which IRB approval has already been given, are **not initiated without prior IRB review and approval** except when necessary to eliminate apparent immediate hazards to the subject."

All investigators and key personnel identified in the protocol must have documented CITI *Training* or *Responsibility in Human Subject Research – IRB 101*on file with this office.

If applicable, approval by the appropriate authority at a collaborating facility is required prior to subject enrollment. If the collaborating facility is *engaged in the research*, an OHRP approved Federal wide Assurance (FWA) may be required. To determine whether the collaborating facility is engaged in research, go to: www.hhs.gov/ohrp/assurances

The UT Arlington Office of Research Administration Regulatory Services appreciates your continuing commitment to the protection of human research subjects. Should you have questions or require further assistance, please contact Philip Oilepo by calling (817) 272-0828.

Sincerely,

Patricia Turpin

Digitally signed by Patricia Turpin
DN: o=The University of Texas System, ou=The University of Texas at Arlington CA, ou=www.verisign.com/repository/CPS Incorp. by Ref.,LIAB.LTD(c)99, cn=Patricia Turpin, email=pturpin@uta.edu
Date: 2011.03.19 20:48:49 -05'00'

Patricia G. Turpin, PhD, RN, NEA, BC
Clinical Associate Professor
UT Arlington IRB Chair

THE UNIVERSITY OF TEXAS AT ARLINGTON

INFORMED CONSENT

PRINCIPAL INVESTIGATOR: Lynn L. Peterson, Ph.D.

TITLE OF PROJECT: Arlington Undergraduate Research Based Achievement for STEM (AURAS)

In order to understand how students are successful in Science, Technology, Engineering, and Mathematics (STEM) majors, to help us evaluate relevant instructional materials and research experience, and to be able to disseminate the knowledge gained in this study, it is imperative to collect some data that can be shared at a scholarly level. The information will be collected via surveys, multiple-choice questionnaires, and class grades. *There are no foreseeable risks involved to any participant. All participants are assured full confidentiality with regard to all of the information collected. No report, oral or written, will reveal any participant by name or identity. Participation or lack thereof will have* ***no effect on the class grade*** *of any student or the class activities that are required of all enrolled students. In order to sign this form and give consent you must be* ***18 years old or older****.*

This Informed Consent will explain about being a research subject in an experiment. It is important that you read this material carefully and then decide if you wish to be a volunteer.

PURPOSE:

The purpose(s) of this research study is/are as follows:

Numerous reports point out the need for more Science Technology Engineering and Mathematics (STEM) majors in the United States. The statistical report produced by the National Science Foundation, the *Science and Engineering Indicators 2008* [National Science Board, 2008] makes it clear that U.S. universities are not producing the number of STEM graduates that will be needed in the future. We want to explore the effectiveness of activities conducted under the Arlington Undergraduate Research Based Achievement for STEM (AURAS) project (including research-based classroom interventions and undergraduate research and internships).

DURATION

The duration of this project is as follows:

1. We will collect data via content based assessments and/or spatial ability assessments over the course of one semester (i.e. in the course that you are currently enrolled in)
2. We will collect grades from currently enrolled course in order to conduct data analysis on (such as correlation analysis)
3. We will be collecting graduation rates from participating students

Please note the collection of grades and graduation rates is to assess the effectiveness of the AURAS program and identities of any students will be kept confidential

_____Subject Initials

PROCEDURES

The procedures, which will involve you as a research subject, include:

1. Informed consent to participate in our research. In order to use data from students, we must have consent of the students themselves.
2. Classroom and on-line instruction on identified topics. Once topics of interest are identified, classroom or on-line instruction my vary in order to incorporate new teaching methods and or demonstrations
3. Demographic survey will be used to collect subject characteristics. Subject characteristics can include some or all of the following: age, gender, ethnic identity, intended major, previous science and/or math course taken either here at UTA, or previous institution (which may included high school), socio-economic background,
4. Multiple-choice and fill-in-the-blank assessments will be used to determine understanding and aid instruction of course content concepts.
5. Spatial ability assessments will be given to some or all students in order to understand students spatial reasoning skills
6. A smaller group of students will be invited to participate in an interview for a more in depth understanding of survey responses. Interview durations will be specified before interviews take place. Interviews will be taped in order to go back and review answers in detail. Student identity will be kept confidential and only researchers involved with the AURAS program will have access to taped interviews.
7. Class grades in all STEM classes will be used to correlate comprehension with spatial ability.
8. Academic History will be collected via demographics surveys as well as transcript records

Please note that data collected will only be reported in an aggregate fashion in order to keep student confidentiality in tact.

POSSIBLE RISKS/DISCOMFORTS

The possible risks and/or discomforts of your involvement include: NONE

POSSIBLE BENEFITS

The possible benefits of your participation are: What is learned from this research will improve STEM major instruction and retention, benefiting all STEM students.

ALTERNATIVE PROCEDURES / TREATMENTS

The alternative procedures / treatments available to you if you elect not to participate in this study are:

There are no alternative lectures or labs. Students electing not to participate in this study will still be required to participate in regular classroom or on-line instruction covering the material. Students electing not to participate will still be asked to participate in all surveys and tests since those data might prove useful to the instructor in evaluating instruction, although the data would not appear in any presentation or publication.

CONFIDENTIALITY

Every attempt will be made to see that your study results are kept confidential. A copy of the records from this study will be stored in a secure location in each department for at least three (3) years after the end of this research. The results of this study may be published and/or presented at meetings without naming you as a subject. Although your rights and privacy will be maintained, the Secretary of the Department of Health and Human Services, the UTA IRB, the FDA (if applicable), and personnel particular to this research (Dr. Lynn L. Peterson, Dr. James A. Epperson, Dr. Ramon Lopez, Dr. Kevin A. Schug, and Dr. J. Carter M. Tiernan) have access to the study records. Your (study data) records will be kept completely confidential according to current legal requirements. They will not be revealed unless required by law, or as noted above.

FINANCIAL COSTS

The possible financial costs to you as a participant in this research study are:

There is no financial obligation for subjects participating in this study.

CONTACT FOR QUESTIONS

If you have any questions, problems or research-related medical problems at any time, you may call the following investigators:

Lynn Peterson, Ph.D.,	(817) 272-5503	Comp. Sci and Eng
James A. Epperson, Ph.D.,	(817) 272- 5047	Mathematics
Ramon Lopez, Ph.D.,	(817) 272-0386	Physics
Kevin A. Schug, Ph.D.,	(817) 272-3541	Chem and Bio Chem
J. Carter M. Tiernan, Ph.D.,	(817) 272-2105	Comp. Sci and Eng
Kenneth Abayan (graduate student)	(817) 272-5436.	Chem and Bio Chem

You may call the Chairman of the Institutional Review Board at (817) 272-1235 for any questions you may have about your rights as a research subject.

VOLUNTARY PARTICIPATION

Participation in this research experiment is voluntary. You may refuse to participate or quit at any time. If you quit or refuse to participate, the benefits (or treatment) to which you are otherwise entitled will not be affected. You may quit by calling the following investigators:

Lynn Peterson, Ph.D.,	(817) 272-5503	Comp. Sci and Eng
James A. Epperson, Ph.D.,	(817) 272- 5047	Mathematics
Ramon Lopez, Ph.D.,	(817) 272-0386	Physics
Kevin A. Schug, Ph.D.,	(817) 272-3541	Chem and Bio Chem
J. Carter M. Tiernan, Ph.D.,	(817) 272-2105	Comp. Sci and Eng
Kenneth Abayan (graduate student)	(817) 272-5436.	Chem and Bio Chem

You will be told immediately if any of the results of the study should reasonably be expected to make you change your mind about staying in the study.

_____Subject Initials

PRINCIPAL INVESTIGATOR: Lynn L. Peterson, Ph.D.
TITLE OF PROJECT: Arlington Undergraduate Research Based Achievement for STEM (AURAS)

By signing below, you confirm that you have read or had this document read to you. You will be given a signed copy of this informed consent document upon request. You have been and will continue to be given the chance to ask questions and to discuss your participation with the investigator.

You freely and voluntarily choose to be in this research project.

PRINCIPAL INVESTIGATOR: _____ DATE

NAME OF VOLUNTEER (PLEASE PRINT) DATE

SIGNATURE OF VOLUNTEER DATE

SIGNATURE OF WITNESS (if applicable)

FEB 10 2014

APPROVED

FEB 10 2015

Institutional Review Board

_____Subject Initials

.

Appendix B

Baseline Questionnaire

Name: _____ UTA ID: 1000

I. BACKGROUND AND DEMOGRAPHICS

1. As of August 2010, are you a: (**CIRCLE ONE RESPONSE ONLY**)

1 Freshman, first semester
2 Freshman, second semester
3 Sophomore, first semester
4 Sophomore, second semester
5 Other (**SPECIFY**): _____

2. What is your age _____ and birthdate MM/DD/YY

3. What is your gender? (**CIRCLE ONE RESPONSE ONLY**)

1 Male 2 Female

4a. What is your ethnicity? (**CIRCLE ONE RESPONSE ONLY**):

1 Hispanic, Latino
2 Non-Hispanic
3 Do not wish to report ethnicity

4b. What is your racial heritage? (**CIRCLE ALL THAT APPLY**)

1 Black or African-American
2 White
3 Asian
4 Native American or Alaska Native
5 Native Hawaiian or Other Pacific Islander
6 Do not wish to report racial heritage

4c. Did you apply for financial aid with the FAFSA? Circle: Yes / No / Do not wish to report

4d. Your citizenship is:

1 US citizen
2 US permanent resident
3 International citizen with valid US visa
4 Other / Do not wish to report

4e. High school name, city, state:

5. In what month and year did you graduate from high school? _____ (month)/____ (year)

5a. In what month and year did you enroll at UTA? _____ (month)/____ (year)

5b. What did you do after you graduated from high school and before you started UTA? (**CIRCLE ALL THAT APPLY**)

1 Worked full-time or part-time
2 Served in the military
3 Attended community college
4 Attended another 4-year college/university
5 Cared for a family member(s)
6 Did volunteer service in the community
7 Traveled
8 Other (**SPECIFY**): _____
9 Nothing

6. What are the highest education levels that your parents attained? (**CHECK THE APPROPRIATE ROW FOR YOUR FATHER AND YOUR MOTHER):**

Education Level	Mother	Father
1. Less than high school		
2. Some high school		
3. High school graduate		
4. Community college or technical/vocational school		
5. Some college		
6. College graduate		
7. Graduate school – MA/MS		
8. Graduate school – Ph.D., MD, Law degree		
9. Other (**SPECIFY**):		

7. Do you have any siblings who are in college or old enough to have gone to college (i.e. 18 or older)?

1 Yes
2 No (**SKIP TO Q.8)**

7a. Is this sibling/(Are these siblings) in college or graduated from college? (**CIRCLE ALL THAT APPLY**)

1 Yes, in college
2 Yes, college graduate
3 None of my siblings currently attends or went to college
4 No, attended college but did not graduate

II. HIGH SCHOOL EXPERIENCES

8. What is the most advanced math class that you took in high school? (**CIRCLE ONE RESPONSE ONLY**)

1	Calculus	5	Trigonometry
2	Pre-Calculus	6	Geometry
3	Algebra 2	7	Other (**SPECIFY**)
			_____
4	Algebra 1		

9. How many classes did you take in high school in: (**RECORD THE APPROPRIATE NUMBER OF CLASSES FOR EACH SUBJECT AREA)**

Subject Areas	**Number of Classes**
Mathematics	
Physics	
Chemistry	
Computer Science	
Statistics	
Engineering	
Other math, science or technology classes	

10. Did you take any Advanced Placement (AP), International Baccalaureate (IB) or dual credit classes in high school: (**CIRCLE "Y" OR "N" FOR EACH AREA**)

AP Classes Taken	**Yes**	**No**	**IB Classes Taken**	**Yes**	**No**
AP Biology	Y	N	IB Biology	Y	N
AP Chemistry	Y	N	IB Chemistry	Y	N
AP Physics B	Y	N	IB Physics	Y	N
AP Physics C	Y	N	IB Math SL II	Y	N
AP Calculus AB	Y	N	IB Math HL I	Y	N
AP Calculus BC	Y	N	IB Math HL II	Y	N
AP Computer Science A	Y	N	IB Computer Science	Y	N
Other AP Science Courses	Y	N	Other IB Sciences	Y	N
Dual credit math, science or engineering college classes: (**LIST**):					

11. How well did your high school prepare you for college in the following areas? (**CIRCLE ONE NUMBER FOR EACH ROW**)

Areas	**Very Well**	**Well**	**Somewhat**	**Poorly**	**Not At All**
Study skills	1	2	3	4	5
Writing skills	1	2	3	4	5
Oral presentation skills	1	2	3	4	5

Interpersonal communications	1	2	3	4	5
Laboratory skills	1	2	3	4	5
Computer literacy (MSWord, Excel)	1	2	3	4	5
Computer programming, advanced	1	2	3	4	5
Mathematics	1	2	3	4	5
Sciences	1	2	3	4	5
Engineering	1	2	3	4	5

III. COLLEGE EXPECTATIONS AND PLANS

12. Think back to high school; which one of the following statements best describes your high school experience? (**CIRCLE ONE RESPONSE ONLY**)

1 It was very easy for me to get the grades I wanted in all my classes
2 With a few exceptions, it was easy for me to get the grades I wanted in my classes
3 I had to work some, but not at all hard to get the grades I wanted in my classes
4 I had to work hard to get the grades I wanted in my classes

12a. What grade point average (GPA) did you want to get in high school? (**CIRCLE ONE LETTER ONLY**)

A B C D

13. As a first year college student, how hard do you expect to work in college to get the grades you want? Do you expect to: (**CIRCLE ONE RESPONSE ONLY**)

1 Work less than you did in high school to get the grades you want
2 Work the same as you did in high school to get the grades you want
3 Work harder than you did in high school to get the grades you want

13a. What grade point average (GPA) do you strive to get in college? (**CIRCLE ONE LETTER ONLY**)

A B C D

14. What is your intended major? (**CIRCLE ONE RESPONSE ONLY**)

1 Aerospace Engineering
2 Bioengineering
3 Biological Chemistry
4 Chemistry/Biochemistry
5 Civil Engineering
8 Electrical engineering
9 Industrial Engineering
10 Mathematics
11 Mechanical Engineering
12 Physics

6 Computer Engineering
7 Computer Science
13 Software Engineering

15. How confident are you that you will keep this major through college? (**CIRCLE ONE RESPONSE ONLY**)

1 Very confident
2 Confident
3 50% confident
4 Not confident
5 Not at all confident

16. What sources of information did you use to decide what major to pursue in college?
(**CIRCLE ALL THAT APPLY**)

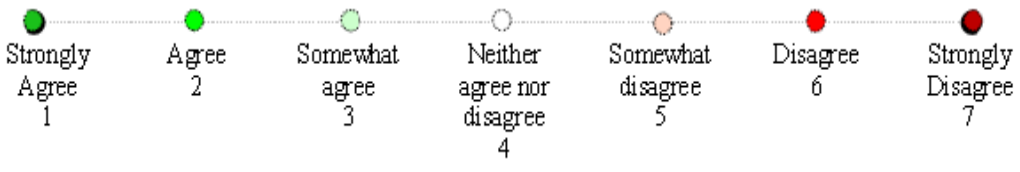
1 University advisors
2 University classes
3 University "open house" or campus visit days
4 Other university activities
5 National ranking data on the college or department
6 High school teacher
7 High school counselor
8 Suggestion(s) from peers
9 Parents' advice
10 Suggestion(s) from sibling, family member or family friend
11 Employer
12 Future employment prospects
13 Other (**SPECIFY**)
_____

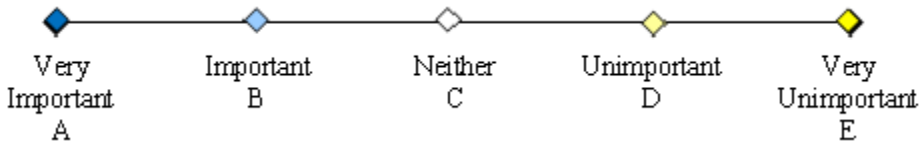
17. How supportive are your parents/guardians of your decision to study the major you specified above? (**CIRCLE ONE RESPONSE ONLY**)

1 Very supportive
2 Supportive
3 Somewhat supportive
4 Neutral
5 Not supportive
6 Against my choice of a major
7 Did not discuss choice with them

18. The statements below address expectations about studying the major you selected and using it in a career. Please indicate for each statement, the extent to which you agree or disagree with the statement and how important the statement is to you.

Use the two scales to indicate your agreement with the statement and the importance of it to you.





FOR EACH STATEMENT: CIRCLE ONE NUMBER ON THE AGREE/DISAGREE SCALE AND ONE LETTER ON THE IMPORTANCE SCALE

Statement 1. I can relate to the people around me in my classes

Statement 2. I think I can succeed in the curriculum of my major

Statement 3. I have a lot in common with the other students in my classes

Statement 4. I can make friends with people from different backgrounds or values

Statement 5. Someone like me can succeed in a getting a degree in the major I chose

Statement 6. Someone like me can succeed in a career in the major I chose

Statement 7. I can cope with being the only person of my race or ethnicity or gender in a class

Statement 8. I think I can succeed (earn an A or B) in my math courses

Statement 9. I think I can succeed (earn an A or B) in my science courses

Statement 10. I think I can succeed in my (earn an A or B) engineering courses

Statement 11. Doing well in math will enhance my career/job opportunities

Statement 12. I can succeed in my major's curriculum while not having to give up participation in my outside interests (e.g. extra-curricular activities, sports, family)

Statement 13. I can succeed in class while maintaining outside employment

Statement 14. I can relate to the people around me in my extra-curricular activities

Statement 15. I can excel in engineering/math/physics/chemistry

Statement 16. A degree in engineering/math/physics/chemistry will allow me to obtain a well paying job

Statement 17. I can complete an engineering/math/physics/chemistry degree

Statement 18. A degree in engineering/math/physics/chemistry will give me the life style I want

Statement 19. A degree in engineering/math/physics/chemistry will allow me to get a job where I can use my talents and creativity

Statement 20. A degree in engineering/math/physics/chemistry will allow me to obtain a job that I like

IV. For Students taking Mathematics

This section consists of statements describing views on mathematics and the study of mathematics.
The example below illustrates the 8 choices that you have for answering the following questions.

EXAMPLE

Learning mathematics requires:
(a) a serious effort
(b) a special talent

SCALE TO USE:

What does each of the 8 choices mean?

1 Only (a) Never (b) ➔ Learning math requires **only** serious effort and any special talent **never** makes a difference.

2 Mostly (a), Rarely (b) ➔ Learning mathematics requires **mostly** serious effort and **rarely** any special talent.

3 More (a) Than (b) ➔ Learning mathematics requires **more** serious effort **than** special talent.

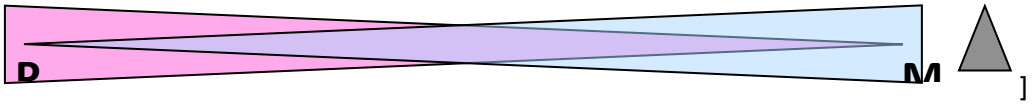
4 Equally (a) & (b) ➔ Learning mathematics **equally** requires **both** serious effort and special talent.

5 More (b) Than (a) ➔ Learning mathematics requires **more** of a special talent **than** of serious effort.

6 Mostly (b), Rarely (a) ➔ Learning mathematics requires **mostly** special talent and **rarely** just serious effort.

7 Only(b), Never(a) ➔ Learning math requires **only** a special talent for math & serious effort **never** makes a difference.

8 Neither (a) Nor (b) ➔ Learning mathematics requires **neither** special talent **nor** serious effort.



Only (a) Never (b)	Mostly (a) Rarely (b)	More (a) Than (b)	Equally (a) and (b)	More (b) Than (a)	Mostly (b) Rarely (a)	Only (b) Never (a)	Neither (a) and (b)
1	2	3	4	5	6	7	8

CIRCLE ONE NUMBER ON THE GRAPHIC SCALE ASOCIATED WITH EACH

STATEMENT.

1. Learning math requires:
   (a) a serious effort
   (b) a special talent

2. If I had a choice:
   (a) I would never take any mathematics courses
   (b) I would still take mathematics for my own benefit

3. Reasoning skills that are taught in mathematics courses can be helpful to me.
   (a) in my everyday life
   (b) if I were to major in mathematics or in a related field

4. I study mathematics:
   (a) to satisfy course requirements
   (b) to learn useful knowledge

5. My score on mathematics exams is a measure of how well:
   (a) I understand the covered material
   (b) I can do things the way they are done by the teacher or in some course materials

6. For me, doing well in mathematics courses depends on:
   (a) how much effort I put into studying
   (c) how well the teacher explains things in class

7. When I experience a difficulty in studying mathematics:
   (a) I immediately seek help or give up trying
   (b) I try hard to figure it out on my own

8. When studying mathematics in a textbook or in course materials:

(a) I find the important information and memorize it the way it is presented
(b) I organize the material in my own way so that I can understand it

9. For me, the relationship of mathematics courses to every day life is usually:
(a) easy to recognize
(b) hard to recognize

10. In mathematics, it is important for me to:
(a) memorize technical terms and mathematics formulas
(b) learn ways to organize information and use it

11. Mathematical formulas:
(a) express meaningful relationships among variables
(b) provide ways to get numerical answers to problems

12. After I go through a mathematics text or course materials and feel that I understand them:
(a) I can solve related problems on my own
(b) I have difficulty solving related problems

13. The first thing I do when solving a real world problem that involves mathematics is:
(a) represent the situation with sketches and drawings
(b) search for formulas that relate givens to unknowns

14. In order to solve a mathematics problem, I need to:
(a) have seen the solution to a similar problem before
(b) apply general problem solving techniques

15. For me, solving a mathematics problem in more than one way:
(a) is a waste of time
(b) helps develop my reasoning skills

16. After I have answered all questions in a homework mathematics problem:
(a) I stop working on the problem
(b) I check my answers and the way I have obtained them

17. After the teacher solves a mathematics problem for which I got a wrong solution:
(a) I discard my solution and learn the one presented by the teacher
(b) I try to figure out how the teacher's solution differs from mine

18. How well I do on mathematics exams depends on how well I can:
(a) recall material in the way it was presented in class
(b) do tasks that are somewhat different from ones I have seen before

19. In order to prove a mathematical theorem one must:
(a) produce evidence from the physical world

(b) provide a logically sound argument

20. When they represent relationships in the physical world, mathematical functions are:
    (a) exact expressions of what is being represented
    (b) approximate expressions of what is being represented

21. After a theorem has been proven and accepted in mathematics:
    (a) it will never be changed
    (b) it may be rejected at a future time

22. The relationship among the sides of a right triangle expressed in the Pythagorean theorem is true because it has been:
    (a) proven by a logical argument
    (b) verified by measurement

23. Collecting and graphing real world data is useful for:
    (a) determining patters and making general predictions
    (b) obtaining numerical answers to specific problems

24. For me, making unsuccessful attempts when solving a mathematics problem is:
    (a) a natural part of my pursuit of a solution to the problem
    (b) an indication of my incompetence in mathematics

25. When solving a challenging mathematics problem, a mathematician:
    (a) makes many incorrect attempts
    (b) moves directly to a correct solution

26. If we want to apply a method used for solving one mathematics problem to another problem, the objects involved in the two problems must be:
    (a) identical in all respects
    (b) similar in some respects

27. Different branches of mathematics, like geometry and algebra:
    (a) are related by common principals
    (b) have no relationship to one another

28. Scientists use mathematics as:
    (a) a tool for analyzing and communicating their data
    (b) a source of factual knowledge about the natural world

29. For me, solving a problem that involves

mathematical reasoning is:
(a) an enjoyable experience
(b) a frustrating experience

30. Graphing calculators and computers:
(a) bring new methods for solving mathematics problems
(b) speed up problem solving using established methods

31. Using graphing calculators or computers:
(a) increases my interest in studying mathematics
(b) is a waste of time

32. In solving mathematics problems, graphing calculators or computers help me:
(a) understand the underlying mathematics ideas
(b) obtain numerical answers to problems

THANK YOU FOR COMPLETING THE QUESTIONNAIRE!

V. FOR STUDENTS TAKING CHEMISTRY

This section consists of statements describing views on chemistry and the study of chemistry.

The example below illustrates the 8 choices that you have for answering the following questions.

EXAMPLE

Learning chemistry requires:
(a) a serious effort
(b) a special talent

What does each of the 8 choices mean?

1 Only (a) Never (b) ➔ Learning chemistry requires **only** a serious effort and **no** special talent at all.

2 Mostly (a), Rarely (b) ➔ Learning chemistry requires **far more** a serious effort than a special talent.

3 More (a) Than (b) ➔ Learning chemistry requires **somewhat more** a serious effort than a special talent.

4 Equally (a) & (b) ➔ Learning chemistry **equally** requires **both** a serious effort and a special talent.

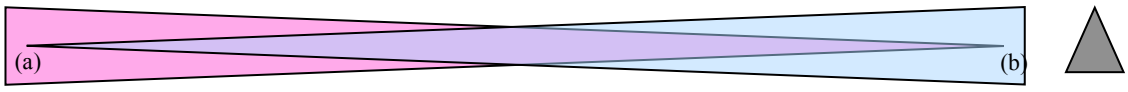
5 More (b) Than (a) ➔ Learning chemistry requires **somewhat more** a special talent than a serious effort.

6 Mostly (b), Rarely (a) ➔ Learning chemistry requires **far more** a special talent than a serious effort.

7 Only (b), Never (a) ➔ Learning chemistry requires **only** a special talent and **no** serious effort at all.

8 Neither (a) Nor (b) ➔ Learning chemistry requires **neither** a special talent **nor** a serious effort.

SCALE TO USE:



Only (a) Never (b)	Mostly (a) Rarely (b)	More (a) Than (b)	Equally (a) and (b)	More (b) Than (a)	Mostly (b) Rarely (a)	Only (b) Never (a)	Neither (a) and (b)
1	2	3	4	5	6	7	8

CIRCLE ONE NUMBER ON THE GRAPHIC SCALE ASOCIATED WITH EACH STATEMENT.

1. Learning chemistry requires:
   (a) a serious effort
   (b) a special talent

2. If I had a choice:
   (a) I would never take any chemistry courses
   (b) I would still take chemistry for my own benefit

3. Reasoning skills that are taught in chemistry courses can be helpful to me.
   (a) in my everyday life
   (b) if I were to become a scientist

4. I study chemistry:
   (a) to satisfy course requirements
   (b) to learn useful knowledge

5. My score on chemistry exams is a measure of how well:
   (a) I understand the covered material
   (b) I can do things the way they are done by the teacher or in some course materials

6. For me, doing well in chemistry courses depends on:
   (a) how much effort I put into studying
   (b) how well the teacher explains things in class

7. When I experience a difficulty while studying chemistry:
   (a) I immediately seek help or give up trying
   (b) I try hard to figure it out on my own

8. When studying chemistry in a textbook or in course materials:
   (a) I find the important information and memorize it the way it is presented
   (b) I organize the material in my own way so that I can understand it

9. For me, the relationship of chemistry courses to every day life is usually:
   (a) easy to recognize
   (b) hard to recognize

10. In chemistry, it is important for me to:
    (a) memorize technical terms and chemistry formulas
    (b) learn ways to organize information and use it

11. In chemistry, mathematical formulas:
    (a) express meaningful relationships among variables
    (b) provide ways to get numerical answers to problems

12. After I go through a chemistry text or course materials and feel that I understand them:

    (a) I can solve related problems on my own

(b) I have difficulty solving related problems

13. The first thing I do when solving a chemistry problem is:
    (a) Try to visualize the process involved
    (b) search for formulas that relate givens to unknowns

14. In order to solve a chemistry problem, I need to:
    (a) have seen the solution to a similar problem before
    (b) apply general problem solving techniques

15. For me, solving a chemistry problem in more than one way:
    (a) is a waste of time
    (b) helps develop my reasoning skills

16. After I have answered all questions in a homework chemistry problem:
    (a) I stop working on the problem
    (b) I check my answers and the way I have obtained them

17. After the teacher solves a chemistry problem for which I got a wrong solution:

    (a) I discard my solution and learn the one presented by the teacher
    (b) I try to figure out how the teacher's solution differs from mine

18. How well I do on chemistry exams
    depends on how well I can:
    (a) recall material in the way it was presented in class
    (b) solve problems that are somewhat different from ones I have seen before

19. To me, chemistry is important as a source of:
    (a) factual information about the natural world
    (b) ways of thinking about the natural world

20. As they are currently used, the ideal gas laws in the kinetic molecular theory:

    (a) are the same through the universe
    (b) change depending on where you are in the universe

21. The laws of chemistry are:
    (a) inherent in the nature of things and independent of how humans think
    (b) invented by chemists to organize their knowledge about the natural world

22. The laws of chemistry portray the natural world:
    (a) exactly the way it is
    (b) by approximation

23. Chemists say that electrons and protons exist in an atom because:
    (a) they have seen these particles in their actual form with some instruments
    (b) they have made observations that can be explained with particles

24. The ideal gas laws in the kinetic molecular theory:
    (a) will always be used as they are

(b) could eventually be replaced by other laws

25. Chemists' current ideas about the particles making up the atom:
    (a) will always be maintained as they are
    (b) could eventually be replaced by other ideas

26. If we want to apply a method used for solving one chemistry problem to another problem, the objects involved in the two problems must be:
    (a) identical in all respects
    (b) similar in some respects

27. Different branches of chemistry, like organic chemistry and inorganic chemistry:
    (c) are interrelated by common principals
    (d) have no relationship to one another

28. Physicists use mathematics as:
    (a) a tool for analyzing and communicating their ideas
    (b) a source of factual knowledge about the natural world

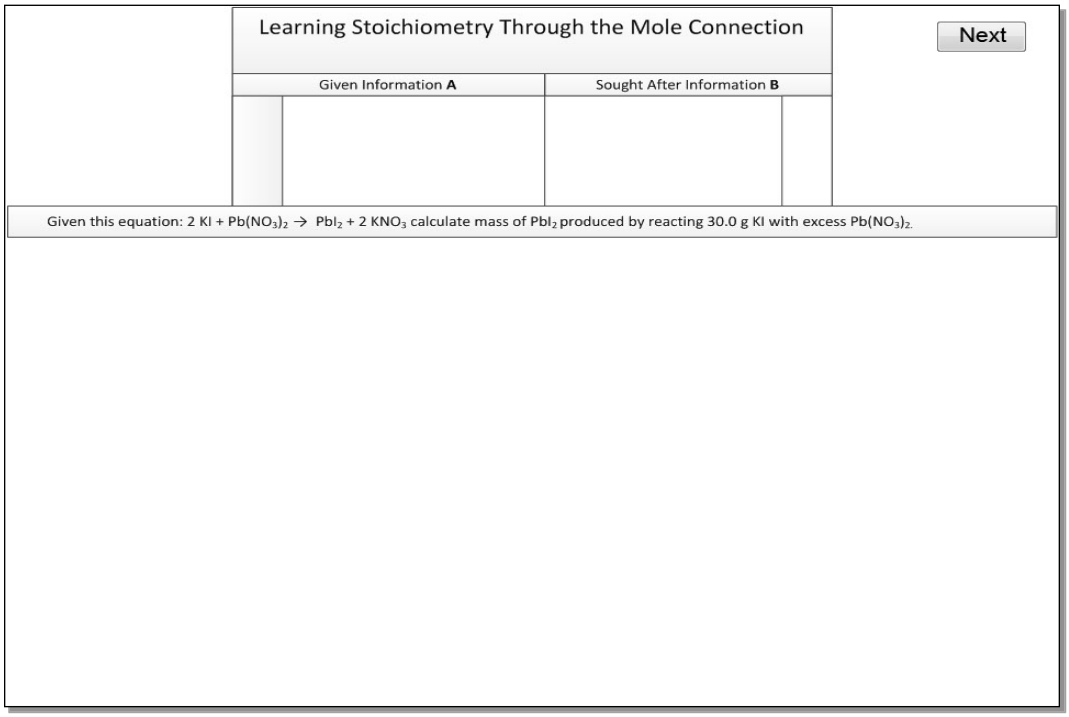
29. Scientific findings about the natural world:
    (a) dependent on current scientific knowledge
    (b) accidental, depending on scientists' luck

30. Knowledge in chemistry is:
    (a) related to knowledge in physics
    (b) independent of knowledge in physics

THANK YOU FOR COMPLETING THE QUESTIONNAIRE!

Appendix C

Mass to Mass Module - Operational Method


Learning Stoichiometry Through the Mole Connection
Next
Given Information A
Sought After Information B
Given this equation: 2 KI + $Pb(NO_3)_2$ → PbI_2 + 2 KNO_3 calculate mass of PbI_2 produced by reacting 30.0 g KI with excess $Pb(NO_3)_2$.

Previous

Learning Stoichiometry Through the Mole Connection

Next

Given Information **A**	Sought After Information **B**

Given this equation: $2\ KI + Pb(NO_3)_2 \rightarrow PbI_2 + 2\ KNO_3$ calculate mass of PbI_2 produced by reacting 30.0 g KI with excess $Pb(NO_3)_2$.

Step #0: **READ THE PROBLEM**. Since there is a reaction given, check if the reaction is balanced!!

$$2\ KI + Pb(NO_3)_2 \rightarrow PbI_2 + 2\ KNO_3$$

Previous

Learning Stoichiometry Through the Mole Connection

Next

Given Information **A**	Sought After Information **B**

Given this equation: $2\ KI + Pb(NO_3)_2 \rightarrow PbI_2 + 2\ KNO_3$ calculate mass of PbI_2 produced by reacting 30.0 g KI with excess $Pb(NO_3)_2$.

Step #0: **READ THE PROBLEM**. Since there is a reaction given, check if the reaction is balanced!!

Balance Check: Remember the number of atoms on the reactant side **must equal** the number of atoms on the products side

$$2\ KI + Pb(NO_3)_2 \rightarrow PbI_2 + 2\ KNO_3$$

Reactants	**Products**
K: 2	**K: 2**
Pb: 1	**Pb: 1**
N: 2	**N: 2**
O: 6	**O: 6**

The reaction is Balanced!

Fill-In-The-Blank

Given this equation: $2\ KI + Pb(NO_3)_2 \rightarrow PbI_2 + 2\ KNO_3$
calculate mass of PbI_2 produced by reacting 30.0 g KI with excess $Pb(NO_3)_2$.

Complete the sentence below by filling in the blanks.

I am given the mass of KI and I want to find the mass of PbI2 .

Review Area

You must answer the question before continuing.

Question 1 of 16

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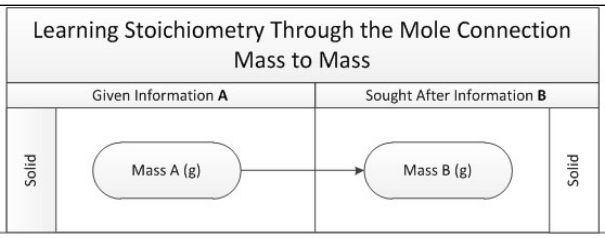
Learning Stoichiometry Through the Mole Connection
Mass to Mass

Next



Given this equation: 2 KI + $Pb(NO_3)_2$ → PbI_2 + 2 KNO_3 calculate mass of PbI_2 produced by reacting of 30.0 g KI with excess $Pb(NO_3)_2$.

Step #1: Setup a strategy for solving the problem by organizing what is given, and identifying what the problem is asking. Ask yourself, "What am I Given?" and "What does the problem Want."

Given this equation: **2 KI** + $Pb(NO_3)_2$ → **PbI_2** + 2 KNO_3
(balanced) calculate mass of PbI_2 produced by reacting of
30.0 g KI with excess $Pb(NO_3)_2$.

Strategy: (Can be done in any order)

I. **Identify** what the question is asking for, an what you **WANT** to know.

II. Highlight any necessary **GIVEN** information and what is needed to solve the problem.

III. If a reaction is needed to solve the problem, produce the balanced chemical reaction.

True/False

Given this equation: $2\ KI + Pb(NO_3)_2 \rightarrow PbI_2 + 2\ KNO_3$ calculate mass of PbI_2 produced by reacting 30.0 g KI with excess $Pb(NO_3)_2$.

You can directly solve for the mass of PbI_2 from the mass of KI using the stoichiometric ratio.

- True
- False

Review Area

You must answer the question before continuing.

Question 2 of 16

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Learning Stoichiometry Through the Mole Connection
Mass to Mass

Given this equation: 2 KI + $Pb(NO_3)_2$ --> PbI_2 + 2 KNO_3 calculate mass of PbI_2 produced by reacting 30.0 g KI with excess $Pb(NO_3)_2$.

Step #1: Setup a strategy for solving the problem by organizing what is given, and identifying what the problem is asking. Ask yourself, "What am I Given?" and "What does the problem Want."

Note: You **CANNOT** go from **Mass KI** to **Mass PbI_2** directly!
Need to go through **Mole** **to** **Mole** Conversion!

Multiple Choice

Given this equation: $2\ KI + Pb(NO_3)_2 \rightarrow PbI_2 + 2\ KNO_3$
calculate mass of PbI_2 produced by reacting 30.0 g KI with excess $Pb(NO_3)_2$.

Since you cannot solve for the mass of PbI_2 directly you need to also find the:

- [x] A) moles of KI
- [ ] B) density of KI
- [x] C) moles of PbI_2
- [ ] D) volume of PbI_2

Review Area

Review Area

You must answer the question before continuing.

Question 3 of 16

Clear Back Skip Submit

Fill-In-The-Blank

Given this equation: $2\ KI + Pb(NO_3)_2 \rightarrow PbI_2 + 2\ KNO_3$
calculate mass of PbI_2 produced by reacting 30.0 g KI with excess $Pb(NO_3)_2$.

Fill in the map needed to solve this problem

mass KI → mol KI → mol PbI2 → mass PbI2

Review Area

You must answer the question before continuing.

Question 4 of 16

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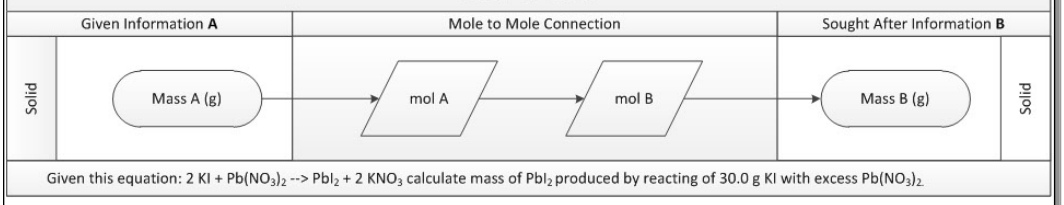
Learning Stoichiometry Through the Mole Connection
Mass to Mass

Next



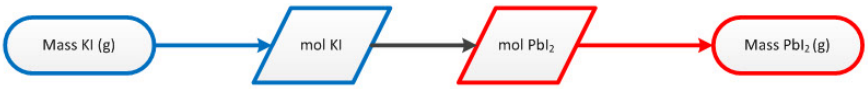
Given this equation: 2 KI + $Pb(NO_3)_2$ --> PbI_2 + 2 KNO_3 calculate mass of PbI_2 produced by reacting of 30.0 g KI with excess $Pb(NO_3)_2$.

Step #1: Setup a strategy for solving the problem by organizing what is given, and identifying what the problem is asking. Ask yourself, "What am I Given?" and "What does the problem Want."

Given
Mass KI: 30.0 g KI

Want
Mass PbI_2: ? g PbI_2

Step #2: Redraw your map including **Mole** to **Mole** Conversion



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Learning Stoichiometry Through the Mole Connection
Mass to Mass

Next

Given Information **A**	Mole to Mole Connection	Sought After Information **B**
Solid: Mass KI (g)	mol KI → mol PbI_2	Mass PbI_2 (g): Solid

Given this equation: 2 KI + $Pb(NO_3)_2$ --> PbI_2 + 2 KNO_3 calculate mass of PbI_2 produced by reacting 30.0 g KI with excess $Pb(NO_3)_2$.

Step #3: Organize any additional information necessary to solve this problem (ie. Molar Mass, Stoichiometric Ratio, etc.)

Given

Mass KI: 30.0 g KI

Want

Mass PbI_2: ? g PbI_2

The problem can be broken down into three parts

Part #1 Requires Molar Mass;
"Mass to Moles" Molar Mass!!

Molar Mass KI: 166 g/mol KI

Previous

Learning Stoichiometry Through the Mole Connection
Mass to Mass

Next

Given Information **A**	Mole to Mole Connection	Sought After Information **B**
Solid: Mass KI (g)	mol KI → mol PbI_2	Mass PbI_2 (g) : Solid

Given this equation: 2 KI + $Pb(NO_3)_2$ --> PbI_2 + 2 KNO_3 calculate mass of PbI_2 produced by reacting 30.0 g KI with excess $Pb(NO_3)_2$.

Step #3: Organize any additional information necessary to solve this problem (ie. Molar Mass, Stoichiometric Ratio, etc.)

Given

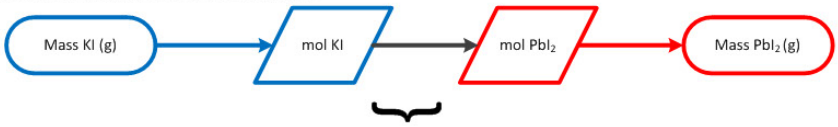
Mass KI: 30.0 g KI

Molar Mass KI: 166 g/mol KI

Want

Mass PbI_2: ? g PbI_2

The problem can be broken down into three parts



Part #2 Requires **Mole** to **Mole** Stoichiometric Ratio

$$\boxed{2\ KI} + 1\ Pb(NO_3)_2 \rightarrow \boxed{1\ PbI_2} + 2\ KNO_3$$

Previous

Learning Stoichiometry Through the Mole Connection
Mass to Mass

Next

Given Information **A**	Mole to Mole Connection	Sought After Information **B**
Solid: Mass KI (g)	mol KI → mol PbI_2	Mass PbI_2 (g): Solid

Given this equation: 2 KI + $Pb(NO_3)_2$ --> PbI_2 + 2 KNO_3 calculate mass of PbI_2 produced by reacting 30.0 g KI with excess $Pb(NO_3)_2$.

Step #3: Organize any additional information necessary to solve this problem (ie. Molar Mass, Stoichiometric Ratio, etc.)

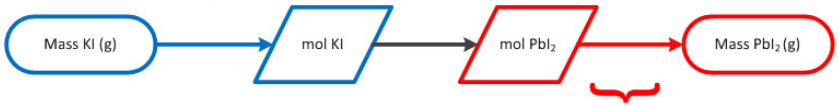
Given

Mass KI: 30.0 g KI
Molar Mass KI: 166 g/mol KI
S. Ratio KI: 2 mol KI

Want

Mass PbI_2: ? g PbI_2
S. Ratio PbI_2: 1 mol PbI_2

The problem can be broken down into three parts



Part #3 Requires Molar Mass;
"Moles to Mass" Molar Mass!!

Molar Mass PbI_2: 461 g/mol PbI_2

Fill-In-The-Blank

Given this equation: $2\ KI + Pb(NO_3)_2 \rightarrow PbI_2 + 2\ KNO_3$
calculate mass of PbI_2 produced by reacting 30.0 g KI with excess $Pb(NO_3)_2$.

Consider the following question and fill in the blank by setting up the operation.

Part I requires you to find the **moles of KI** from the **mass of KI (MW: 166 g/mol KI)**.

mass KI → mol KI

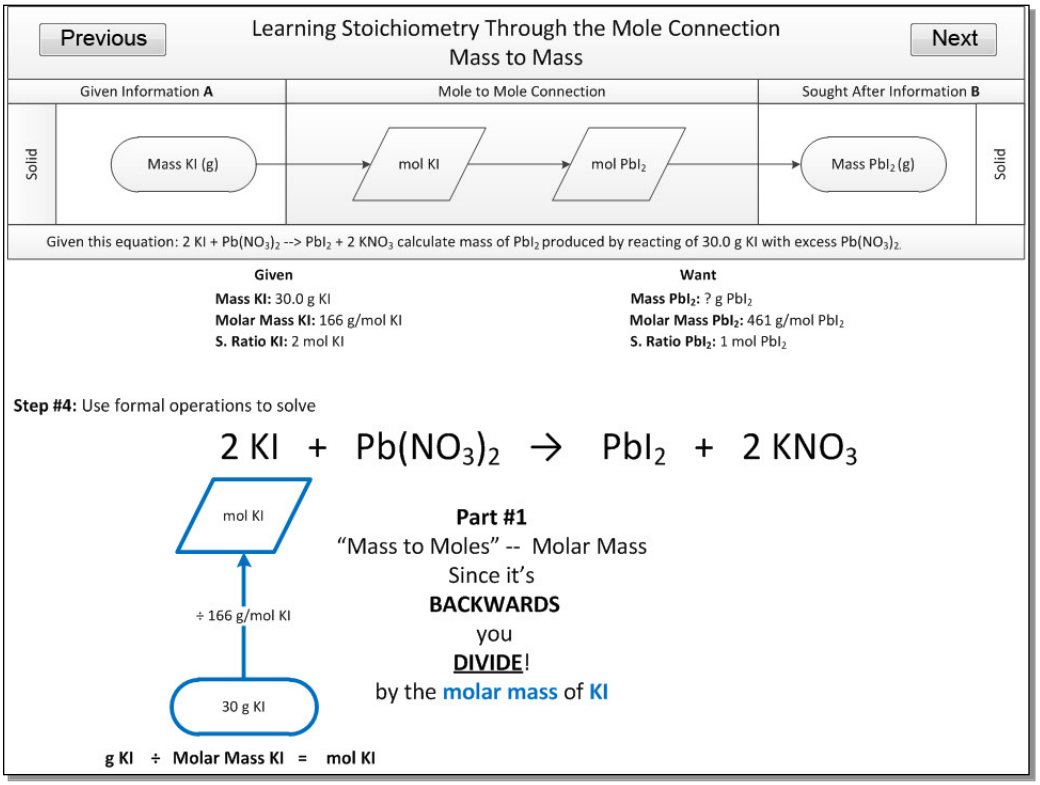
moles of KI (mol) = 30.0 g KI / 166 g/mol KI

Review Area

You must answer the question before continuing.

Question 5 of 16

Clear Back Skip Submit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Learning Stoichiometry Through the Mole Connection
Mass to Mass
Next
Given Information A
Mole to Mole Connection
Sought After Information B
Solid
Mass KI (g)
mol KI
mol PbI2
Mass PbI2 (g)
Solid
Given this equation: 2 KI + Pb(NO3)2 --> PbI2 + 2 KNO3 calculate mass of PbI2 produced by reacting of 30.0 g KI with excess Pb(NO3)2.
Given
Mass KI: 30.0 g KI
Molar Mass KI: 166 g/mol KI
S. Ratio KI: 2 mol KI
Want
Mass PbI2: ? g PbI2
Molar Mass PbI2: 461 g/mol PbI2
S. Ratio PbI2: 1 mol PbI2
Step #4: Use formal operations to solve
2 KI + Pb(NO3)2 → PbI2 + 2 KNO3
mol KI
÷ 166 g/mol KI
30 g KI
Part #1
"Mass to Moles" -- Molar Mass
Since it's
BACKWARDS
you
DIVIDE!
by the molar mass of KI
g KI ÷ Molar Mass KI = mol KI

Fill-In-The-Blank

Given this equation: $2\ KI + Pb(NO_3)_2 \rightarrow PbI_2 + 2\ KNO_3$
calculate mass of PbI_2 produced by reacting 30.0 g KI with excess $Pb(NO_3)_2$.

Consider the following question and fill in the blank.

Part II requires you to find the **moles of PbI_2** from the **moles of KI** found in **Part I**.

mol KI → mol PbI_2

moles of PbI_2 (mol) = 1.807×10^{-1} mol KI * $\frac{\text{1 mol PbI2 (want)}}{\text{2 mol KI (given)}}$

You must answer the question before continuing.

Review Area

Question 6 of 16

Clear Back Skip Submit

Previous

Learning Stoichiometry Through the Mole Connection
Mass to Mass

Next

Given Information **A**	Mole to Mole Connection	Sought After Information **B**
Solid: Mass KI (g)	mol KI → mol PbI_2	Mass PbI_2 (g) :Solid

Given this equation: 2 KI + $Pb(NO_3)_2$ --> PbI_2 + 2 KNO_3 calculate mass of PbI_2 produced by reacting of 30.0 g KI with excess $Pb(NO_3)_2$.

Given

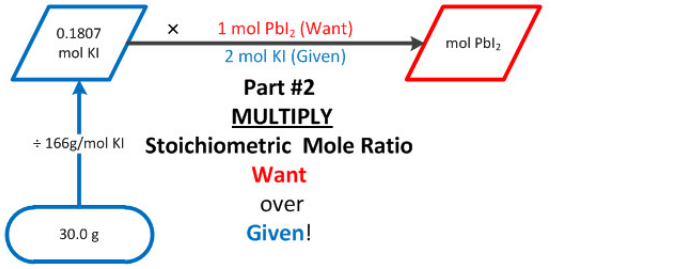
Mass KI: 30.0 g KI
Molar Mass KI: 166 g/mol KI
S. Ratio KI: 2 mol KI

Want

Mass PbI_2: ? g PbI_2
Molar Mass PbI_2: 461 g/mol PbI_2
S. Ratio PbI_2: 1 mol PbI_2

Step #4: Use formal operations to solve

$$2\ KI + Pb(NO_3)_2 \rightarrow PbI_2 + 2\ KNO_3$$



Part #2
MULTIPLY
Stoichiometric Mole Ratio
Want
over
Given!

Fill-In-The-Blank

Given this equation: 2 KI + $Pb(NO_3)_2$ → PbI_2 + 2 KNO_3
calculate mass of PbI_2 produced by reacting 30.0 g KI with excess $Pb(NO_3)_2$.

Consider the following question and fill in the blank.

Part III requires you find the **mass of PbI_2** (MW: 461 g/mol PbI_2) from the **moles of PbI_2** found in **Part II**.

mol PbI_2 → mass PbI_2

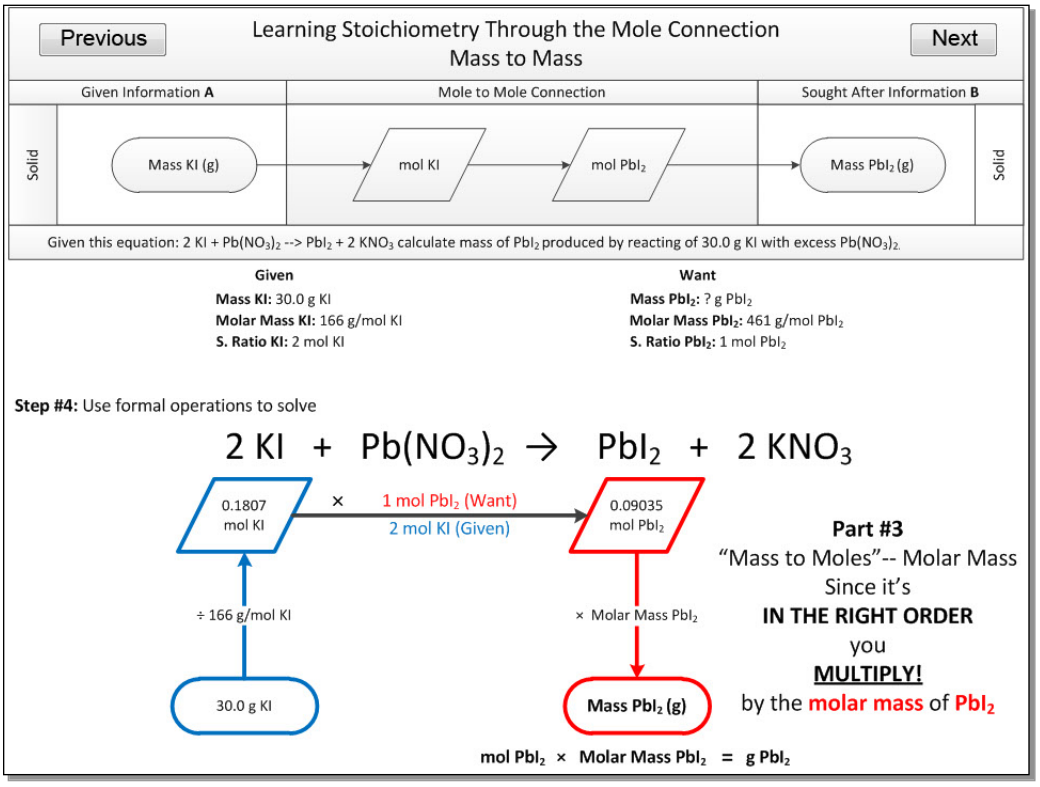
mass of PbI_2 (g) = 9.035 x 10^{-2} mol PbI_2 * 461 g/mol PbI2

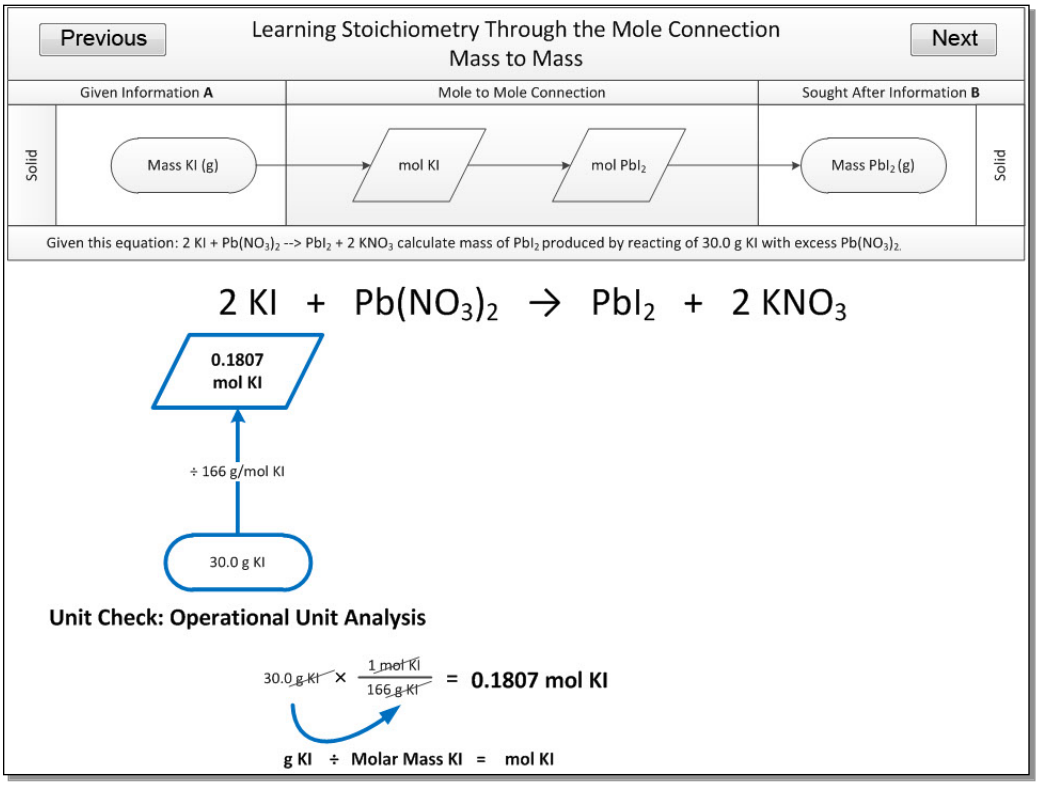
Review Area

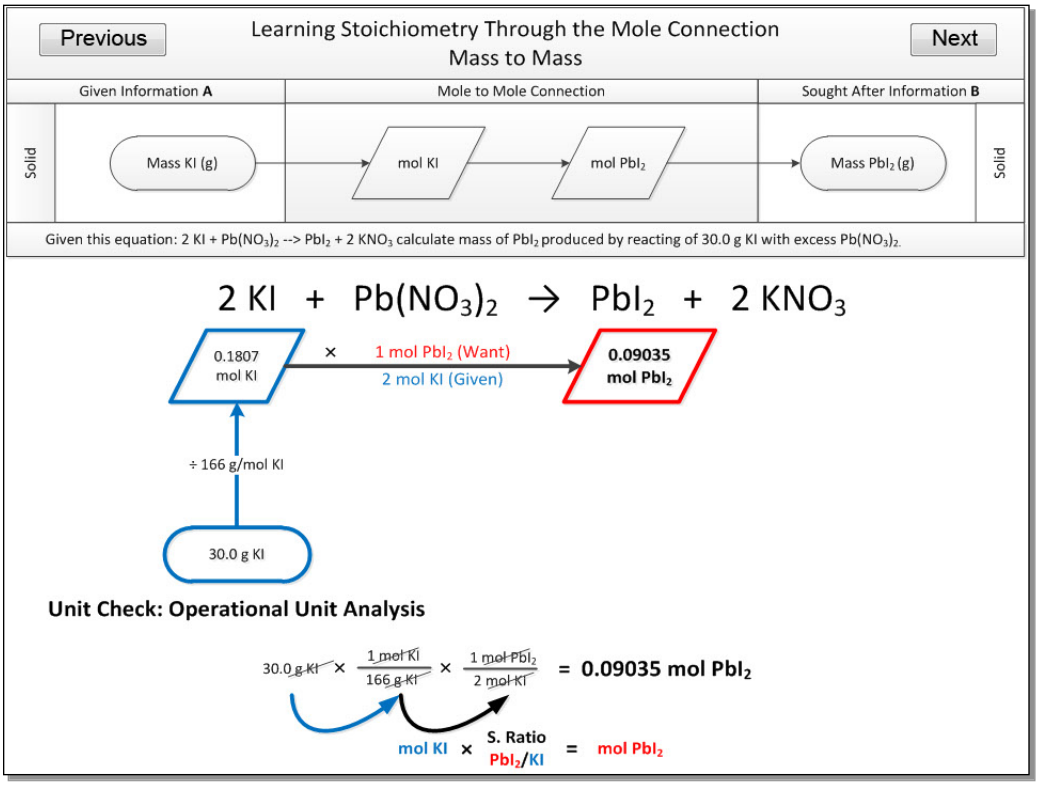
You must answer the question before continuing.

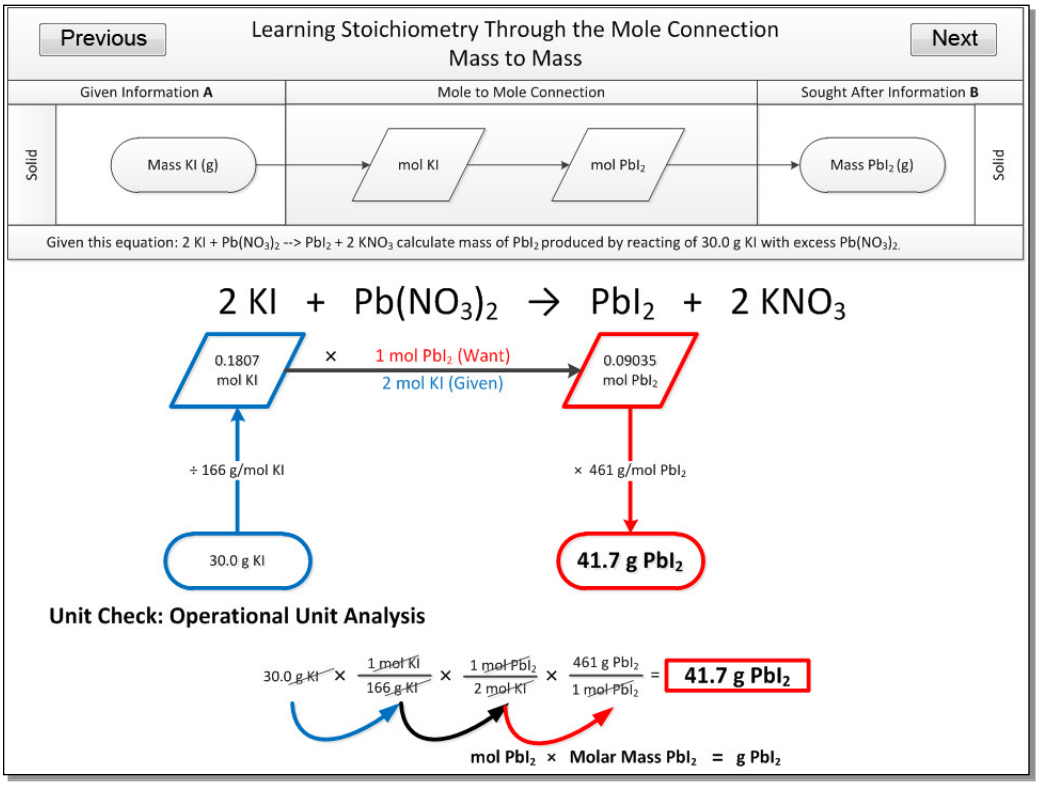
Question 7 of 16

Clear Back Skip Submit


Previous
Learning Stoichiometry Through the Mole Connection
Mass to Mass
Next
Given Information A
Mole to Mole Connection
Sought After Information B
Solid
Mass KI (g)
mol KI
mol PbI2
Mass PbI2 (g)
Solid
Given this equation: 2 KI + Pb(NO3)2 --> PbI2 + 2 KNO3 calculate mass of PbI2 produced by reacting of 30.0 g KI with excess Pb(NO3)2.
Given
Mass KI: 30.0 g KI
Molar Mass KI: 166 g/mol KI
S. Ratio KI: 2 mol KI
Want
Mass PbI2: ? g PbI2
Molar Mass PbI2: 461 g/mol PbI2
S. Ratio PbI2: 1 mol PbI2
Step #4: Use formal operations to solve
2 KI + Pb(NO3)2 → PbI2 + 2 KNO3
0.1807 mol KI
×
1 mol PbI2 (Want)
2 mol KI (Given)
0.09035 mol PbI2
÷ 166 g/mol KI
× Molar Mass PbI2
30.0 g KI
Mass PbI2 (g)
Part #3
"Mass to Moles"-- Molar Mass
Since it's
IN THE RIGHT ORDER
you
MULTIPLY!
by the molar mass of PbI2
mol PbI2 × Molar Mass PbI2 = g PbI2


Previous
Learning Stoichiometry Through the Mole Connection
Mass to Mass
Next
Given Information A
Mole to Mole Connection
Sought After Information B
Solid
Mass KI (g)
mol KI
mol PbI2
Mass PbI2 (g)
Solid
Given this equation: 2 KI + Pb(NO3)2 --> PbI2 + 2 KNO3 calculate mass of PbI2 produced by reacting of 30.0 g KI with excess Pb(NO3)2.
2 KI + Pb(NO3)2 → PbI2 + 2 KNO3
0.1807 mol KI
÷ 166 g/mol KI
30.0 g KI
Unit Check: Operational Unit Analysis
30.0 g KI × 1 mol KI / 166 g KI = 0.1807 mol KI
g KI ÷ Molar Mass KI = mol KI


Previous
Learning Stoichiometry Through the Mole Connection
Mass to Mass
Next
Given Information A
Mole to Mole Connection
Sought After Information B
Solid
Mass KI (g)
mol KI
mol PbI2
Mass PbI2 (g)
Solid
Given this equation: 2 KI + Pb(NO3)2 --> PbI2 + 2 KNO3 calculate mass of PbI2 produced by reacting of 30.0 g KI with excess Pb(NO3)2.
2 KI + Pb(NO3)2 → PbI2 + 2 KNO3
0.1807 mol KI
× 1 mol PbI2 (Want) / 2 mol KI (Given)
0.09035 mol PbI2
÷ 166 g/mol KI
30.0 g KI
Unit Check: Operational Unit Analysis
30.0 g KI × 1 mol KI / 166 g KI × 1 mol PbI2 / 2 mol KI = 0.09035 mol PbI2
mol KI × S. Ratio PbI2/KI = mol PbI2


Previous
Learning Stoichiometry Through the Mole Connection
Mass to Mass
Next
Given Information A
Mole to Mole Connection
Sought After Information B
Solid
Mass KI (g)
mol KI
mol PbI2
Mass PbI2 (g)
Solid
Given this equation: 2 KI + Pb(NO3)2 --> PbI2 + 2 KNO3 calculate mass of PbI2 produced by reacting of 30.0 g KI with excess Pb(NO3)2.
2 KI + Pb(NO3)2 → PbI2 + 2 KNO3
0.1807 mol KI
× 1 mol PbI2 (Want) / 2 mol KI (Given)
0.09035 mol PbI2
÷ 166 g/mol KI
× 461 g/mol PbI2
30.0 g KI
41.7 g PbI2
Unit Check: Operational Unit Analysis
30.0 g KI × 1 mol KI / 166 g KI × 1 mol PbI2 / 2 mol KI × 461 g PbI2 / 1 mol PbI2 = 41.7 g PbI2
mol PbI2 × Molar Mass PbI2 = g PbI2

Fill-In-The-Blank

Given this equation: $2\ KI + Pb(NO_3)_2 \rightarrow PbI_2 + 2\ KNO_3$
calculate mass of PbI_2 produced by reacting of 30.0 g KI with excess $Pb(NO_3)_2$.

Using the map
mass KI → mol KI → mol PbI_2 → mass PbI_2

Combine all three parts into 1 set of operations to solve for the mass of PbI_2.

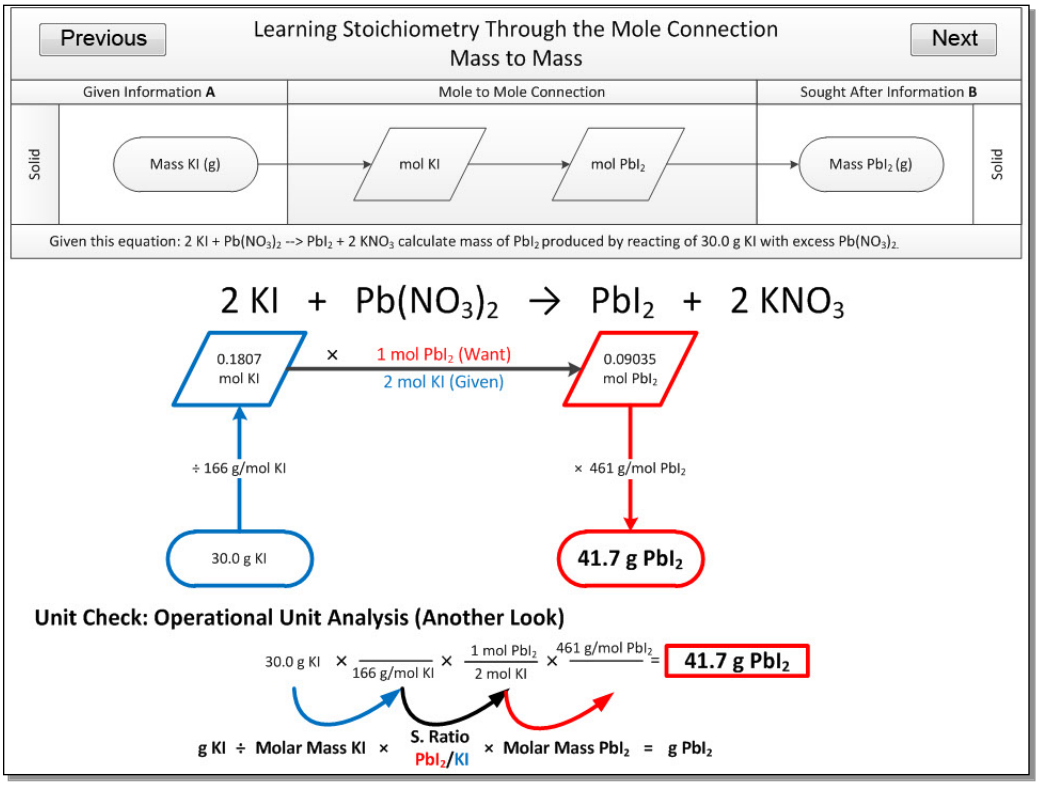
mass of PbI_2 (g) = 30 g KI / 166 g/mol KI * 1 mol PbI2 * 461 g/mol PbI2
2 mol KI

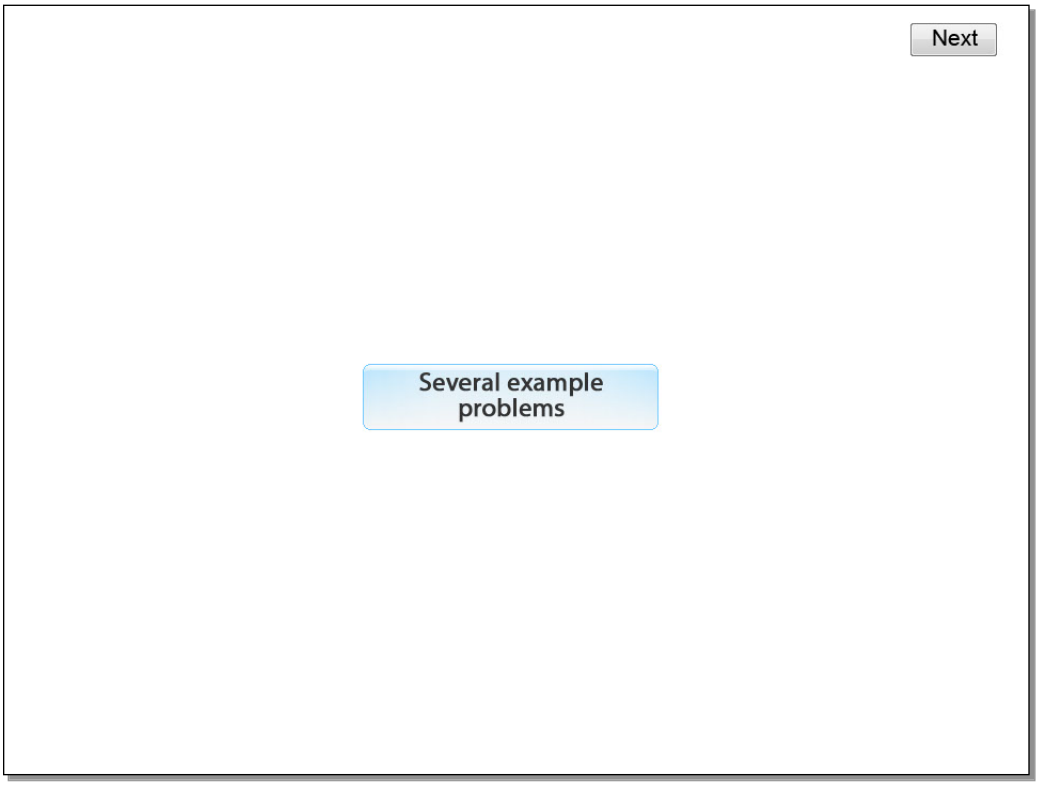
Review Area

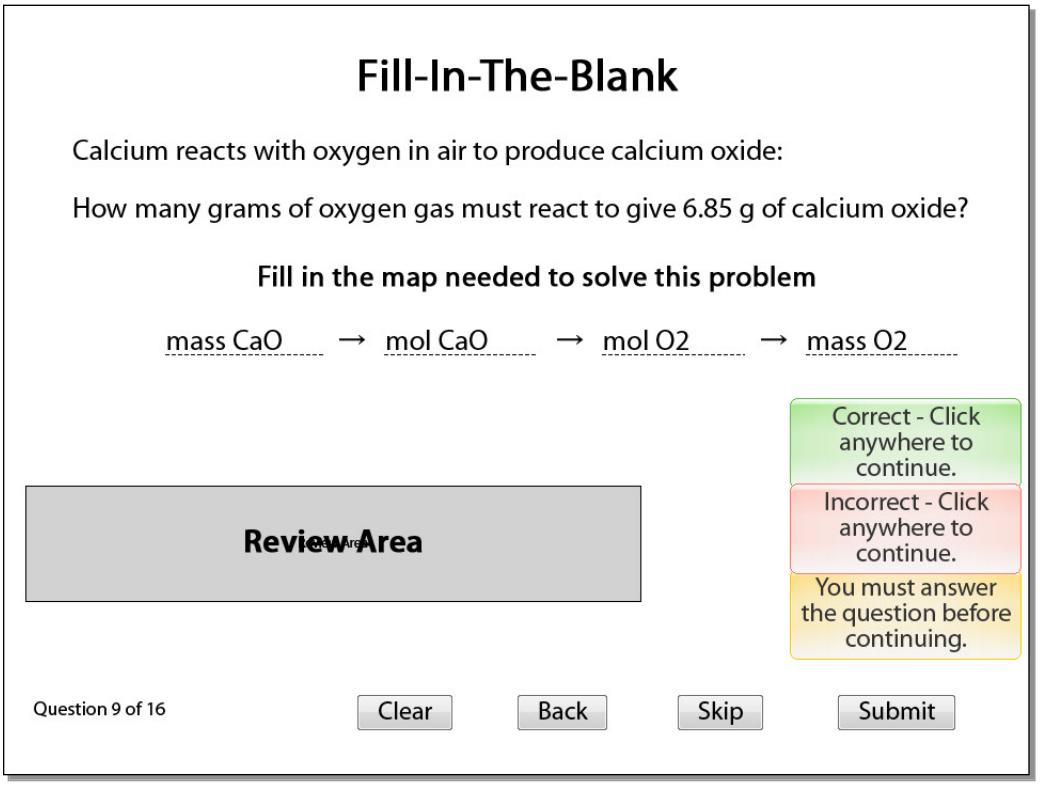
You must answer the question before continuing.

Question 8 of 16

Clear Back Skip Submit


Previous
Learning Stoichiometry Through the Mole Connection
Mass to Mass
Next
Given Information A
Mole to Mole Connection
Sought After Information B
Solid
Mass KI (g)
mol KI
mol PbI2
Mass PbI2 (g)
Solid
Given this equation: 2 KI + Pb(NO3)2 --> PbI2 + 2 KNO3 calculate mass of PbI2 produced by reacting of 30.0 g KI with excess Pb(NO3)2.
2 KI + Pb(NO3)2 → PbI2 + 2 KNO3
0.1807 mol KI
× 1 mol PbI2 (Want) / 2 mol KI (Given)
0.09035 mol PbI2
÷ 166 g/mol KI
× 461 g/mol PbI2
30.0 g KI
41.7 g PbI2
Unit Check: Operational Unit Analysis (Another Look)
30.0 g KI × 1 / 166 g/mol KI × 1 mol PbI2 / 2 mol KI × 461 g/mol PbI2 / 1 = 41.7 g PbI2
g KI ÷ Molar Mass KI × S. Ratio PbI2/KI × Molar Mass PbI2 = g PbI2


Next
Several example problems


Fill-In-The-Blank
Calcium reacts with oxygen in air to produce calcium oxide:
How many grams of oxygen gas must react to give 6.85 g of calcium oxide?
Fill in the map needed to solve this problem
mass CaO → mol CaO → mol O2 → mass O2
Correct - Click anywhere to continue.
Incorrect - Click anywhere to continue.
You must answer the question before continuing.
Review Area
Question 9 of 16
Clear
Back
Skip
Submit

Fill-In-The-Blank

Calcium reacts with oxygen in air to produce calcium oxide:

How many grams of oxygen gas must react to give 6.85 g of calcium oxide?

Given the map: **mass CaO → mol CaO → mol O_2 → mass O_2**

Part I requires you to find the **moles of CaO** from the **mass of CaO (MW: 56.1 g/mol)**.

moles of CaO (mol) = 6.85 g CaO / 56.1 g/mol CaO

Review Area

Question 10 of 16

Correct - Click anywhereto continue.

Incorrect - Click anywhereto continue.

You must answer the question before continuing.

Clear Back Skip Submit

Fill-In-The-Blank

Calcium reacts with oxygen in air to produce calcium oxide:

How many grams of oxygen gas must react to give 6.85 g of calcium oxide?

Given the map: **mass CaO → mol CaO → mol O_2 → mass O_2**

Balanced Reaction: **2 Ca (s) + O_2 (g) → 2 CaO (s)**

Part II requires you to solve for the moles of O_2 from the moles of CaO found in **Part I:**

moles of O_2 (mol) = 1.221×10^{-1} mol CaO * $\frac{\text{1 mol O2 (want)}}{\text{2 mol CaO (given)}}$

Review Area

Correct - Click anywhereto continue.

Incorrect - Click anywhereto continue.

You must answer the question before continuing.

Question 11 of 16

Clear Back Skip Submit

Fill-In-The-Blank

Calcium reacts with oxygen in air to produce calcium oxide:

How many grams of oxygen gas must react to give 6.85 g of calcium oxide?

Given the map: **mass CaO → mol CaO → mol O_2 → mass O_2**

Part III requires you to solve for the mass of O_2 from the moles of O_2 (MW: 32.0 g/mol O_2) from **Part II**.

mass of O_2 (g) = 6.105×10^{-2} mol O_2 * 32.0 g/mol O2

Review Area

Question 12 of 16

Correct - Click anywhereto continue.

Incorrect - Click anywhereto continue.

You must answer the question before continuing.

Clear | Back | Skip | Submit

Fill-In-The-Blank

Calcium reacts with oxygen in air to produce calcium oxide:

How many grams of oxygen gas must react to give 6.85 g of calcium oxide?

Given the map: **mass CaO → mol CaO → mol O_2 → mass O_2**

Balanced Reaction: **2 Ca (s) + O_2 (g)--> 2 CaO (s)**

Solve for the mass of O_2, by combing all operations in one step (MW: CaO 56.1 g/mol CaO ; MW O_2 32.0 g/mol O_2)

mass of O_2 (g) = 6.85 g CaO / 56.1 g/mol CaO * $\frac{\text{1 mol O2}}{\text{2 mol CaO}}$ * 32.0 g/mol O2

Review Area

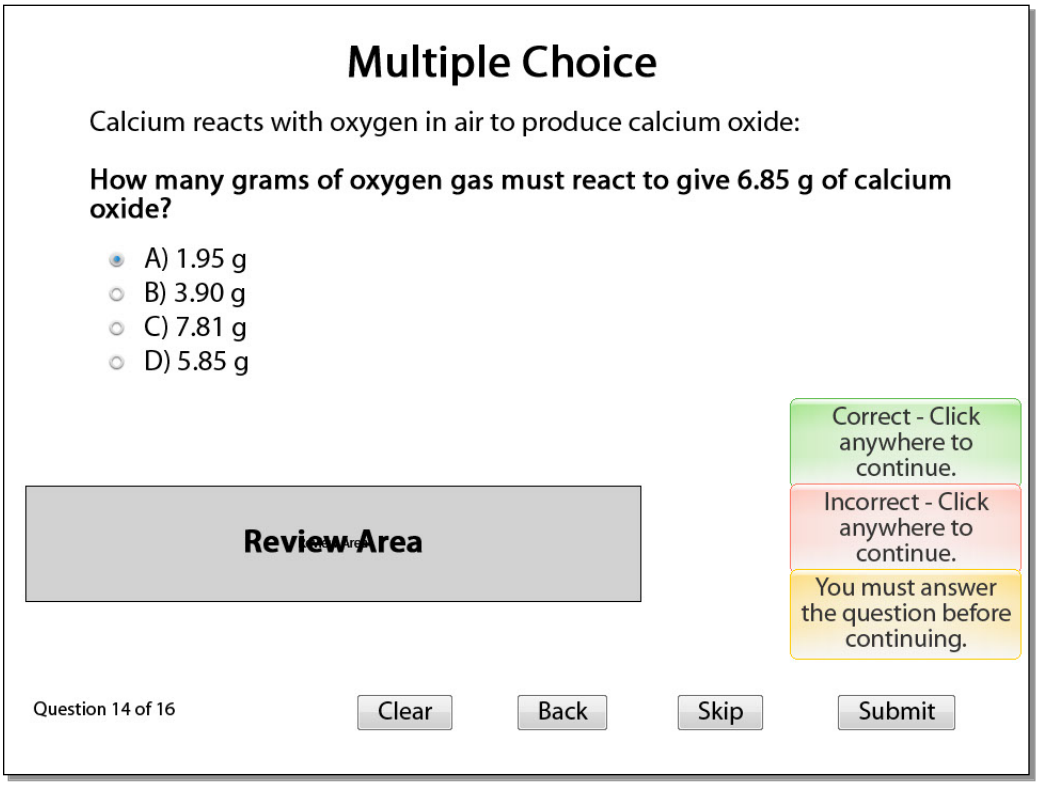
Correct - Click anywhere to continue.

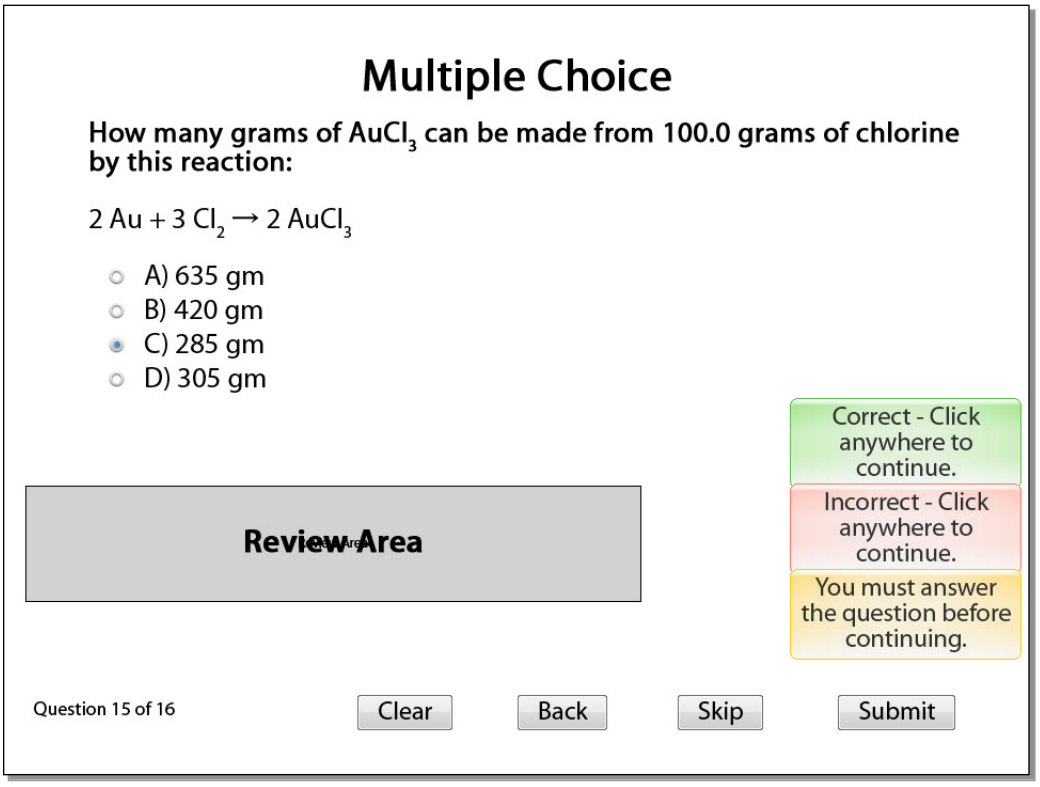
Incorrect - Click anywhere to continue.

You must answer the question before continuing.

Question 13 of 16

Clear Back Skip Submit


Multiple Choice
Calcium reacts with oxygen in air to produce calcium oxide:
How many grams of oxygen gas must react to give 6.85 g of calcium oxide?
A) 1.95 g
B) 3.90 g
C) 7.81 g
D) 5.85 g
Correct - Click anywhere to continue.
Incorrect - Click anywhere to continue.
You must answer the question before continuing.
Review Area
Question 14 of 16
Clear
Back
Skip
Submit


Multiple Choice
How many grams of $AuCl_3$ can be made from 100.0 grams of chlorine by this reaction:
$2\ Au + 3\ Cl_2 \rightarrow 2\ AuCl_3$
A) 635 gm
B) 420 gm
C) 285 gm
D) 305 gm
Correct - Click anywhere to continue.
Incorrect - Click anywhere to continue.
You must answer the question before continuing.
Review Area
Question 15 of 16
Clear
Back
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Submit

Multiple Choice

Sodium metal and chlorine gas react to form sodium chloride, or table salt:

$Na(s) + Cl_2(g) \rightarrow NaCl(s)$

What mass of table salt is produced from 2.50 g of chlorine gas?

- A) 1.62 g
- B) 8.24 g
- C) 4.12 g
- D) 2.06 g

Correct - Click anywhere to continue.

Incorrect - Click anywhere to continue.

You must answer the question before continuing.

Review Area

Question 16 of 16

Clear | Back | Skip | Submit

Appendix D

Limiting Reagent – Dimensional Analysis

Stoichiometry: Limiting Reagent

Next

One of the steps in the commercial process for converting ammonia to nitric acid is the conversion of NH_3 to NO:

$$4\ NH_3\ (g) + 5\ O_2\ (g) \rightarrow 4\ NO\ (g) + 6\ H_2O\ (g)$$

In a certain experiment, 1.50 g of NH_3 reacts with 2.75 g of O_2. How many grams of NO are produced?

Previous

Stoichiometry: Limiting Reagent

Next

One of the steps in the commercial process for converting ammonia to nitric acid is the conversion of NH_3 to NO:

$4\ NH_3\ (g) + 5\ O_2\ (g) \rightarrow 4\ NO\ (g) + 6\ H_2O\ (g)$

In a certain experiment, 1.50 g of NH_3 reacts with 2.75 g of O_2. How many grams of NO are produced?

Step #0: **READ THE PROBLEM**. Since there is a reaction given, check if the reaction is balanced!!

$$4\ NH_3\ (g) \quad + \quad 5\ O_2\ (g) \quad \rightarrow \quad 4\ NO\ (g) \quad + \quad 6\ H_2O\ (g)$$

Previous | **Stoichiometry: Limiting Reagent** | Next

One of the steps in the commercial process for converting ammonia to nitric acid is the conversion of NH_3 to NO:

$4\ NH_3\ (g) + 5\ O_2\ (g) \rightarrow 4\ NO\ (g) + 6\ H_2O\ (g)$

In a certain experiment, 1.50 g of NH_3 reacts with 2.75 g of O_2. How many grams of NO are produced?

Step #0: **READ THE PROBLEM**. Since there is a reaction given, check if the reaction is balanced!!

Balance Check: Remember, the number of atoms on the reactant side **must equal** the number of atoms on the products side

$4\ NH_3\ (g) + 5\ O_2\ (g) \rightarrow 4\ NO\ (g) + 6\ H_2O\ (g)$

Reactants

N: 4
H: 12
O: 10

Products

N: 4
H: 12
O: 10

The reaction is Balanced!

Previous

Stoichiometry: Limiting Reagent

Next

One of the steps in the commercial process for converting ammonia to nitric acid is the conversion of NH_3 to NO:

$4\ NH_3\ (g) + 5\ O_2\ (g) \rightarrow 4\ NO\ (g) + 6\ H_2O\ (g)$

In a certain experiment, 1.50 g of NH_3 reacts with 2.75 g of O_2. How many grams of NO are produced?

Step #1: Setup a strategy for solving the problem by organizing what is given, and identifying what the problem is asking. Ask yourself, "What am I Given?" and "What does the problem Want."

One of the steps in the commercial process for converting ammonia to nitric acid is the conversion of NH_3 to NO:

$4\ NH_3$ (g) + $5\ O_2$ (g) → $4\ NO$ (g) + 6 H_2O (g) (balanced)

In a certain experiment, **1.50 g of NH_3** reacts with **2.75 g of O_2**. **How many grams of NO** are produced?

Strategy: (Can be done in any order)

I. **Highlight** what the question is asking for, or what you **WANT** to know.

II. Highlight any necessary **GIVEN** information needed to solve the problem.

III. If a reaction is needed to solve the problem, produce a balanced chemical reaction.

Short Answer

One of the steps in the commercial process for converting ammonia to nitric acid is the conversion of NH_3 to NO:

$4\ NH_3\ (g) + 5\ O_2\ (g) \rightarrow 4\ NO\ (g) + 6\ H_2O\ (g)$ **(balanced)**

In a certain experiment, 1.50 g of NH_3 reacts with 2.75 g of O_2. How many grams of NO are produced?

Given the information, how can you tell this is a limiting reagent problem?

Review Area

You must answer the question before continuing.

Question 1 of 16

Clear | Back | Skip | Submit

Previous

Stoichiometry: Limiting Reagent

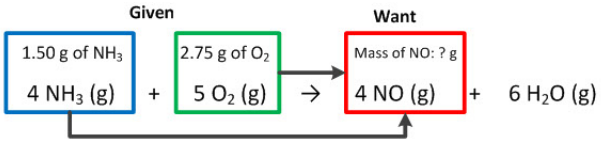
Next

One of the steps in the commercial process for converting ammonia to nitric acid is the conversion of NH_3 to NO:

$$4\ NH_3\ (g) + 5\ O_2\ (g) \rightarrow 4\ NO\ (g) + 6\ H_2O\ (g)$$

In a certain experiment, 1.50 g of NH_3 reacts with 2.75 g of O_2. How many grams of NO are produced?

Step #1: Setup a strategy for solving the problem by organizing what is given, and identifying what the problem is asking. Ask yourself, "What am I Given?" and "What does the problem Want."



Note: You are given information on more than one of the reactants and you are trying to find information on one or more of the products.

This is a **LIMITING REAGENT PROBLEM**

True/False

One of the steps in the commercial process for converting ammonia to nitric acid is the conversion of NH_3 to NO:

$4\ NH_3\ (g) + 5\ O_2\ (g) \rightarrow 4\ NO\ (g) + 6\ H_2O\ (g)$ **(balanced)**

In a certain experiment, 1.50 g of NH_3 reacts with 2.75 g of O_2. How many grams of NO are produced?

In order to determine the limiting reagent you need to find the reactant that produces the least mass.

- True
- False

Review Area

You must answer the question before continuing.

Question 2 of 16

Clear | Back | Skip | Submit

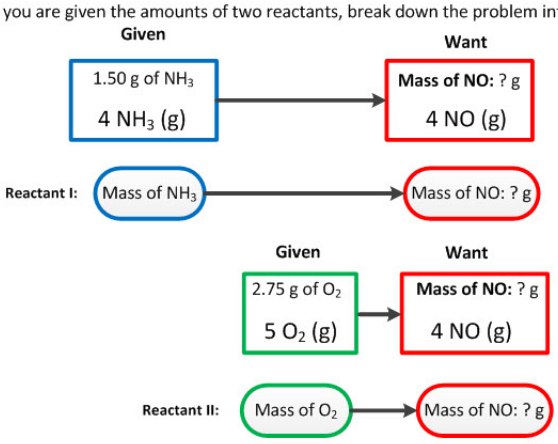
Previous | **Stoichiometry: Limiting Reagent** | Next

One of the steps in the commercial process for converting ammonia to nitric acid is the conversion of NH_3 to NO:

$4\ NH_3\ (g) + 5\ O_2\ (g) \rightarrow 4\ NO\ (g) + 6\ H_2O\ (g)$

In a certain experiment, 1.50 g of NH_3 reacts with 2.75 g of O_2. How many grams of NO are produced?

Step #1.5: Since you are given the amounts of two reactants, break down the problem into two separate problems



Note: You have to determine which reaction will yield the least product in either **moles** or **grams.**

Fill-In-The-Blank

One of the steps in the commercial process for converting ammonia to nitric acid is the conversion of NH_3 to NO:

$4\ NH_3\ (g) + 5\ O_2\ (g) \rightarrow 4\ NO\ (g) + 6\ H_2O\ (g)$ **(balanced)**

In a certain experiment, 1.50 g of NH_3 reacts with 2.75 g of O_2. How many grams of NO are produced?

Fill in the two maps needed to solve this problem

Reagent I (NH_3): mass NH3 → mol NH3 → mol NO → mass NO

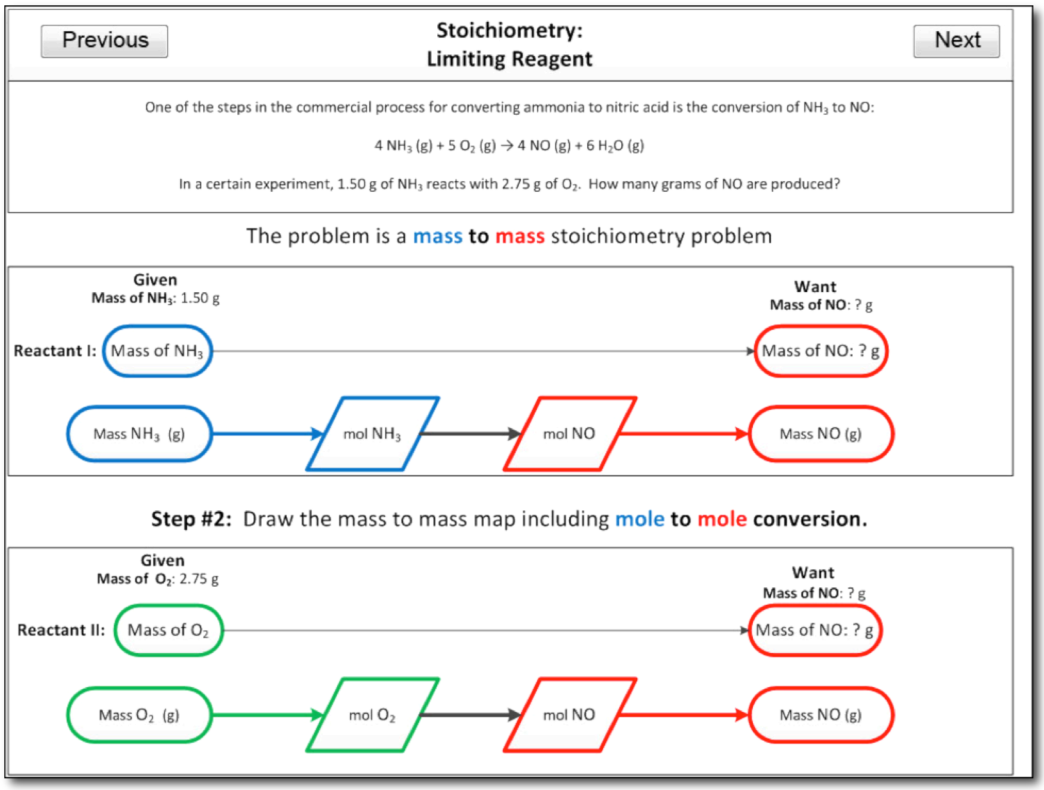
Reagent II (O_2): mass O2 → mol O2 → mol NO → mass NO

Review Area

You must answer the question before continuing.

Question 3 of 16

Clear Back Skip Submit


Previous
Stoichiometry:
Limiting Reagent
Next
One of the steps in the commercial process for converting ammonia to nitric acid is the conversion of NH3 to NO:
4 NH3 (g) + 5 O2 (g) → 4 NO (g) + 6 H2O (g)
In a certain experiment, 1.50 g of NH3 reacts with 2.75 g of O2. How many grams of NO are produced?
The problem is a mass to mass stoichiometry problem
Given
Mass of NH3: 1.50 g
Want
Mass of NO: ? g
Reactant I:
Mass of NH3
Mass of NO: ? g
Mass NH3 (g)
mol NH3
mol NO
Mass NO (g)
Step #2: Draw the mass to mass map including mole to mole conversion.
Given
Mass of O2: 2.75 g
Want
Mass of NO: ? g
Reactant II:
Mass of O2
Mass of NO: ? g
Mass O2 (g)
mol O2
mol NO
Mass NO (g)

Previous

Stoichiometry:
Limiting Reagent

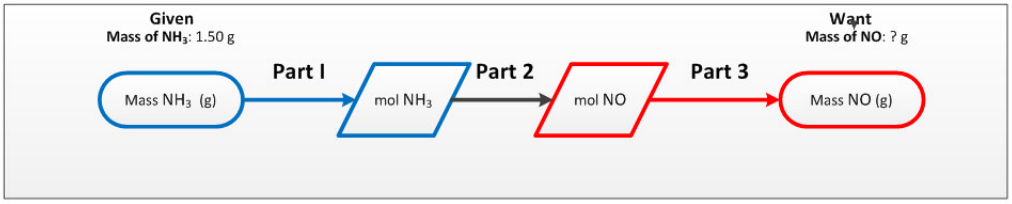
Next

One of the steps in the commercial process for converting ammonia to nitric acid is the conversion of NH_3 to NO:

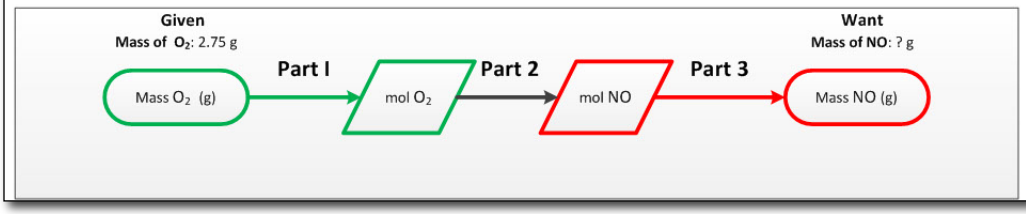
$4\ NH_3\ (g) + 5\ O_2\ (g) \rightarrow 4\ NO\ (g) + 6\ H_2O\ (g)$

In a certain experiment, 1.50 g of NH_3 reacts with 2.75 g of O_2. How many grams of NO are produced?

Step #3: Organize any additional information necessary to solve this problem (ie. Molar Mass, Stoichiometric Ratio, etc.)



Note: Each problem can be separated into three parts



Previous

Limiting Reagent

Next

One of the steps in the commercial process for converting ammonia to nitric acid is the conversion of NH_3 to NO:

$4\ NH_3\ (g) + 5\ O_2\ (g) \rightarrow 4\ NO\ (g) + 6\ H_2O\ (g)$

In a certain experiment, 1.50 g of NH_3 reacts with 2.75 g of O_2. How many grams of NO are produced?

ep #3: Organize any additional information necessary to solve this problem (ie. Molar Mass, Stoichiometric Ratio, etc.)

Molar Mass NH_3:

17.0 g NH_3 : 1 mol NH_3

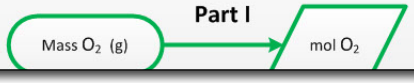
Part #1

Requires Molar Mass

"Mass to Moles" -- **Molar Mass!!**

Molar Mass O_2:

32.0 g O_2 : 1 mol O_2



Previous | **Stoichiometry: Limiting Reagent** | Next

One of the steps in the commercial process for converting ammonia to nitric acid is the conversion of NH_3 to NO:

$4\ NH_3\ (g) + 5\ O_2\ (g) \rightarrow 4\ NO\ (g) + 6\ H_2O\ (g)$

In a certain experiment, 1.50 g of NH_3 reacts with 2.75 g of O_2. How many grams of NO are produced?

Step #3: Organize any additional information necessary to solve this problem (ie. Molar Mass, Stoichiometric Ratio, etc.)

S. Ratio NH_3: 4 mol NH_3 **S. Ratio NO:** 4 mol NO

Part #2 Requires **Mole to Mole** Stoichiometric Ratio

$$4\ NH_3\ (g) + 5\ O_2\ (g) \rightarrow 4\ NO\ (g) + 6\ H_2O\ (g)$$

S. Ratio O_2: 5 mol O_2 **S. Ratio NO:** 4 mol NO

Previous

Stoichiometry:
Limiting Reagent

Next

One of the steps in the commercial process for converting ammonia to nitric acid is the conversion of NH_3 to NO:

$4\ NH_3\ (g) + 5\ O_2\ (g) \rightarrow 4\ NO\ (g) + 6\ H_2O\ (g)$

In a certain experiment, 1.50 g of NH_3 reacts with 2.75 g of O_2. How many grams of NO are produced?

Step #3: Organize any additional information necessary to solve this problem (ie. Molar Mass, Stoichiometric Ratio, etc.)

Molar Mass NO:
30.0 g NO : 1 mol NO

Part #3
Requires Molar Mass
"Moles to Mass" -- **Molar Mass!!**

Molar Mass NO:
30.0 g NO : 1 mol NO

Fill-In-The-Blank

One of the steps in the commercial process for converting ammonia to nitric acid is the conversion of NH_3 to NO:

$4\ NH_3\ (g) + 5\ O_2\ (g) \rightarrow 4\ NO\ (g) + 6\ H_2O\ (g)$ **(balanced)**

In a certain experiment, 1.50 g of NH_3 reacts with 2.75 g of O_2. How many grams of NO are produced?

Reagent I (NH_3): mass NH_3 → mol NH_3 → mol NO → mass NO

Using the map for NH_3,(MW: 17.0 g NH_3 : 1 mol NH_3) set up the dimensional analysis required to solve for the moles of NO, which will help determine the limiting reagent.

moles of NO (mol) = $\dfrac{1.50\ g\ NH_3}{} \times \dfrac{1\ mol\ NH3}{17.0\ g\ NH3} \times \dfrac{4\ mol\ NO}{4\ mol\ NH3}$

Review Area

You must answer the question before continuing.

Question 4 of 16

Clear | Back | Skip | Submit

Fill-In-The-Blank

One of the steps in the commercial process for converting ammonia to nitric acid is the conversion of NH_3 to NO:

$4\ NH_3\ (g) + 5\ O_2\ (g) \rightarrow 4\ NO\ (g) + 6\ H_2O\ (g)$ **(balanced)**

In a certain experiment, 1.50 g of NH_3 reacts with 2.75 g of O_2. How many grams of NO are produced?

Reagent II (O_2): mass O_2 → mol O_2 → mol NO → mass NO

Using the map for O_2, (MW: 32.0 g O_2 : 1 mol O_2) set up the dimensional analysis to solve for the moles of NO, which will help determine the limiting reagent.

$$\text{moles of NO (mol)} = 2.75\ \text{g } O_2 \times \frac{1\ \text{mol O2}}{32.0\ \text{g O2}} \times \frac{4\ \text{mol NO}}{5\ \text{mol O2}}$$

Review Area

You must answer the question before continuing.

Question 5 of 16

Clear | Back | Skip | Submit

Previous | **Stoichiometry: Limiting Reagent** | Next

Step #4: Solve for the **moles** of the product to determine which **reactant** is the **limiting reagent.**

Given
Mass of NH_3: 1.50 g
Molar Mass NH_3: 17.0 g NH_3 : 1 mol NH_3
S. Ratio NH_3: 4 mol NH_3

Want
Mass of NO: ? g
Molar Mass NO: 30.0 g NH_3 : 1 mol NO
S. Ratio NO: 4 mol NO

Reactant I: Mass NH_3 (g) → **Part I** → mol NH_3

Reactant I: $\frac{1.50\text{ g } NH_3}{\frac{\textbf{1 mol } NH_3}{\textbf{17.0 g } NH_3}}$

Given
Mass of O_2: 2.75 g
Molar Mass O_2: 32.0 g O_2 : 1 mol O_2
S. Ratio O_2: 5 mol O_2

Want
Mass of NO: ? g
Molar Mass NO: 30.0 g NO : 1 mol NO
S. Ratio NO: 4 mol NO

Reactant II: Mass O_2 (g) → **Part I** → mol O_2

Reactant II: $\frac{2.75\text{ g } O_2}{\frac{\textbf{1 mol } O_2}{\textbf{32.0 g } O_2}}$

Previous

Stoichiometry:
Limiting Reagent

Next

Step #4: Solve for the **moles** of the product to determine which **reactant** is the **limiting reagent.**

Given
Mass of NH_3: 1.50 g
Molar Mass NH_3: 17.0 g NH_3 : 1 mol NH_3
S. Ratio NH_3: 4 mol NH_3

Want
Mass of NO: ? g
Molar Mass NO: 30.0 g NH_3 : 1 mol NO
S. Ratio NO: 4 mol NO

Reactant I:

$$\frac{1.50\text{ g } NH_3}{} \left| \begin{array}{c|c} 1\text{ mol } NH_3 & 4\text{ mol NO} \\ \hline 17.0\text{ g } NH_3 & 4\text{ mol } NH_3 \end{array} \right.$$

Given
Mass of O_2: 2.75 g
Molar Mass O_2: 32.0 g O_2 : 1 mol O_2
S. Ratio O_2: 5 mol O_2

Want
Mass of NO: ? g
Molar Mass NO: 30.0 g NO : 1 mol NO
S. Ratio NO: 4 mol NO

Reactant II:

$$\frac{2.75\text{ g } O_2}{} \left| \begin{array}{c|c} 1\text{ mol } O_2 & 4\text{ mol NO} \\ \hline 32.0\text{ g } O_2 & 5\text{ mol } O_2 \end{array} \right.$$

Multiple Choice

One of the steps in the commercial process for converting ammonia to nitric acid is the conversion of NH_3 to NO:

$4\ NH_3\ (g) + 5\ O_2\ (g) \rightarrow 4\ NO\ (g) + 6\ H_2O\ (g)$ **(balanced)**

In a certain experiment, 1.50 g of NH_3 reacts with 2.75 g of O_2. How many grams of NO are produced?

Which do you think is limiting reagent?

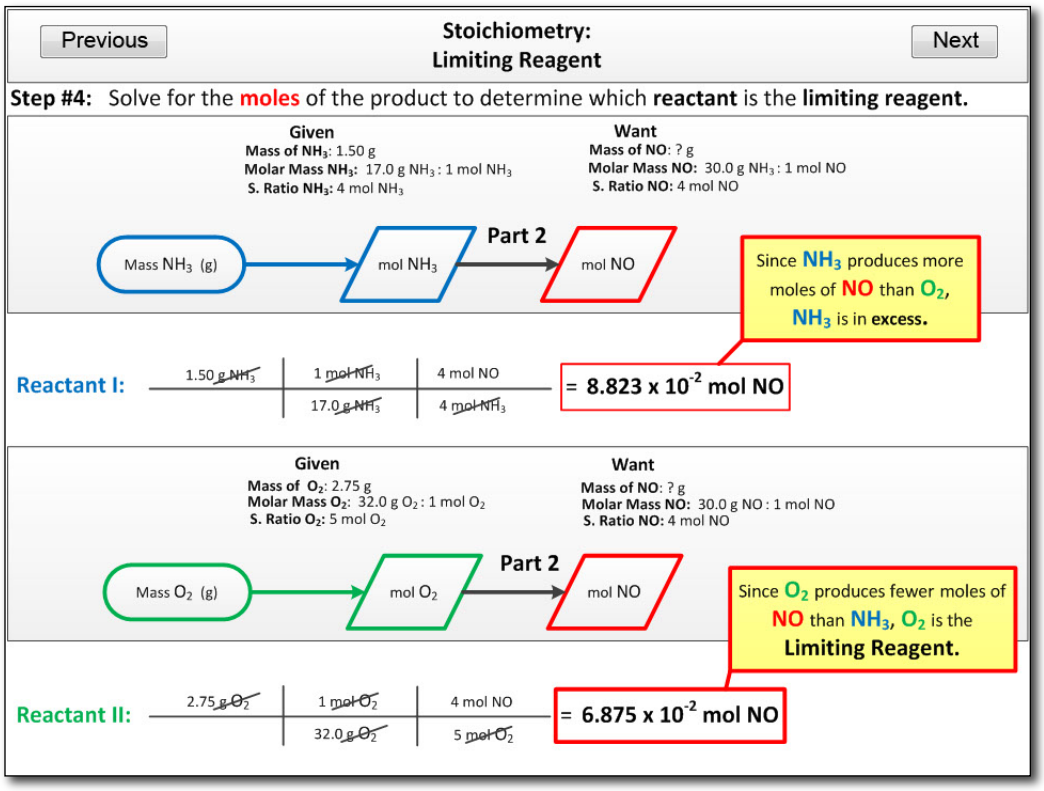
- A) NH_3
- B) O_2
- C) H_2O
- D) NO

Review Area

You must answer the question before continuing.

Question 6 of 16

Clear | Back | Skip | Submit


Previous
Stoichiometry:
Limiting Reagent
Next
Step #4: Solve for the moles of the product to determine which reactant is the limiting reagent.
Given
Mass of NH3: 1.50 g
Molar Mass NH3: 17.0 g NH3 : 1 mol NH3
S. Ratio NH3: 4 mol NH3
Want
Mass of NO: ? g
Molar Mass NO: 30.0 g NH3 : 1 mol NO
S. Ratio NO: 4 mol NO
Mass NH3 (g)
mol NH3
Part 2
mol NO
Since NH3 produces more moles of NO than O2, NH3 is in excess.
Reactant I:
1.50 g NH3
1 mol NH3
17.0 g NH3
4 mol NO
4 mol NH3
= 8.823 x 10-2 mol NO
Given
Mass of O2: 2.75 g
Molar Mass O2: 32.0 g O2 : 1 mol O2
S. Ratio O2: 5 mol O2
Want
Mass of NO: ? g
Molar Mass NO: 30.0 g NO : 1 mol NO
S. Ratio NO: 4 mol NO
Mass O2 (g)
mol O2
Part 2
mol NO
Since O2 produces fewer moles of NO than NH3, O2 is the Limiting Reagent.
Reactant II:
2.75 g O2
1 mol O2
32.0 g O2
4 mol NO
5 mol O2
= 6.875 x 10-2 mol NO

Fill-In-The-Blank

One of the steps in the commercial process for converting ammonia to nitric acid is the conversion of NH_3 to NO:

$4\ NH_3\ (g) + 5\ O_2\ (g) \rightarrow 4\ NO\ (g) + 6\ H_2O\ (g)$ **(balanced)**

In a certain experiment, 1.50 g of NH_3 reacts with 2.75 g of O_2. How many grams of NO are produced?

Reagent II (O_2): mass O_2 → mol O_2 → mol NO → mass NO

Now that you have determined that O_2 is the limiting reagent, set up the remaining dimensional analysis to solve for the mass of NO (MW: 30.0 g NO : 1 mol NO).

mass of NO (g) = $\dfrac{6.875 \times 10^{-2}\ \text{mol NO}}{\quad}$ $\dfrac{30.0\ \text{g NO}}{1\ \text{mol NO}}$

Review Area

You must answer the question before continuing.

Question 7 of 16

Clear Back Skip Submit

Previous

Stoichiometry:
Limiting Reagent

Given
Mass of NH_3: 1.50 g
Molar Mass NH_3: 17.0 g NH_3 : 1 mol NH_3
S. Ratio NH_3: 4 mol NH_3

Want
Mass of NO: ? g
Molar Mass NO: 30.0 g NH_3 : 1 mol NO
S. Ratio NO: 4 mol NO

Reactant I: Mass NH_3 (g) → mol NH_3 → mol NO

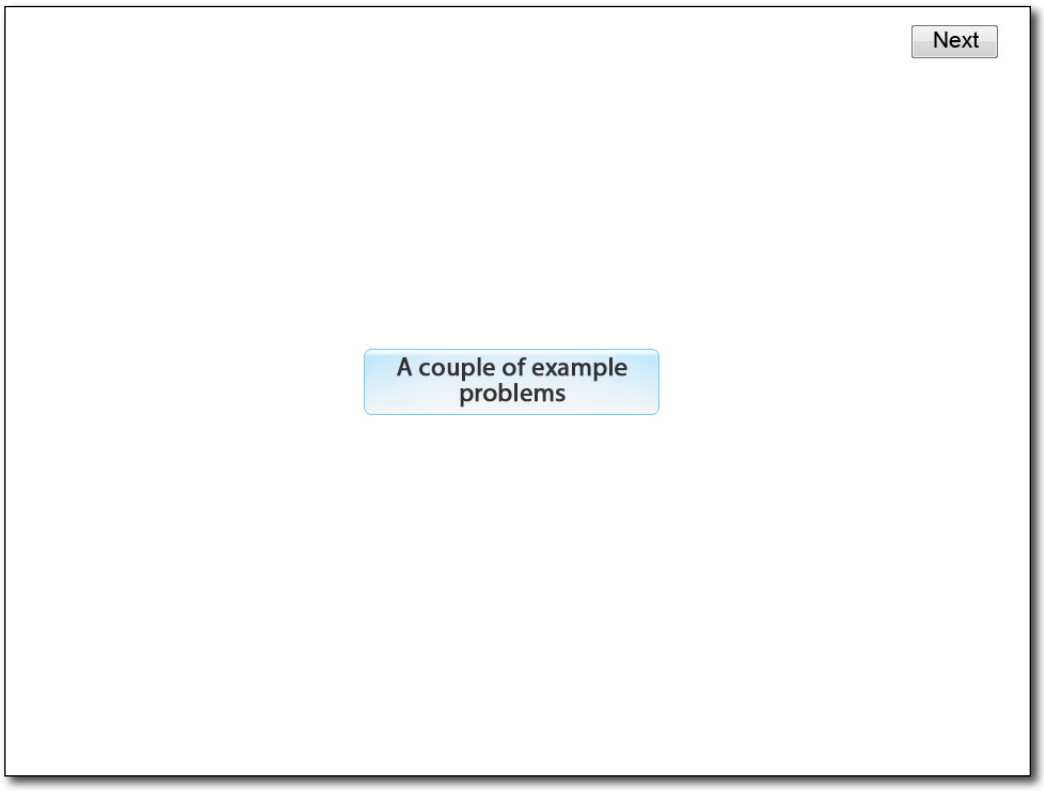
Step #5: Calculate the **mass** of the product to determine using the **limiting reagent.**

Given
Mass of O_2: 2.75 g
Molar Mass O_2: 32.0 g NH_3 : 1 mol O_2
S. Ratio O_2: 5 mol O_2

Want
Mass of NO: ? g
Molar Mass NO: 30.0 g NO : 1 mol NO
S. Ratio NO: 4 mol NO

Reactant II: Mass O_2 (g) → mol O_2 → mol NO → **Part 3** → Mass NO (g)

$$6.875 \times 10^{-2}\ \cancel{\text{mol NO}} \times \frac{30.0\ \text{g NO}}{1\ \cancel{\text{mol NO}}} = \textbf{2.06 gm NO}$$


Next
A couple of example problems

Next

Consider the following reaction

$$Na_3PO_4\,(aq) + Ba(NO_3)_2\,(aq) \rightarrow Ba_3(PO_4)_2\,(s) + NaNO_3\,(aq)$$

Suppose a solution containing 3.50 g of Na_3PO_4 is mixed with 6.40 g of $Ba(NO_3)_2$. How many grams of $Ba_3(PO_4)_2$ will be formed?

Short Answer

Consider the following reaction

$$Na_3PO_4\,(aq) + Ba(NO_3)_2\,(aq) \rightarrow Ba_3(PO_4)_2\,(s) + NaNO_3\,(aq)$$

Suppose a solution containing 3.50 g of Na_3PO_4 is mixed with 6.40 g of $Ba(NO_3)_2$. How many grams of $Ba_3(PO_4)_2$ will be formed?

Is this a limiting reagent problem? Explain your answer.

Review Area

You must answer the question before continuing.

Question 8 of 16

Clear | Back | Skip | Submit

Fill in the blank

Consider the following reaction

$$Na_3PO_4\,(aq) + Ba(NO_3)_2\,(aq) \rightarrow Ba_3(PO_4)_2\,(s) + NaNO_3\,(aq)$$

Suppose a solution containing 3.50 g of Na_3PO_4 is mixed with 6.40 g of $Ba(NO_3)_2$. How many grams of $Ba_3(PO_4)_2$ will be formed?

Since the reaction is not balanced, **balance the reaction.**

$$\underline{2}\,Na_3PO_4\,(aq) + \underline{3}\,Ba(NO_3)_2\,(aq) \rightarrow \underline{1}\,Ba_3(PO_4)_2\,(s) + \underline{6}\,NaNO_3\,(aq)$$

Correct - Click anywhere to continue.

Incorrect - Click anywhere to continue.

You must answer the question before continuing.

Review Area

Question 9 of 16

Clear | Back | Skip | Submit

Fill-In-The-Blank

Consider the following reaction

$$2\ Na_3PO_4\ (aq) + 3\ Ba(NO_3)_2\ (aq)\ \text{-->}\ Ba_3(PO_4)_2\ (s) + 6\ NaNO_3\ (aq)$$

Suppose a solution containing 3.50 g of Na_3PO_4 is mixed with 6.40 g of $Ba(NO_3)_2$. Using the map for reagent I:

Reagent I:

mass Na_3PO_4 → mol Na_3PO_4 → mol $Ba_3(PO_4)_2$ → mass $Ba_3(PO_4)_2$

Set up the dimensional analysis required to solve for the moles of $Ba_3(PO_4)_2$, (MW: 164 g Na_3PO_4 : 1 mol Na_3PO_4) which will help determine the limiting reagent.

moles of $Ba_3(PO_4)_2$ (mol) = 3.50 g Na_3PO_4 × $\frac{\text{1 mol Na3PO4}}{\text{164 g Na3PO4}}$ × $\frac{\text{1 mol Ba3(PO4)2}}{\text{2 mol Na3PO4}}$

Review Area

Question 11 of 16

Correct - Click anywhere to continue.

Incorrect - Click anywhere to continue.

You must answer the question before continuing.

Clear | Back | Skip | Submit

Fill-In-The-Blank

Consider the following reaction

$$2\ Na_3PO_4\ (aq) + 3\ Ba(NO_3)_2\ (aq) \rightarrow Ba_3(PO_4)_2\ (s) + 6\ NaNO_3\ (aq)$$

Suppose a solution containing 3.50 g of Na_3PO_4 is mixed with 6.40 g of $Ba(NO_3)_2$. Using the map for reagent II:

Reagent II:

mass $Ba(NO_3)_2$ → mol $Ba(NO_3)_2$ → mol $Ba_3(PO_4)_2$ → mass $Ba_3(PO_4)_2$

Set up the dimensional analysis required to solve for the moles of $Ba_3(PO_4)_2$, (MW: 261 g $Ba(NO_3)_2$: 1 mol $Ba(NO_3)_2$) which will help determine the limiting reagent.

moles of $Ba_3(PO_4)_2$ (mol) = 6.40 g $Ba(NO_3)_2$ × 1 mol Ba(NO3)2 / 261 g Ba(NO3)2 × 1 mol Ba3(PO4)2 / 3 mol Ba(NO3)2

Review Area

Correct - Click anywhere to continue.

Incorrect - Click anywhere to continue.

You must answer the question before continuing.

Question 12 of 16

Clear Back Skip Submit

Multiple Choice

Consider the following reaction

$$2\ Na_3PO_4\ (aq) + 3\ Ba(NO_3)_2\ (aq) \rightarrow Ba_3(PO_4)_2\ (s) + 6\ NaNO_3\ (aq)$$

Suppose a solution containing 3.50 g of Na_3PO_4 is mixed with 6.40 g of $Ba(NO_3)_2$.

Which do you think is the limiting reagent?

- A) Na_3PO_4
- B) $Ba(NO_3)_2$
- C) $Ba_3(PO_4)_2$
- D) $NaNO_3$

Correct - Click anywhere to continue.

Incorrect - Click anywhere to continue.

You must answer the question before continuing.

Review Area

Question 13 of 16

Clear | Back | Skip | Submit

Multiple Choice

Consider the following reaction

$$2\ Na_3PO_4\ (aq) + 3\ Ba(NO_3)_2\ (aq) \rightarrow Ba_3(PO_4)_2\ (s) + 6\ NaNO_3\ (aq)$$

Suppose a solution containing 3.50 g of Na_3PO_4 is mixed with 6.40 g of $Ba(NO_3)_2$.

How many grams of $Ba_3(PO_4)_2$ will be formed?

- A) 12.8 g
- B) 6.41 g
- C) 4.92 g
- D) 14.7 g

Correct - Click anywhere to continue.

Incorrect - Click anywhere to continue.

You must answer the question before continuing.

Review Area

Question 14 of 16

Clear | Back | Skip | Submit

Multiple Choice

A strip of zinc metal having a mass of 2.00 g is placed in an aqueous solution containing 2.50 g of silver nitrate, causing the folowing reaction to occur:

$Zn\ (s) + 2\ AgNO_3\ (aq) \rightarrow 2\ Ag\ (s) + Zn(NO_3)_2\ (aq)$

Which is the limiting reagent?

- A) Ag
- B) $Zn(NO_3)_2$
- C) $AgNO_3$
- D) Zn

Correct - Click anywhere to continue.

Incorrect - Click anywhere to continue.

You must answer the question before continuing.

Review Area

Question 15 of 16

Clear Back Skip Submit

Multiple Choice

A strip of zinc metal having a mass of 2.00 g is placed in an aqueous solution containing 2.50 g of silver nitrate, causing the folowing reaction to occur:

$Zn\ (s) + 2\ AgNO_3\ (aq) \rightarrow 2\ Ag\ (s) + Zn(NO_3)_2\ (aq)$

How many grams of Ag will be formed?

- A) 1.59 g
- B) 1.39 g
- C) 1.52 g
- D) 1.48 g

Correct - Click anywhere to continue.

Incorrect - Click anywhere to continue.

You must answer the question before continuing.

Review Area

Question 16 of 16

Clear Back Skip Submit

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Biographical Information

Kenneth Munoz Abayan was born in Dagupan City, Philippines. He started his primary education in Daly City California. He received his Bachelors Degree in Chemistry from the University of California Berkeley in 1998. From 1998-2000, he worked as a DSL instructor and trainer, at the time was Pacific Bell Internet Services, which is now AT&T Global Services. From 2000-2002, he returned to his chemistry roots and worked as a lab technician, doing combinatorial synthesis for Exelixis, a pharmaceutical company located in South San Francisco, California. In his final year at Exelixis, he became an assistant research scientist developing methods for combinatorial synthesis to create large libraries of small compounds, under the supervision of Dr. Elena Koulton.

In 2002, he moved to Irving, Texas, where from 2002-2008 he worked as a chemistry lab nstructor for Northlake Community. From 2007-2008 he was able to be an instructor for second semester general chemistry. In 2008, he started at the University of Texas at Arlington for a Doctor of Philosophy in Chemistry, first under the supervision of Prof. Frederick M. MacDonnell, studying the anti-neoplastic properties for two ruthenium polypyridal complexes. After two years of traditional bench chemistry, he transitioned to Dr. Kevin Schug, where he would start his study in the use of e-learning tools to support the learning of stoichiometry.