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Carrie Obenland

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**Incorporation of Conceptual Understanding of Chemistry in
Assessments, Undergraduate General Chemistry Classrooms
and Laboratories, and High School Classrooms**


by

Carrie Amber Obenland

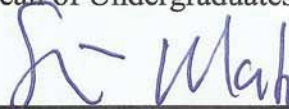
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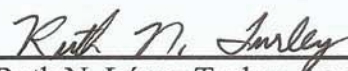
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ABSTRACT

Incorporation of Conceptual Understanding of Chemistry in Assessments, Undergraduate General Chemistry Classrooms and Laboratories, and High School Classrooms

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Carrie Amber Obenland

The novel assessment models and studies developed in this work provided new insight on effective teaching practices in chemistry classrooms and laboratories through the framework of constructivism. Each project aimed to promote greater levels of understanding and inspire interest in chemistry, both of which are great challenges within the U.S. educational system.

Assessment drives learning, so appropriate tests are essential to good courses. However, large classes often make written exams impractical. A multiple-choice test of conceptual knowledge in general chemistry was created and validated to provide the chemical education community with a reliable and functional tool that correlates with open-ended General Chemistry exams.

Large classes make active-learning implementation challenging, as not all students can participate. Students in a large General Chemistry course taught via active-learning were studied through surveys and interviews. The data revealed that “silent” students are engaged in the active-learning experience, yet “vocal” students outperform silent students on measures of conceptual understanding in chemistry. The motivation behind being vocal suggested students participate in

order to improve their grade, and while doing so, also see the benefit to their learning.

Another mixed-methods study focused on the traditionally formatted General Chemistry Laboratories. Initial data on student expectations lead to the creation of a pilot lab section and ultimately a new format of the labs with the inclusion of a discussion session. The changes resulted in the students being better prepared, focusing on the content rather than the process of the labs, and reporting better understanding of chemistry due to labs.

Two novel laboratory experiences were also developed to promote conceptual understanding, and their creation and use are outlined.

The impact of a professional development program on high school chemistry courses was analyzed via interviews, teacher observations and a case study. The professional development exposed teachers to novel chemistry teaching practices of inquiry-based concept development and active-learning methods. The case study showed implementation of the instructional strategies to be successful within an existing exemplary chemistry classroom.

Each of these projects advanced best practices in teaching chemistry by expanding the current understanding of teaching concepts and analyzing applications of research-based pedagogies.

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Nomenclature

ANOVA	Analysis of Variance
AP	Advanced Placement
CCRT	Chemistry Concept Reasoning Test
CDS	Concept Development Studies
CHEM 121	First semester General Chemistry course at Rice University
CHEM 123	First semester General Chemistry Laboratory at Rice University
CHEM 122	Second semester General Chemistry course at Rice University
CHEM 124	Second semester General Chemistry Laboratory at Rice University
CHEM 1411	First semester General Chemistry course at Lone Star College
CHEM 1412	Second semester General Chemistry course at Lone Star College
CHEM 151	First semester Honors General Chemistry course at Rice University
CHEM 152	Second semester Honors General Chemistry course at Rice University
CHEM 570	Nanotechnology for Teachers/Teaching Chemical Concepts via Inquiry, professional development for secondary science teachers
CHEM 571	Teaching Chemical Concepts via Inquiry II, professional development for secondary science teachers
CHEMX	Validated survey of cognitive expectations in learning chemistry
IB	International Baccalaureate
IRB	Institutional Review Board
LSC	Lone Star College
OwlSpace	Online course management application at Rice University

RESST	Rice Excellence in Secondary Science Teaching
SST	Rice University School Science and Technology program
STEM	Science Technology Engineering & Mathematics
TAKS	Texas Assessment of Knowledge and Skills standardized exams

Introduction

The research presented in this thesis is based upon the foundations and frameworks previously established in the field of chemical education. Chemical education has a long history and can be defined in terms of the practice of teaching chemistry and research about the teaching and learning of chemistry. Chemistry was regularly included in U.S. collegiate course offerings beginning in the early 1800's, and chemistry laboratories were commonly included as components of teaching courses at the start of the 20th century (Lewenstein, 1989). The history of teaching chemistry began as chemists shared their increasing knowledge and recruited future scientists.

Chemical education research seeks to determine the best practices of teaching and learning chemistry. However, best practices are elusive due to the individualized nature of each classroom setting, population of students, specific scientific content, and instructor. Teachers well-versed in the chemistry content

often find it challenging to successfully transfer their knowledge to their students. Historically, science education has been riddled with ineffective classes and has produced a weeding out effect that leaves many students feeling unable to excel in science (Tobias, 1990). Chemical education research stemmed from these difficulties as scientists took their skills in understanding nature and focused them on understanding how students of all levels grasp the nature of chemical science. Chemical education began as an organized section of the American Chemical Society in 1921 (Rakestraw, 1958), yet it was not until the late 1970s that researchers began to strive to understand the impact of teaching practices on students' learning of chemistry (Bunce and Robinson, 1997).

Chemical education research employs scientists with social science research methods to acquire quantitative and qualitative data in response to questions regarding teaching and learning chemistry (Towns, 2008). As the field of chemical education has been established, research questions became rooted in the theoretical frameworks such as constructivism (Abraham, 2008; Bodner, 2007; Tsaparlis, 2001). Each of the questions I have addressed in this thesis stems from the constructivist theoretical framework, the idea that students must actively construct their own knowledge in order to truly understand a concept (Bodner, 1986; Ferguson, 2007).

Constructivism is a theory of learning with a longstanding tradition in cognitive science (Bodner, 1986; Bransford et al., 1999; Tsaparlis, 2001). While there are multiple forms of constructivism, the common theme is a focus on

meaning-making through the association of previous ideas with new experiences within the mind of the student (Ferguson, 2007; Woolfolk, 2010). Constructivism can be seen as an individual activity as well as a social building of knowledge, because in the classroom, individuals must construct their own knowledge within the social interactions and context provided by fellow students (Driver et al., 1994; Smith, 1995).

The idea of constructing knowledge suggests that the standard tradition of lecture is limited in effectiveness (Byers and Eilks, 2009; Gallagher-Bolos and Smithenry, 2004; Johnson et al., 1998). Students easily disengage during lecture, and even if they can stay focused, they are often unable to actively connect with the content (Donovan et al., 1999; Michael and Modell, 2003). Knowledge transfer requires much more than rote learning associated with memorizing ideas, facts, formulas and examples (Byers and Eilks, 2009; Ebenezer, 1992). Students need to make the ideas their own, understand the premise behind facts, realize how formulas are used, and transfer this knowledge beyond rote examples. Classrooms must be structured to allow for the engagement of students into the subject matter in order for them to construct meaning (Bonwell and Sutherland, 1996; Bretz, 2001; Ingram et al., 2004). Active learning techniques that allow for inquiry come from the theory of constructivism. Incorporating active learning and inquiry-based teaching is more than a simple shift of a lecture course (Bonwell and Eison, 1991; Fata-Hartley, 2011; Felder et al., 2000). Presentation of material must be restructured in a format that allows for the students to collect or experience data, create their own models and theories, and construct their knowledge in a step-by-step fashion

(Keefer, 1998; Trout et al., 2008). Instructors must shift their roles from dispenser of knowledge to experience provider, modeler of scientific reasoning, and guide through questioning (Crawford, 2000; Taber, 2000). The individual creation of knowledge by students can then actively happen as students combine previous experiences with incoming observations, social interaction, and engagement in the classroom (Michael, 2006; Prince, 2004).

My research focuses on developing and assessing best practices to allow students to construct a conceptual understanding of chemistry. My projects have involved the creation of a specific assessment for conceptual understanding, research on active student participation in inquiry-focused classrooms, improvement of learning experiences in the laboratory, and research on teaching high school chemistry. Each chapter of this thesis addresses one of these areas, provides a literature review to set the stage for my research, and presents the work I have completed on each topic.

The next chapter of this thesis outlines the creation and validation of the Chemistry Concept Reasoning Test (Cloonan and Hutchinson, 2011). This test was created as a tool to measure students' conceptual understanding and scientific reasoning skills in relation to General Chemistry topics. It was created and validated for this purpose and has since been used in my own research and shared with the chemical education community.

The third chapter of this thesis details two years of research in understanding the engagement of students in an active learning General Chemistry

class (Obenland et al., 2012a, 2012b). Students were defined as either vocal or silent depending on their level of oral participation in class. These designations of silent and vocal were not correlated with students' engagement in class. However, vocal students did outperform silent students on academic measures of achievement.

The fourth chapter outlines a three-year study of the General Chemistry Laboratories at Rice University. Baseline quantitative and qualitative data established that students did not use the labs as constructive learning experiences. Through active research, changes were implemented to facilitate the use of labs for promoting construction of knowledge in chemistry. A pilot study was followed by a full implementation of changes with the inclusion of specific time for students to discuss their observations in lab, analyze and interpret data together, and come to a greater depth of understanding of chemical concepts.

The fifth chapter details two of the laboratory activities I have developed and published (Cloonan et al., 2011a, 2011b). These activities were derived from my focus on helping students make observations and create conceptual understanding through the analysis of their observations.

The final body chapter presents my research on the impact of a professional development program for high school chemistry students. The program demonstrated the premise and pedagogy of active, inquiry-focused learning. My study followed teachers back into their classrooms to determine if and how the professional development was implemented. A case study with one teacher showed

implementation of this approach in the teaching of chemistry can be successful and have a positive impact on students.

In combination, these projects present my work in furthering the field of chemical education from the perspective that students need access to data, observations, and experiences and chances to engage and construct meaning in chemistry on a conceptual level.

Chemistry Concept Reasoning Test

This chapter outlines the creation, validation and use of a test to measure conceptual knowledge and scientific reasoning in chemistry (Cloonan and Hutchinson, 2011).

2.1. Introduction

The prime objective of a chemistry class should be for students to become knowledgeable in chemical concepts, models, and theories beyond rote memorization or surface understanding. More recent views include in this objective that students are able to analyze data, develop models, and interpret observations. In short, chemistry classes should include critical scientific thinking as a major component. This has led to the creation of course content incorporating scientific inquiry. Inquiry-based pedagogies follow from a constructivist understanding of

how people learn, and focus on building understanding of a concept initially from experiences, observations, or existing knowledge (Bodner, 1986; Bransford et al., 1999). Inquiry-based approaches have been developed over the past twenty years at Rice University using a combination of active learning and inductive reasoning via “Concept Development Studies” (CDS). This approach has been documented as successful for introductory Chemistry at the undergraduate level (Hutchinson, 2000). The corresponding textbook of case studies documents how chemical concepts were historically developed via experimental observations and allows students to experience the scientific process (Hutchinson, 2007). The fundamental difference in pedagogy is the integration of scientific reasoning as students actively develop each chemical concept. The current research builds on this focus of promoting conceptual understanding of chemistry by offering an assessment to test such knowledge.

In any class, assessment drives learning. Whatever means is put before students to measure learning defines the manner in which students learn (Crooks, 1988). Thus, if curricular goals include a focus on having students build scientific reasoning and create their own knowledge of the concepts, an assessment aligned to those goals is absolutely necessary. The most obvious type of assessment of these goals would include open-ended questions requiring responses including scientific reasoning via essays. This is the approach that has been used at Rice University by John Hutchinson and colleagues for decades, and I have used this approach myself in Fall 2011, General Chemistry, CHEM 121.

To extend the approaches developed for conceptual learning to larger and broader audiences of students, it is necessary to have an objective, multiple-choice instrument to measure the aforementioned understanding and reasoning skills. The necessity of the multiple-choice format is due to the challenge of managing the time and resources required for creating and grading open-ended exam questions for large class sizes. For learning focused on concepts and reasoning, an appropriate multiple-choice test instrument is challenging to create. For the majority of multiple-choice questions, it is not possible to distinguish an accurately memorized or calculated response from a correctly reasoned answer due to understanding of the phenomenon addressed. Thus, accurate answers may not indicate real understanding of the topic. For some time, studies have shown a lack of correlation between multiple-choice test performance and written or verbalized knowledge of concepts (Frederiksen, 1984; Mazur, 1997). My primary goal in the work reported here was the creation of multiple-choice questions equivalent to open-ended essay style inquiries and without rote or formula-driven responses.

2.2. Literature Review

Traditional assessment that relies primarily on worked problems with numerical solutions does not accurately identify the level of a students' understanding (Lythcott, 1990). Two studies focused on the differences between conceptual learning and problem solving using quantitative methods to illustrate that general chemistry college students rely mainly on their algorithmic problem

solving skills and have gaps in their conceptual understanding of chemistry (Nakhleh and Mitchell, 1993; Cracolice et al., 2008). While both studies used assessments with both conceptual and algorithmic questions, one included interviews where students worked problems aloud. It was observed that students adept at solving algorithmic problems often attempted to solve conceptual problems in an algorithmic manner (Nakhleh and Mitchell, 1993). The absence of reasoning ability was concluded to be the cause of poorer performance on conceptual questions on standardized chemistry exams (Cracolice et al., 2008).

Physics instruction has encountered similar issues with assessing conceptual understanding. The Force Concept Inventory developed out of the Halloun-Hestenes Mechanics Diagnostic Test has greatly improved the quality of instruction in entry-level physics courses by allowing reliable testing of conceptual understanding (Hestenes et al., 1992; Halloun and Hestenes, 1995; Hake, 1998). Due to the multiple-choice format and the ease with which the Force Concept Inventory can be used, instructors can gain feedback on students' misconceptions or lack of understanding. They can then focus on such issues and work to promote better conceptual understanding. A call for 'Concept Inventories' in many disciplines has led to the development of instruments focused on circuits, statistics, etc. (Evans et al., 2003). Instruments focused on general chemistry topics have been created, (Nurrenbern and Robinson, 1998; Mulford and Robinson, 2002; Krause et al., 2004), but none assess skills of both conceptual understanding and scientific reasoning as does the assessment discussed in this chapter.

Many researchers chose an area of interest in chemistry that has been documented to illicit misconceptions from students as a basis for creating a “concept test.” Such tests are often created for what seems the sole purpose of a single study on a single topic in chemistry. One such example is an assessment on acids and bases created to determine the effectiveness of a new method of teaching in the first year undergraduate chemistry curriculum by Tarhan and Sesen (2012). While such a test has inherent value to the study for which it was created, without a more complete validation process or a wider applicability, its further use by the chemical education community is limited. Othman, et al. (2008) also created an assessment focused on common high school student misconceptions, and their focus was the particulate nature of matter and chemical bonding. They validated their test as they used it, and the wider applicability of the instrument seems limited due to its narrow focus. Heredia, et al. (2012) did use the particulate nature of matter and chemical bonding test as a diagnostic tool for students entering college general chemistry to help inform the role of preparatory chemistry. Tan, et al. (2005) went through a very rigorous development and validation procedure to create their ionization energy concept test for high school. However, this test is also limited to a single topic. The feasibility for teachers in high school or instructors in college to administer multiple multiple-choice tests for each topic is plausible, but the time for constant testing might inhibit time for other types of assessments. While these tests are meant to mimic the results from open-ended exams, there is inherent value in requiring students to put their thoughts into their own words rather than circling an

answer choice. When multiple-choice tests are used, they should also be used in tandem with other types of assessments.

This chapter presents the creation and validation of an easy-to-administer tool, the Chemistry Concept Reasoning Test (CCRT), for assessing scientific reasoning of chemical concepts generally including in introductory chemistry courses. This test was designed to create an accurate measure of understanding and scientific reasoning in chemistry, similar to free-response questions requiring reasoning and explanations yet easy to administer and grade.

2.3. Assessment Development

The development of the CCRT focused on creating a tool to assess scientific reasoning in alignment with the curricular goals discussed above. To do this, the topics to be covered were determined, questions were written using a variety of styles, and responses were developed to appropriately assess understanding. The test was developed as a short, easy-to-administer, multiple-choice exam requiring little to no computation.

2.3.1. Content Areas

The following list of broad topics covered in an undergraduate General Chemistry course (alphabetically) was created to provide an outline and determine coverage for the content of the test.

- Atomic Molecular Theory
- Atomic Structure
- Chemical Bonding
- Chemical Equilibrium
- Chemical Kinetics
- Chemical Reactions
- Kinetic Molecular Theory
- Phase Equilibrium
- Thermochemistry
- Thermodynamics

2.3.2. Question Types

A new style of multiple-choice questioning was developed to mirror an essay question type developed at Rice University. In the essay style question, the student is confronted with a possible answer to a stated question and is asked to 'assess the accuracy' of the possible answer, evaluating both the accuracy of stated experimental data and the correctness of the reasoning based on that data. This has found this to be an extremely effective measure of students' understanding, since it taps into knowledge at the highest level of Bloom's Taxonomy (Bloom, 1956). As

such, it is important to have multiple-choice questions that reflect this style of assessment.

In the multiple-choice 'assess the accuracy' format, students are asked to examine three to four numbered statements for accuracy and reasoning. The statements provide observations and conclusions. Students are required to go beyond determining which statements are true and which are false. Students must also understand how the statements are logically connected and if the conclusion can be based on those observations. The type of question can be illustrated by a simple example shown in Figure 2.1. I have developed several such questions containing statements to be assessed for logic and accuracy, which are included on the CCRT.

A number of two part questions are included, similar to the format used by others, including Treagust (1988). In this format, the first of the paired questions requires a straightforward prediction of Chemical phenomenon, e.g. which substance has a higher boiling point. The second of the paired questions goes further to ask for the reasoning for and explanation of the previous answer. There are five sets of paired questions included on the CCRT.

Similarly to the two part questions, certain questions include both choosing an answer and justifying the reasoning within one set of answer choices. The general format of these questions is to provide a comparison between two

Assess the accuracy and logic of each of the statements below and select the best answer choice.

I Color is the perception of light emitted or reflected by a substance due to its physical properties.

II The sky and water both often appear blue.

III Therefore, the sky and water must be made of the same substance.

Answer choices:

a. Statements I and II are true and lead logically to Statement III.

b. Statement I is false and Statement II is true, therefore Statement III does not follow logically from I and II.

c. Statement I is true and Statement II is false, therefore Statement III does not follow logically from I and II.

d. Statements I and II are true, but Statement III is not a logical conclusion of Statements I and II.

e. All statements are false.

Figure 2.1 - Example of an assess the accuracy style multiple-choice question

statements or situations and ask “Which assessment of this is correct, and why?” The answer choices then include multiple assessments in which either or both

statements are incorrect and with different reasoning for these determinations.

Thus, test takers must go beyond determining the correct answer and assess both the answer and the reasoning. In similar fashion, one question specifically asks for

the assessment of the accuracy of two representations of the same molecule. The

question follows a type developed by others, including Kimbrough and Jensen

(2010). This type of question can be illustrated by a simple example shown in Figure

2.2. There is one question that specifically follows the model below and three other

questions that include choosing both an answer and justification within one set of responses.

Consider the following proposed solutions to the algebraic equation: $x + 2 = 7$.

I $x = 5$

II $x = 9$

Which of the assessments is correct?

- Solution I is incorrect because 5 and 2 do not add up to 7.
- Solution I is incorrect because 5 is less than 7.
- Solution II is incorrect because 7 is greater than 2.
- Solution II is incorrect because 9 and 2 do not add up to 7.
- Both solutions are incorrect

Figure 2.2 - Example of a multiple-choice question to assess the accuracy of a solution

Four questions specifically require understanding of particulate level visualization. They each show the particulate level on a simplified macroscopic scale with atoms as circles using either space-filling or ball and stick representations of molecules. The questions regarding the illustrations test the understanding of the phenomena addressed at the particulate level.

The remaining questions focus on eliciting student understanding of topics by asking students to select the best reason for the given observations or to make predictions from data. Discussion and diagnostic questions from Rice University General Chemistry courses written by Wiediger and Hutchinson (2002) were updated, and a few were incorporated into the test.

2.3.3. Response Development

The different types of questions themselves were assessed through use with the General Chemistry course at Rice University, CHEM 121/122, in Fall 2009 and

Spring 2010. The first of multiple-choice 'assess the accuracy' questions discussed above was piloted on the Final Exam, Fall 2009. Responses from the students prompted a revision of the answer choice format. The students' responses led to the combination of two questions, one assessing the line of reasoning of the statements and one assessing the accuracy of the statements, into a single question where logic and accuracy are integrated in the answer choices. This format is exemplified in the model shown in the previous section.

One of the visualization questions was piloted during the second semester General Chemistry course at Rice University, CHEM 122, as a discussion question given before and after the learning objective was covered in Spring 2010. The question required students to sequence different representations of matter in order of increasing temperature to show phase transitions from solid to liquid to gas. The discussion question was given to the class in an open-ended format so students could create their own response rather than selecting from options. Before and after discussing physical states of matter in class, 18% and 13%, respectively, included a nonsensical sequence in their response. These data and further analysis of student responses guided the creation of multiple-choice answers that include common misconceptions and distracters from the correct answer.

Select questions other than those discussed here were also piloted as exam or discussion questions for the General Chemistry students at Rice University. Students' responses were used as feedback to determine whether the questions were clear and to accurately test the concept under consideration.

2.3.4. Test Format

Two forms of the CCRT were created with 38 analogous questions referred to as Versions A and B, with Version A included in the appendix. In most questions, the data presented or molecules considered were simply changed between the two versions, so that the actual content is equivalent. In cases where that was not possible, the questions were reworded to test the same content, or the answer choices were modified. Both versions of the test were uploaded to the Rice University virtual workspace and course management system, OwlSpace. Through OwlSpace, the test could be given anonymously via a specific web address or confidentially through specific course webpages. Differing levels of feedback could be given to test takers. The online system added flexibility for the use of the test and provided a reliable means for data collection.

2.4. Validation Results

The validity of the CCRT has been established via several strategies (Hopkins, 1998). To establish content validity of the test, experts in teaching chemistry reviewed the assessment and provided feedback. Two Rice University professors who had recently taught General Chemistry, and a Ph.D. Chemist focusing on chemical education at another institution provided comments that were discussed and incorporated into the test. To provide further content validity, the CCRT was then given in paper format to science teachers enrolled in a professional development course for secondary science teachers and chemistry graduate

students at Rice University. Not only were these participants asked to take the test, but also to provide feedback and write notes regarding the content of the test, appropriateness of the answers, and breadth of the material covered. The comments, mainly those from high school chemistry teachers, were taken into consideration to provide further content validity.

In order to ensure concurrent criterion-related validity, the test was also administered to people with a high degree of education outside the field of chemistry. For the 11 test takers with little to no background in chemistry, the average score was $23 \pm 7\%$. This low average and minimal distribution is an indicator that the test discriminates between low and high levels of concept knowledge in chemistry accurately. The CCRT was able to identify these test takers as not proficient in chemical understanding and reasoning. The test takers with no chemistry background included only one undergraduate student, with the remainder holding at least a bachelor's degree. Because the test takers were educated and seasoned at test taking yet still performed poorly, my results show that the answers to the CCRT were not able to be easily deduced by good test takers.

To determine criterion-related convergent validity, the CCRT was given to chemistry students and compared with other measures of knowledge of chemistry already in place using a protocol deemed exempt by the Rice University IRB. At the end of the second semester of the two-semester General Chemistry course at Rice University, CHEM 122, both versions of the complete exam were administered to the students for voluntary graded extra credit. The frequency distribution of scores is

shown in Figure 2.3. The response rate was 92% with 146 students taking Version A for an average score of $64 \pm 13\%$, and 142 students taking Version B for an average of $61 \pm 14\%$. An F-test showed the scores from the two versions to have the same variation, and no significant difference for the overall scores was found with a t-test. However, when the test was broken down by topics covered in the first or second semester of General Chemistry, there was a significant difference in the students' accuracy on the second semester material. For Version A, the average number correct out of 14 questions covering second semester material was 10.5 ± 2.1 , and for Version B the average was 9.83 ± 2.32 . An F-test showed the scores on the two versions to have equal variance, but a t-test calculated a significant p-value of 0.014. Upon review of the data, four questions from the second semester material were identified as more challenging on one version of the exam. By analyzing the most

Figure 2.3 - Frequency distribution of scores on the CCRT at the end of CHEM 122

common wrong answers, modifications were made to those questions to remove inconsistencies in level of difficulty between analogous questions.

Scores on either version of the concept test were analyzed for correlation with students' overall scores in the first and second semesters and final exam score of the second semester course to determine criterion-related convergent validity. The overall scores in the first and second semesters of General Chemistry separately included contributions from three midterm scores, one final exam score, and scores for laboratory, homework, and participation. The second semester Final Exam consisted of 14 open-ended questions covering second semester material, with half requiring some computation. The Pearson product moment correlation coefficients for each version of the CCRT, separately and combined, are shown in Table 2.1. All correlations were positive and very high, showing excellent convergent validity. The scatterplots of the data confirm the strong correlation as seen in Figure 2.4. The correlation between the CCRT, course scores, and final exam grades indicate the test to be a valid measure of conceptual knowledge of the material covered in General Chemistry.

Table 2.1 - Pearson correlation coefficients of CCRT with CHEM 121/122 scores

	Version A	Version B
CHEM 121 overall score	0.663*(139)	0.679*(136)
CHEM 122 overall score	0.649*(146)	0.717*(142)
CHEM 122 Final Exam score	0.639*(146)	0.649*(142)

Figure 2.4 - Scatterplots of overall CHEM 121/122 scores and CCRT scores

2.5. Implementation of the Test

2.5.1. Rice University General Chemistry

The test was used as a pre and post-assessment to measure change in conceptual understanding of Chemistry over two semesters of General Chemistry (CHEM 121/122) and Honors General Chemistry (CHEM 151/152) at Rice University in 2010-2011. Both sequences of courses, CHEM 121/122 and CHEM 151/152, generally covered the same content. CHEM 121/122 was a high enrollment course that incorporated the Concept Development Studies in Chemistry (Hutchinson, 2007), as well as a traditional Chemistry text, (McMurry and Fay, 2008). However, CHEM 151/152 was a smaller course taught in a traditional lecture format with a more rigorous focus on the mathematical basis for some of the concepts covered. They used a different textbook (Atkins and Jones, 2009), which also incorporated a calculus focus. Students could have registered for either course at their own discretion, as both courses could be considered outstanding General Chemistry courses when compared to what is offered similarly at any other institution of higher learning.

CHEM 121 in Fall 2010 offered three sections to accommodate the initial enrollment of 438 students. CHEM 122 in Spring 2011 was condensed to two sections with an enrollment of 336 students. CHEM 151 was a single smaller section of 51 students initially enrolled in Fall 2010, and 31 students were in the Spring 2011 class of CHEM 152. The complete Version A of the CCRT was given as a pre-test

during the first week of both CHEM 121 and CHEM 151 for optional minimal extra credit based on completion. The test was given confidentially via OwlSpace. In the last week of the semester, a partial post-test was given to both CHEM 121 and CHEM 151 using Version B of the CCRT. Only questions pertaining to material covered during the semester were included on the first semester post-test, which was 23 questions for CHEM 121 and 24 questions for CHEM 151. The post-test was also given as a voluntary assignment, but extra credit was awarded based on both completion and accuracy. During the last week of CHEM 122 and CHEM 152, the second semester courses for General Chemistry, the final portion of the Version B post-test was administered. For CHEM 122, this included 15 questions, and for CHEM 152, this was only 14 questions. For each of these administrations of the test, no feedback was given to students online. They were instead encouraged to visit their instructors to discuss any questions regarding the test or to view a key for the test. Averaged results for each of these test administrations are shown below in Table 2.2, showing only the number of students who completed both portions of the post-test.

Table 2.2 - Average pre-test and post-test CCRT scores

	Version	N	Average	Standard Deviation
CHEM121 Pre-test	A	290	35%	11%
CHEM151 Pre-test	A	43	45%	14%
CHEM121/122 Post	B	270	62%	13%
CHEM151/152 Post	B	20	62%	9%

The pre-test score for the Honors General Chemistry class was 10% greater than for General Chemistry. This difference might be due to the prior preparation of the students, mainly which Chemistry courses they took in high school. A survey question to illuminate such information was given at the same time as the CCRT, as shown in Figure 2.5. This data shows that 49% of the CHEM 151 students had taken a college level chemistry course in high school via either Advanced Placement (AP) or International Baccalaureate (IB) programs. However, only 34% of CHEM 121 students responded that they had taken such courses. Thus, this difference in preparation seems to explain the difference in the pre-test scores between the classes. Also, the fact that students can self-select to take an honors chemistry class

Figure 2.5 - Responses to: "Which chemistry courses did you take in high school?"

may cause those students more interested or already more well-versed in chemistry to elect to take CHEM 151/152 over CHEM 121/122.

The scores increased significantly between pre-test and post-test for both groups, as shown via the score distributions in Figure 2.6 and Figure 2.7. Even though the CHEM 151/152 class started out at a higher pre-test score, both classes had the same final average on the post-test. This indicates that both classes did gain similar levels of knowledge in general chemistry concepts, and that any initial pre-test difference could be overcome by two semesters of college chemistry. The score distributions and differences in standard deviation indicate that there was a much broader distribution of grades for the CHEM 121/122 students than for CHEM 151/152 students, which is somewhat predictable due to the much greater number of students taking the test for CHEM 121/122. However, it is interesting to note that

Figure 2.6 - CHEM 121/122 pre-test and post-test score distributions

Figure 2.7 - CHEM 151/152 pre-test and post-test score distributions

6% of the CHEM 121/122 students had greater than an 80% on the post-test, yet the maximum score for the CHEM 151/152 students was 76%. This is also true at the other end of the spectrum. For CHEM 121/122, 6% of the students scored 40% or less on the post-test, whereas the minimum score for CHEM 151/152 was 41%. Thus with more students in CHEM 121/122, there were some who had a very high conceptual understanding of chemistry and some with a very low understanding. In CHEM 151/152, the students were all within a more narrow range of levels of understanding. Overall, both classes showed substantial improvement over the course of the year on the CCRT, indicating the test was a successful quantitative tool for measuring the increase of understanding over time.

The greater improvement on the CCRT for CHEM 121/122 versus CHEM 151/152 indicates that the active learning pedagogy of CHEM 121 and conceptually

focused curriculum of both CHEM 121 and CHEM 122 were successful. So, despite the self-selection and better preparation of the CHEM 151/152 students, the CHEM 121/122 students were able to reach the same level within the first year of instruction and close any achievement gap. Also, it is interesting to note that this gain was achieved by CHEM 121/122, despite the large class size and the inherent issues that come along with such a high student to teacher ratio. While the active learning strategies of Socratic questioning and discussion questions were mainly used only in CHEM 121, the Concept Development Studies approach was consistent across semester. The data shows this approach to be successful in achieving conceptual understanding of chemistry.

An item analysis was performed on the pre-test and post-test scores for the large population in CHEM 121/122. Discrimination indices were calculated for each of the questions as shown in Table 2.3. The discrimination index is a measure of how well a question discriminates between top and bottom performers. It is calculated by taking the average score on a question by the top third performers minus the average score by the bottom third performers on that question. A high discrimination index indicates that top performers do substantially better than low performers. A low discrimination index indicates that either both top and low performers get that question right or both get that question wrong.

The pre-test (Version A) discrimination indices had a wide range, as with an average score of only 35%, students would have guessed on many of the questions. The data showed that some questions might have been easy for those students who

Question	Discrimination Index	
	Version A	Version B
Q1	45%	31%
Q2	39%	16%
Q3	37%	36%
Q4	25%	33%
Q5	9%	14%
Q6	36%	35%
Q7	-7%	10%
Q8	25%	14%
Q9	8%	21%
Q10	29%	47%
Q11	34%	18%
Q12	35%	44%
Q13	44%	21%
Q14	36%	36%
Q15	44%	41%
Q16	4%	37%
Q17	24%	37%
Q18	17%	40%
Q19	4%	26%
Q20	20%	3%
Q21	24%	18%
Q22	21%	23%
Q23	23%	47%
Q24	32%	9%
Q25	25%	12%
Q26	23%	50%
Q27	13%	44%
Q28	22%	29%
Q29	49%	13%
Q30	5%	15%
Q31	28%	30%
Q32	42%	47%
Q33	10%	17%
Q34	-2%	26%
Q35	62%	38%
Q36	23%	35%
Q37	31%	40%
Q38	38%	27%
Average	26%	28%
St Dev	15%	13%
Max	62%	50%
Min	-7%	3%

Table 2.3 - Discrimination indices of versions A and B of the CCRT

had good knowledge of chemistry prior to high school, with five questions having discrimination indices greater than 40%. The two questions that each have a negative index indicate there were also questions that might exemplify misconceptions perpetuated in high school that were held even by well-prepared, high achievers. Overall, the questions as a pre-test were discriminatory more on the basis of what content was covered most often in high school level chemistry rather than on level of difficulty of the questions. However, the post-test Version B discrimination indices were useful in determining how well each question divided the students. For 5 of the 12 questions with the low discrimination indices, i.e., less than 20%, the low score was due to the fact it was a very challenging question. The other 7 questions were generally easy questions for a post-test. It was important to include at least a few easier questions throughout the test to prevent students from getting frustrated and giving up while taking the test. The very hard questions were there to challenge every student. The remaining 26 questions were very good at discriminating between the high and low performing students. The calculation of the discrimination index for each question of each version of the test does provide good data showing that this is a hard test that will discriminate students who understand chemistry from those who do not.

2.5.2. Lone Star College

The CCRT was also used as a pre and post-assessment in another venue, Lone Star College Kingwood (LSC-Kingwood) in Kingwood, Texas. LSC-Kingwood is a community college that is part of the larger Lone Star College System. They offer a

two-semester General Chemistry course to students who have taken high school chemistry within five years or have taken an Introduction to Chemistry course in community college. General Chemistry, CHEM 1411/1412 is offered during the fall, spring and summer semesters. In coordination with a LSC-Kingwood instructor previously at Rice University, an IRB protocol was approved by the Lone Star College System for confidential data collection with CCRT. CHEM 1411/1412 was a standard General Chemistry course taught via lecture, some questioning, group work and problem solving. The classes were capped at 24 students and used a traditional text (Whitten et al., 2009).

In Summer 2011, in a CHEM 1411 course, 10 students took the Version A CCRT as a pre-test in the first week of the semester. One student had previously seen the test as part of the cohort of teachers in professional development at Rice University who reviewed the CCRT during validation, so that student's scores were removed from the analysis. At the end of the semester, 6 students completed the Version B post-test consisting of 26 questions. In Fall 2011, in one CHEM 1411 courses, 18 students took the Version A CCRT as a pre-test in the first week of the semester. At the end of the semester, 14 students completed the Version B post-test consisting of 26 questions. In another Fall 2011 CHEM 1411 course taught by another instructor, only one student opted to take the pre-test CCRT; however none of these students completed the post-test in that class. The final post-test data for the remainder of Version B of the CCRT has yet to be collected from a CHEM 1412 class. Students were offered minimal extra credit for completing the pre-test and

post-test. The tests were given in paper form and hand graded by the LSC-Kingwood instructor. Data was sent for analysis without any identifying information.

Scores from both semesters were compiled due to the low participation numbers. The pre-test average score for the 28 students was $26 \pm 10\%$ on the complete Version A. The average score was also $26 \pm 9\%$ for the pre-test including only the 26 questions also used on the post-test. The post-test average for those 19 students was $32 \pm 12\%$. Thus, improvement was a minimal 6% over a one-semester course. For those 19 students, the post-test scores were analyzed with course grades, and a Pearson correlation coefficient was significant at 0.418. This positive correlation was not as strong as those correlations of the complete post-test with course grades for the Rice University validation study. However, the positive correlation indicated that the CCRT did correlate with course grade as a measure of conceptual understanding in chemistry.

The discrepancy in the different pre-test and post-test scores between LSC-Kingwood and Rice University indicated that there was a difference in the knowledge gained in these courses. The pre-test averages started out with only a 9% difference, yet the Rice University post-test average was 30% greater than LSC-Kingwood. The student populations at each of the institutions differed in their level of academic accomplishment prior to admission and also, according to this data, in General Chemistry. Also, General Chemistry at both institutions aimed to teach students basic concepts in chemistry. However, the focus at Rice University had always been on understanding the concepts, putting forth valid scientific reasoning,

and mastering the challenging problems. While at LSC-Kingwood, much more time was spent in class mastering the basic problems, and there is less emphasis on being able to explain concepts or understand scientific reasoning. Thus, the difference in post-test scores on the CCRT was anticipated. This comparison allowed for the purpose of the CCRT to be apparent as a test for scientific reasoning of chemical concepts.

2.5.3. Teacher Professional Development

CHEM 570/571, Teaching Chemistry via Inquiry Learning, was a year long professional development program offered by Rice University's School Science and Technology Program. The course was for high school chemistry teachers in Houston and the surrounding area. Teachers were provided with content at the college level via the Concept Development Studies in Chemistry (Hutchinson, 2007), experience with active learning pedagogy and laboratories, and curriculum they could use at the high school level.

On the first day of the Summer 2011 workshop that began the professional development program, 20 of the 21 teachers took Version A of the CCRT as a pre-test. One of the 38 questions was omitted making the full test only 37 questions. The question regarding the concept of entropy was not deemed necessary as a topic for high school teachers. Then, at the last CHEM 570 meeting of Fall 2011, 14 questions from Version B of the CCRT were given as a post-test taken by 18 teachers. Data from the remaining Version B questions has yet to be collected as a post-test. At

both test administrations, the test was given via OwlSpace with confidential settings so that scores could not be traced to individual teachers.

The pre-test average for the 20 teachers was 50+/-18% for the overall test and 45+/-19% for the 14 pre-test questions that corresponded to the post-test. It is important to note that 7 of the teachers in the cohort (1/3) had previously taken a similar course offered at Rice University that also provided similar chemistry content. Thus, the pre-test score is not fully reflective of a true pre-assessment. Only 18 teachers took the post-test for an average score of 55+/-21%, showing a 10% improvement over the first semester of the program. High school chemistry teachers would be expected to have a high conceptual understanding of general chemistry concepts and avid abilities of scientific reasoning. The pre-test average being substantially higher than that for college freshman is reassuring evidence that high school teachers know more than high school students regarding chemistry. However, the improvement was minimal. This could be indicative of the teachers' view of the professional development as more of a curriculum and pedagogy resource and less of a place to expand content knowledge. It is also the case that this data was skewed by such a high percentage of the teachers having already been exposed to the content of the course for the pre-test. The CCRT does indicate to the professional development program that adding greater accountability for the teachers to expand their understanding of chemistry may add to the value of the program. Also, the pre-test could have been used more as a diagnostic tool to assess the areas where the teachers needed to build their scientific foundations and

allowed for curriculum tailored to make the most impact on teachers' content knowledge. The impact of teacher professional development programs will be discussed in much further detail in Chapter 6.

2.6. Impact

The CCRT has been designed and validated for use in college General Chemistry courses. The CCRT could have significant impact in the designing of curriculum to allow for the greatest gains in student learning. The next chapter of this thesis outlines how I used the CCRT as one measure of learning to understand the impact of students' participation in an active learning chemistry classroom.

The test has been available on request to instructors and teachers by email. Since publication of this test in April 2010, 29 instructors and science education researchers from 18 different countries have received the test. Some have used all or part of it in their own classrooms. Feedback from fellow instructors has been positive, as they have seen the value of asking challenging conceptual questions of their students. One instructor used questions from the test both on examinations and as discussion questions during class with positive informal feedback from students. Within high school chemistry courses, the CCRT would be of use mainly in the second course in chemistry or Advanced Placement chemistry. The test can be easily administered due to its multiple-choice format, and will provide reliable feedback on the level of general chemistry knowledge gained and student understanding of particular topics. Diagnostically, the CCRT as a pre-test in science

courses that build upon General Chemistry would allow instructors to address areas of weak understanding. Overall, the CCRT is now a valid and accessible tool to quantitatively measure conceptual understanding of chemical concepts in a reliable manner that has broad applicability across the chemical education community.

Silent and Vocal Students

This chapter presents a multiphase study performed to understand the impact of an active-learning atmosphere in General Chemistry on both students who are vocal and silent in the classroom (Obenland et al., 2012a, 2012b).

3.1. Literature Review

“Active learning” pedagogical methods inspired a great deal of innovation and research recently, and with good reason (Donovan et al., 1999; National Research Council, 2000). Many studies have shown that students benefit significantly from innovative classroom approaches that actively engage students in their own learning, and these studies are consistent with our increasing understanding of how students learn (Fata-Hartley, 2011; Felder et al., 2000; Michael, 2006; Prince, 2004).

Active learning is far from a new concept in teaching. Small seminar discussions have long been used in upper-level and graduate courses. Socratic teaching has been used in law schools for decades. Problem-based learning has been a key ingredient in senior level courses, including engineering design courses and senior research projects. Perhaps most significantly, apprenticeships are the ultimate form of active learning, and these survive in graduate schools and medical residencies. Thus, the idea that students should be fully engaged in their own learning is a well-established, time-tested concept.

What is new and exciting is the rise of active learning in large enrollment college science classrooms, particularly in introductory level chemistry and physics courses (Buchanan et al., 2004; Klionsky, 2002; Kovac, 1999; Meltzer and Manivannan, 2002; Murphy et al., 2010). Such courses have traditionally been taught in a standard lecture format where students are passive, taking notes as rapidly as material can be written on the board or paged through on prepared presentation slides (Walczyk and Ramsey, 2003). The foundation for such an approach is primarily not pedagogy but pragmatism, since this is the most straightforward manner to address large audiences.

Recently, a variety of active learning approaches that are both practical and pedagogically sound have been developed with documented success. These include, but are not limited to, peer instruction, problem-based learning, and student-centered active learning (SCALE-UP) (Bonwell and Eison, 1991; Gaffney et al., 2008; Johnson et al., 1998; Mazur 1997;). Another popular approach has been the use of

discussion or “clicker” questions periodically during lecture, which are used to gain feedback from every student as well as facilitate peer and class discussion (Bruff, 2009; Duncan, 2005; MacArthur and Jones, 2008). In many instances, students are asked to think about their answer to each question and then talk to fellow students in a “think-pair-share” fashion (Bruff, 2009; Duncan, 2005; King, 1993). While discussion questions are usually used to break up the standard lecture as an active learning supplement, the Socratic or “interactive questioning” approach can be used to replace the traditional large lecture (Hutchinson, 2000). In a single 50-minute class period of Socratic questioning, the instructor may ask between thirty and forty interactive questions, calling on students to respond orally. The variety within these active learning approaches allows instructors to address misconceptions and support the needs of students with various learning styles (Felder and Silverman, 1988). Research and practice have shown that students in active learning environments on average perform better academically, enjoy their courses more, and remain in these classes at a higher rate (Felder et al., 2000; Michael, 2006; Prince, 2004).

3.2. Research Questions

One major difference between active learning approaches in small and large classes is the possibility of students remaining silent in large classes despite the active learning approaches. Students in small classes are conspicuous in their silence, so that peer pressure and instructor insistence can be effective in

preventing students from remaining silent. This is generally not true in large classes, where students can remain anonymously quiet (Tobias, 1990). Moreover, the opportunities for individual students to participate actively, for example in class discussion, are clearly much more frequent in small classes. In large classes, even when active learning approaches are in use and students participate as frequently as possible, all students will be silent for the vast majority of any class period.

The first phase of my study addresses two related questions about the behavior of silent students in large, active learning science classes. First, what are silent students doing in an active learning class? Second, do silent students derive the same benefits from active learning as their more vocal classmates? The goal was to understand the engagement, self-reported learning, and perceptions of silent students in these classroom settings. A review of the literature revealed essentially no information about students who remain silent in the large active learning classroom, particularly in science or mathematics courses. Thus, prior to this study, there was no real understanding of how, or even if, silent students learn in an active learning environment. This study demonstrated that silent students were indeed engaged in the active learning experience, found the active learning environment to be beneficial to their understanding, and had positive perceptions of active learning methods.

The next phase in this study was to address further questions, primarily concerning the comparative learning progress and outcomes for silent and vocal students. Simply stated, do the silent students learn as well as the vocal students?

The primary tool for comparison was the Chemistry Concept Reasoning Test (CCRT), as presented in Chapter 2 (Cloonan and Hutchinson, 2011). The CCRT is a battery of multiple choice questions which were designed to analyze students' ability to reason with chemical concepts, including their ability to analyze and interpret data in the context of chemical models.

The CCRT was employed in a paired pre-test and post-test analysis. The results showed that vocal and silent students were not significantly different in their prior knowledge of Chemistry as measured by the CCRT performance. Hence, prior preparation did not distinguish the two groups of students. After a semester in an active learning environment, both groups of students showed substantial improvement on the CCRT, but the active students showed a statistically significantly greater improvement. This observation will be analyzed in detail.

These results lead to another significant question addressed in this chapter. If vocal students make greater progress in learning outcomes than do silent students, how might teachers encourage silent students to become vocal? To facilitate identifying method to encourage vocal participation, motivational factors and study habits of vocal students were compared to silent students. The results provided insights into how and why vocal students chose to be vocal and thus provided a window into understanding why silent students chose to remain silent. In combination, these results indicate how silent students might be encouraged to become vocal in future work.

In the next sections, I describe the active learning environment in the General Chemistry course, as well as the methods used in this study. Detailed definitions of “silent” and “vocal” are based on student-reported data. The analysis of student engagement, perceived learning, and perceptions of the environment is presented. Performance gains on both the CCRT and course examinations are analyzed. Further results from the final phase of the study are analyzed for motivational factors and study habits of vocal and silent students. Conclusions and recommendations based on this body of work are presented for future incorporation into science classrooms.

3.3. Research Setting and Methods

This study was situated within an active learning class that allowed opportunities for students to participate. This section outlines aspects of the class pertinent to the study and also defines the tools used for the study itself.

3.3.1. Class Setting

The population for this study was the first semester General Chemistry class at Rice University over two years. Enrollment was 434 students for Fall 2010 and 394 students for Fall 2011. The class was approximately 90% freshman and unevenly divided across three sections each semester. The three sections were taught in tandem by different instructors with a common syllabus including identical reading assignments, homework, grading scheme, and exams. Students

could attend any of the sections, as the content and teaching strategies across the three were consistent. Three midterm exams were used to assess student learning, as well as one final exam. Each of these exams was made up of approximately an even division of challenging traditional chemistry problems and concept focused questions that required students to write out explanations of chemical phenomena.

The curriculum for this course included the traditional General Chemistry content but also emphasized the Concept Development Studies approach. Created at Rice, this approach leads students through observations and logical reasoning to the development of chemistry models and major chemical concepts. This concept development focus, implemented via Concept Development Studies in Chemistry by Hutchinson (2007) has been found to be successful at this institution for a number of years (Hutchinson, 2000).

3.3.2. Active Learning Approach

The active learning approach for General Chemistry at Rice University has been developed over the past few decades and fits within the three dimensions of active learning outlined by Watkins et al., (2007) as well as the fourth dimension of affect added by Drew and Mackie (2011). In tandem with the concept development approach of providing students with the observations and reasoning for chemical concepts, students were asked to verbally express both their logic and understanding in this course. Throughout the course, Socratic questioning was used during class time to probe students' comprehension and guide students to the

accepted understanding of concepts. During each 50-minute class period, approximately 40 questions were posed to the class. Students were asked to respond by raising their hands, a behavioral dimension of active learning. The instructor would then call on a student for their response to be shared with the class. However, even those students who were not called on but sat quietly thinking of an answer to the question were actively participating cognitively. Students were incentivized to participate within the grading scheme, which also added an external motivation or affective dimension to the active learning. Each day a student responded with an answer in class, that student received one point extra credit towards their grade based on a 1000 point scale.

Socratic questions were based on topics from reading assignments students were asked to complete before coming to class. Thus, students were able to familiarize themselves with the content via reading. In class, through questioning and class discussion, the chemical concepts and models were built via that same reasoning presented in the reading. The class discussion format allowed students to ask questions often during class, which the instructor encouraged other students to answer. The flow of discussion provided an atmosphere where students could learn from each other's ideas and also added a social dimension to the active learning.

Discussion or "clicker" questions are also used each class period in a think-pair-share fashion. Discussion questions are multiple-choice and typically focus on understanding of major concepts or working through problems. Rather than using an electronic clicker system for response, students are given colored index cards at

the beginning of the semester. After time in class to think and talk to peers, students respond to questions by holding up the colored card corresponding to their selected answer choice. Discussion questions allow instructors to get a poll of student understanding and probe deeper by asking students to defend and provide reasoning for their responses; and they also provide a means for every student to be actively engaged.

3.3.3. Survey Instruments and Interviews

In order to learn the students' perceptions of the active learning classroom, the study utilized surveys, interviews and exam questions. In the 11th and 12th week of the semester, students were asked to voluntarily participate in an online survey both in Fall 2010 and 2011. The surveys included multiple-choice questions regarding students' amount of participation, Likert-scale questions regarding their perceptions of the active learning classroom, and for Fall 2011 only, further multiple-choice questions about their consistency in participation and feelings about Socratic questions. In both Fall 2010 and Fall 2011, the survey response rate was 84%.

Survey responses were confidential, as one question regarded willingness to participate in interviews. From those students willing to participate in interviews, random selection was used to choose the students to schedule via email. In Fall 2010, 17 students were interviewed, all who would be considered in the silent category. In Fall 2011, 21 interviews and one focus group consisting of four students

were conducted. Of those students, 16 were vocal, and 9 were silent. All interviews followed a semi-structured protocol based on the survey questions. Surveys and interview protocols were approved by the IRB.

3.3.4. Definitions of Silent and Vocal Students

As the primary goal of this study is to understand the activity of those who rarely appear to be participating in class, the analysis of the survey data began by classifying students according to their responses to the questions the multiple-choice survey question: *How often do you attempt to participate by raising your hand in lecture?* Students who self-reported that they attempted to participate at least once a week were categorized as “**vocal**.” Students who self-reported that they attempted to participate less often than once a week were categorized as “**silent**.” Of the students who completed the survey for Fall 2010, there were 245 vocal students and 121 silent students. For Fall 2011, there were 223 vocal students and 109 silent students. Categorization of students by how often they try to participate rather than how often they actually get called on simplifies analysis. However, it is important to note that the categorization of silent does not preclude a student from being an active participant in the classroom.

3.3.5. Assessment Tools

The second phase of this study utilized student responses to the Chemistry Concept Reasoning Test (CCRT) to evaluate any differences in learning between vocal and silent students. The CCRT was previously created as a tool for measuring

conceptual understanding and scientific reasoning pertaining to general chemistry topics, as detailed in Chapter 2. The test is made up of multiple-choice questions and has two analogous forms to allow for pre and post testing. While being constrained to multiple-choice for easy administration and grading, novel question structures were designed to test students' understanding of the molecular level, logical reasoning, and the basis of scientific models. The test was validated at Rice University with previous classes of General Chemistry, so its use as a tool for this study's population was particularly appropriate. The CCRT was administered online to General Chemistry students in the first week of the Fall 2010 semester as a pre-test. The test was a voluntary opportunity to earn minimal extra credit based on completion, and 71% of the class completed the test. In the last week of the semester, the post-test version of 23 questions that corresponded with the topics covered in the first semester of General Chemistry was given online to students. Extra credit was assigned based on completion and accuracy, and 86% of the students completed the test.

Certain exam questions were also analyzed to compare the performance of vocal and silent students in the second phase of the study. A style of question that was included at least once on every test was "assess the accuracy." In an "assess the accuracy" question, there is a question stated and a possible response to that question that students are asked to evaluate, as shown in Figure 3.1. This question format provides a venue to test misconceptions and probe higher level thinking skills. Two midterm exams included one of this type of questions, each worth 20

The following question was posed on an exam: **Please explain how observations from Rutherford's gold foil experiment generated a nuclear model of the structure of the atom.**

A student responded with the following answer:

Rutherford's gold foil experiment proved that there was a nucleus in the atom and that nucleus contained the atom's atomic number worth of positive charges, because some of the alpha particles were deflected or rebounded straight back. Rutherford's experiment also showed that atoms are mostly empty space, because the majority of alpha particles went straight through the air in the gold foil. Electrons are located in the air between the gold atoms.

Assess the accuracy of the student's response. In your assessment, note what information is correct or incorrect, provide correct information where needed, explain whether the reasoning presented is logical, and provide logical reasoning where needed.

Figure 3.1- Example of an "assess the accuracy" exam question

points, and one midterm exam included two of this type of questions, totaling 30 points.

3.3.6. Data Analysis

Each survey question had Likert-scale options Strongly Disagree, Disagree, Undecided, Agree, Strongly Agree. The survey contained questions phrased both affirmatively and negatively, as seen in Table 3.1. In order to obtain a measure of student reaction to the course, a value was assigned to each response on the survey. A coding of -2 was designated for the least positive response (e.g. Strongly Agree with a negative statement) and increasing incrementally up to a value of 2 for the most positive response (e.g. Strongly Disagree with a negative statement).

The quantitative analysis involved testing for differences in mean scores across the silent and vocal groups and determining correlation between responses

and groups. In order to evaluate whether silent and vocal students would respond differently to the course, individual question scores were grouped according to the definitions of silent or vocal as previously discussed, and a sample mean score was computed for each group. Two sample t-tests were run on the selected questions shown in Table 1 to determine if the mean scores across the groups differed.

Table 3.1 - Selected Likert-scale survey questions

Construct	Question
A Engagement	The Socratic questions in lecture keep me engaged.
B Engagement	The discussion questions (with colored cards) in lecture keep me engaged.
C Engagement	Even when I don't raise my hand, I try to think of the answer to the question.
D Understanding	Being asked questions in class helps me understand the concepts.
E Understanding	Discussion questions (with colored cards) help me understand the concepts we are covering in lecture.
F Perceptions	I do not understand chemistry.
G Perceptions	I worry about how I am perceived by my professor.
H Perceptions	I worry about how I am perceived by my classmates.
I Perceptions	I prefer to be silent in class.

Selected questions were examined in order to determine if responses were correlated with the designation of silent versus vocal. For each survey question, responses were coded according to the previously defined Likert-scale, and a Spearman's rho correlation coefficient was computed, providing an analysis of whether silent and vocal students respond differently to a given question. A high Spearman's rho indicates that the silent versus vocal designation strongly correlates

with student response to a question. Meanwhile, a low rho suggests student responses are not related to their silent versus vocal status. This type of analysis is appropriate when working with categorical data such as this (Glass and Hopkins, 1984).

The data from the Fall 2010 was analyzed to include every student who responded to both an online survey and the pre and post administrations of the CCRT. This allowed for pairing of the individual student responses to these three instruments. The survey responses were used to categorize students according to their level of participation. The survey question "How often do you attempt to participate by raising your hand in lecture?" had six possible responses, and scores on the CCRT were compared across these six groups via an Analysis of Variance (ANOVA). Two ANOVA's were completed. The first compared the pre-test scores only across participation levels, to confirm that participation was not motivated by prior knowledge. A second ANOVA was then completed to determine if the different categories of participation displayed any significant differences with respect to the increase in knowledge from pre to post.

Also of interest was whether student perceptions towards the Socratic and discussion questions used in the classroom were correlated to post-test performance on the CCRT. The Spearman's rho correlation coefficient was computed for responses to selected survey questions against post-test scores.

Student grades were also available for given questions on the mid-term and final exams. For students categorized between silent and vocal, a two-sample t-test was performed to detect if vocal students displayed a significantly higher score than silent students on relevant questions.

Interviews were conducted with a total of 42 students all done by the author to allow for uniformity. As the interviewer, I took notes about the prepared semi-structured protocol and also made audio recording when approved by the interviewee. The notes were coded for emergent themes and guided survey data analysis.

3.4. Results and Discussion

As previously mentioned, this study had multiple phases and two data collections, one from Fall 2010 students and another from Fall 2011 students. Both were first semester courses in General Chemistry. The data from the 2010 students was used as the first phase to understand differences in engagement, learning and perception between silent and vocal students via self-reporting. Then assessment instruments were used in the second phase to establish any differences in performance between silent and vocal students. Finally, the modified survey used in the 2011 data collection was intended to provide insight into the motivational factors that encourage vocal students in the active classroom. The methods used and motivation for these analyses were detailed in the previous section. The results and

discussion are divided between the 2010 survey data, the 2010 performance data and the 2011 motivation data.

3.4.1. Analysis of Survey Data from 2010

One might expect students who do not attempt to answer questions to be non-participatory. However, it was the working hypothesis of this study that both vocal and silent students participated in the active learning environment of a large chemistry classroom. The terms "vocal" and "silent" were precisely chosen for the two groups of students under comparison as they reflect this main hypothesis. These categorizations also reflect the literal meaning of the question, "How often do you attempt to participate by raising your hand in lecture?", without presuming an implication of participation or non-participation.

Coding of Fall 2010 interview data revealed themes including student engagement, understanding, and perceptions. Survey questions common to these themes were grouped and analyzed in conjunction with qualitative data. Interview data is specifically included to motivate the discussion of quantitative results.

Questions that showed a statistically significant difference in responses between vocal and silent students are noted in Figures 3.2 and 3.3. These figures show the averaged responses, which are a numerical mean value plotted according to Likert-scale responses. Figure 3.4 provides the survey data as histograms.

Figure 3.2 - Averaged responses to Questions A, B, C, D, and E, * indicates t-test significance at level $\alpha = 0.05$

Figure 3.3 - Averaged responses to Questions F, G, H, and I, * indicates t-test significance at level $\alpha = 0.05$

Figure 3.4 - Histograms of student responses to Questions A, B, C, D, E, and I

Spearman's rho correlation coefficients, as appear in Table 3.2, added to the interpretation of the survey data. The Spearman's rho coefficient is a unitless number between -1 and 1 that describes the correlation between silent and vocal

responses. A rho close to 0 indicates a weak association between groups and responses. Since the working hypothesis was that both vocal and silent students were benefitting from the active learning approaches, it was anticipated that the correlations should be low. As the results indicated, this was generally true, with the exception of Question I, which was expected to have a high correlation, since silent students would likely report a preference towards silence in the class.

Table 3.2. Spearman's rho correlation coefficients by question

Question	A	B	C	D	E	F	G	H	I
Spearman's rho	0.264	0.139	0.124	0.263	0.030	0.231	0.053	0.073	0.550

3.4.1.1. Engagement

Responses to Questions A, B and C reflected students' engagement in the active learning classroom. The averaged responses were positive, indicating that students were more likely to agree with these statements. Question C had the highest average for both vocal and silent students of all the questions shown in Table 1. There were statistically significant differences between the silent and vocal groups for these three questions. However, the responses to these questions were positive for both groups according to the Likert-scale. This statistically significant difference lacked practical significance, since the results did not indicate a meaningful distinction between the silent and vocal students. (Glass and Hopkins,

1984; Navidi, 2010). Thus, there was minimal distinction between silent and vocal students with respect to their level of engagement.

Quantitative and qualitative results suggested that vocal and silent students were engaged by the active learning classroom. One silent student stated, "I do like it because you are being constantly engaged: listen and process and understand. It does help you understand the concepts better." To see if this result was common to the broader population, responses to Question A in the survey were examined, as shown in Figures 3.1 and 3.3. Analysis indicated that the majority of students felt Socratic questions in lecture did keep them engaged. There was a greater percentage of silent students than vocal students that responded "Agree" to Question A, as indicated in the histogram. Reflecting on the averaged responses as shown in Figure 3.2, there was a positive response by both vocal and silent students to engagement via Socratic questions with a statistically significant difference between the groups. However, there was minimal distinction between the groups; and the correlation between groups was relatively low, indicating there was not strong preference to the Socratic questions between groups. Analysis of Question B was very similar, with 53% of both groups responding "Agree" regarding engagement in discussion questions. A statistically significant difference was again displayed between the responses of silent and vocal students, the histogram shows both groups responded positively, with minimal distinction. The instructors anecdotally reported that most students responded to the discussion questions, as well as talked with their peers during time for think-pair-share. However, in

interviews with self-identified silent students, not all students discussed the questions with their peers on a regular basis in class, yet most generally still provided a colored card response.

Question C offered clear insight into how students were engaged as they responded to questions in class. Overwhelmingly, both silent and vocal students responded that they do try to think of answers to questions posed in class. By formulating answers, students engaged with the content, their knowledge, and the class discussion. Again, a greater percentage of silent students responded “Agree” to Question C. There was a statistically significant difference in the responses of the two groups, yet Figure 3.2 and a low correlation coefficient as shown in Table 3.2 suggested a minimal distinction between silent and vocal students. One silent student commented, “I think about what I would answer if I don’t raise my hand. What would I say and then if I agree or [not].”

Therefore the data reveal that silent students were not passive. They were engaged by Socratic and discussion questions and attempted to think of answers to such questions. Silent students, while responding differently than vocal students to the survey questions, also indicated that they participated in the active classroom even though they were not verbally responding in class.

3.4.1.2. Understanding

Responses to Questions D and E showed that students valued Socratic questions and discussion questions as aids in understanding. A statistically

significant difference was found between silent and vocal student responses to Question D regarding Socratic questions aiding understanding. The averaged responses for both groups were positive indicating that both groups of students were more likely to agree with these statements.

Similar to the questions on student engagement, the quantitative and qualitative data were analyzed to determine how silent and vocal students felt the active learning techniques furthered their understanding of the course content. One silent student captured how active learning methods help by saying, "It's like there's a wider variety of ways to learn. First, you hear the teacher talking, and then you hear the students' thoughts, and then you discuss with students." Vocal and silent students' responses to Questions D and E indicated that both Socratic questions and discussion questions aided in understanding, as shown in Figures 3.2 and 3.4. When interpreting student responses to Question D regarding Socratic questions aiding understanding, a statistically significant difference was found between silent and vocal students. However, the averaged responses for both groups were positive indicating that Socratic questions did indeed have a generally helpful impact on student understanding, although that benefit may be greater for vocal students. This finding was corroborated by a relatively low correlation between group responses, as shown in Table 3.2. One silent student commented, "It's really nice to be able to hear how other people reach the conclusions and helps to be able to think for yourself in class." When interpreting students' responses regarding discussion questions furthering understanding in Question E, no statistically significant

difference was displayed and the correlation between the groups' responses was extremely low. The averaged responses were both quite positive; thus, whether students chose to be silent or vocal, they felt their understanding of the content was improved by discussion questions.

It appeared that silent students used the opportunities provided in the active learning classroom to enhance their understanding of the material. However, they generally did so without talking in front of class or always taking the opportunities to talk with peers in class.

3.4.1.3. Perceptions

In an attempt to understand why students are silent in a large active classroom, some questions were included to probe student perceptions of the content and environment. Questions F, G, and H reflected students' perceptions of themselves in the active learning classroom. Question F was a blunt statement regarding the student's perception of their understanding of chemistry and showed a statistically significant difference in responses from silent and vocal students. However, no statistical differences were found in student responses to Questions G or H. Question I indicated the expected result that silent students preferred to be silent significantly more often than vocal students.

Question F, as shown in Figure 3.3, revealed that there was a difference between vocal and silent students' confidence in their chemistry content knowledge. Those who felt they understood chemistry might have been more willing to provide

verbal responses. Lack of understanding of the content of a course might have inhibited oral answering of questions, so this result was not surprising. However, there was a relatively low correlation, indicating that lack of understanding was not likely a strong motivation behind remaining silent. There was no statistical significant difference in the responses of silent and vocal students to Questions G or H. These questions focused on whether students had worries about how they were perceived by their peers and instructors. Whether or not a student chose to be vocal did not hinge upon their thoughts on how others saw them. This was again displayed in the extremely low correlations between the groups' responses to these questions, as seen in Table 3.2.

Responses to Question I displayed the expected pattern that silent students preferred to be silent significantly more often than vocal students (Figures 3.3, 3.4, and Table 3.2). While this result was not surprising, student interviews added more insight. One silent student noted, "I'm not that big of a question and answer person in class. I prefer to listen to others. It helps me understand better." Other silent students also referenced individual preference or learning style. One student specifically said, "For me, the way I learn, I have to look at it longer. I'm not very articulate with my answers, so I don't like raising my hand." Silent students may have chosen not to raise their hands in response to Socratic questions due to learning style preferences or confidence with the content rather than due to worry about how they were perceived by their classmates or professors.

The results showed that student perceptions' of the active learning classroom were generally positive. Neither vocal nor silent students were intimidated by the classroom discussion format. Interviews suggested that the learning style preference of silent students might have be a significant motivation for abstaining from answering questions. However, students' confidence in their own understanding of the content may also have influenced their decision to remain silent.

3.4.2. Analysis of Performance Data from 2010

3.4.2.1. Pre and Post CCRT Results

In order to determine whether those students categorized as vocal and those students categorized as silent started with different levels of prior knowledge, a two-sample t-test was run on the pre-test scores, 23 CCRT questions associated with the content in the first semester of General Chemistry. These results are given in Table 3.3.

Table 3.3 - Two-sample t-test of CCRT pre-test for vocal and silent students

	Post Minus Pre Test Score	St. Deviation	p-value
Vocal	8.21	2.82	0.220
Silent	7.74	2.85	

There was no significant difference between the starting levels of these two groups. Given that there were six possible categories of participation from which students could select on the survey question used to define vocal or silent, the analysis was extended to include an ANOVA. The ANOVA tested whether students categorized by the six different participation levels began with different levels of prior knowledge. Across the six categories of participation, there was no significant difference in prior knowledge, with a p-value of 0.324. Since the ANOVA verified that none of six categories displayed performance differences, the remainder of the analyses divided the students into only the two categories of vocal and silent.

These two tests established that the silent and vocal participants began the Chemistry course with the same level of knowledge. This result was of primary importance to the study, as it confirms that those students who answer questions in class are not necessarily those students who start the course with the strongest Chemistry background.

I then sought to determine if the level of participation had an impact on how much learning occurred over the course of a semester. The difference in the score distributions between vocal and silent students is shown in Figure 3.5, representing the post-test scores on the CCRT. The vocal students had a slightly higher peak of scores at the median with a larger shoulder towards higher scores. The silent student score distribution, however, was more slanted towards lower performance. This was analyzed statistically via a two-sample t-test of the paired improvement

over the semester, which was calculated by post-pre points on the CCRT. The results are shown in Table 3.4.

Figure 3.5. Fall 2010 post-test CCRT score distribution

Table 3.4 - Two-sample t-test of CCRT post-pre points for vocal and silent students

	Mean Pre Test Score	St. Deviation	p-value
Vocal	6.80	3.49	0.005*
Silent	5.51	3.10	

There was a significant difference between the silent and vocal student performance improvement. The previous phase of the study indicated that both silent and vocal students perceived a benefit to the active classroom and were participating in the active classroom, albeit in different ways. The results from the pre and post-test demonstrated that there was a comparative advantage in learning for those students who were willing to be vocal versus those that were silent in the active classroom. Vocal students outperformed silent students on a test of conceptual understanding in chemistry, on average and statistically significantly with the same baseline average for both of the groups.

3.4.2.2. Exam Results

The analysis also included results for “assess the accuracy” exam questions, as defined previously, that were written with the intent of testing students’ ability to reason and explain. The analysis of these questions determined if students who were vocal had an increased score and thus an increased ability to reason scientifically on these questions over silent students. These questions were worth a total of 70 points across three midterm exams, and a two-sample t-test was run on the mean scores for silent and vocal students, as shown in Table 3.5.

There was a significant difference between the silent and vocal groups, although the differential of points was not large. This comparison of performance on another means of assessment reinforced that vocal students had an increased performance improvement of learning over silent students.

Table 3.5 - Comparison of scores on “assess the accuracy” exam questions

	N	Mean Points	St. Deviation	p-value
Vocal	241	53.11	9.32	0.000*
Silent	115	48.13	9.10	

3.4.2.3. Survey and CCRT Correlations

Finally, the study used the 2010 data to compare performances against perceptions of the active classroom from the survey data. The active classroom mainly used Socratic questions to engage students. Results have established that vocal students seemed to have an advantage over those students who are silent. I also sought to determine if the post-test scores on the CCRT had a relationship with the perception of usefulness for Socratic questions used in class. For two questions regarding the perceived impact of Socratic questions, a Spearman’s rho was calculated for survey response versus possible points scored on the post-test CCRT. Correlations are given in Table 3.6.

Table 3.6 - Spearman’s rho correlations for post-test CCRT scores and survey responses

Question	Spearman’s rho
A: The Socratic questions in lecture keep me engaged.	0.131
D: Being asked Socratic questions in class helps me better understand the concepts.	0.238

These values indicated that a weak correlation existed between perceived usefulness of Socratic questions and a high post-test CCRT score. Thus, students with a high score on the CCRT were somewhat more likely to perceive the Socratic questions to be useful to the learning process, yet not substantially more likely. The weak relationship between a high level of learning and response to the Socratic method indicated that the active learning methods were valuable to both silent and vocal students, as well as both high achieving and low achieving students, according to the CCRT.

3.4.3. Analysis of Motivation Data from 2011

The previous analyses have established that a learning benefit exists for those students who choose to be vocal during class. The data used in all previous tests came from the Fall 2010 collection. This leads naturally to the question of why vocal students are vocal. Thus, the next step for the study was to analyze the motivations for students to be vocal. To this end, additional survey questions were incorporated into the Fall 2011 survey in order to better understand the behavior of vocal and silent students. This required a comparison between the 2010 and 2011 groups. A chi-squared test for homogeneity was performed to demonstrate that the percentage of silent and vocal students were similar across the two years, as shown in Table 3.7. There was no evidence to suggest that the two cohorts differ in the sets of students who report themselves to be vocal or silent in the classroom. Thus, we continued the analysis by using comparisons across the 2010 and 2011 students.

Table 3.7 - Comparison of vocal and silent groups across 2010 and 2011

	Vocal	Silent	p-value
2010	245	121	0.949
2011	223	109	

A survey question was created for students to indicate how they responded to Socratic questions. The most selected responses were divided to compare how either silent or vocal students responded, as shown in Table 3.8. Students were asked to select a description that matched their participation over the course of the semester from the following options: increased, decreased, stayed the same, or did not participate. For those students who either increased or decreased their participation over the course of the semester, data is included in Table 3.8 regarding the percentiles of those populations identifying with statements about Socratic questions. Interview data has been tied to the survey data to understand student survey responses and to understand why vocal students were vocal in class. Discussion of the survey data has been interwoven with findings from the interviews in the following sections on the impact of think-pair-share, extra credit, learning from questions, preparation for class, and studying in groups.

3.4.3.1. Learning via Socratic questions

Survey and interview results indicated the educational value of answering Socratic questions. Almost half of vocal students, 46%, saw how answering Socratic

Table 3.8. Percentage of vocal/silent and increased/decreased participation students who identified with statements regarding Socratic questions

<i>Please check all of the statements that you identify with about the Socratic questions in class.</i>	Vocal N=223	Silent N=109	Increased Participation N=101	Decreased Participation N=48
1. I feel as though, once I started answering questions, my understanding of the material increased.	46%	8%	48%	29%
2. My primary motivation for answering questions was always so that I could get extra credit points.	62%	33%	70%	52%
3. Once I correctly answered a question in class, I was motivated to try to participate more often.	68%	17%	74%	46%
4. My ability to participate was affected by how much time I had to prepare for class due to other demands on my time.	75%	63%	79%	81%
5. As I began to understand the material, I was more able to answer questions.	83%	34%	88%	52%

questions helped them understand the material better according to responses to statement 1. This view was also held by about half, 48%, of those students who increased their participation over the semester.

Interview responses were generally positive towards Socratic questioning, with many students realizing the questions were aimed at helping them truly understand the material. One student said of an instructor, “I think he wanted us to figure it out rather than him just tell us.” Many students stated that Socratic questions helped them stay engaged in class and keep up with the ideas being discussed. One student said, “[Class] is not just a lecture...I’m being forced to think of the answers each time that the question is asked versus just listening to lecture. I

think that's very helpful in staying tuned in." Whereas another student expressed the same idea saying she liked Socratic questioning because of, "Always being involved in lecture, always being part of it and feeling like you're following along as it goes, and the questions are kind of like checkpoints." A few students responded regarding the helpfulness of listening to other students answer questions. One student said, "It helps to hear it explained from a student. Different wording of the same idea that is clearer."

A high percentage of the vocal students, 68%, responded to statement 3 that answering a question correctly motivated further participation. Most of those who increased their participation, 74%, also identified with the statement regarding motivation from answering correctly in class. The majority percentages demonstrated that getting positive feedback encouraged more participation from the vocal students.

Few students really verbally expressed that answering questions correctly was the main motivator to continue participating, as indicated by the survey responses. However, students did see the value in participating as by answering questions they got feedback on their understanding and were challenged to actually put their understanding into words. A student shared this comment, "Sometimes I feel like I know the material, but I don't necessarily know how to phrase it. So I think answering questions definitely helps with...how to put concepts into words." And another said, "Even though I knew the answer, I probably wouldn't be able to explain it how I wanted coherently." Thus, once students did start to answer

questions, the feedback they received was helpful to them, as well as the challenge of putting their thoughts into words. Due to the open-ended nature of the graded assessments in this course, the benefit of practicing explaining concepts out loud was obvious to students.

Vocal students were motivated to answer Socratic questions because the inquiries kept them engaged, let them hear other students' explanations, provided an outlet for feedback, and forced them to put the concepts into their own words.

3.4.3.2. Extra Credit for Participation

Many students needed external motivation to participate by being vocal in class, such as the extra credit gained via participation points. There were 62% of vocal students and 33% of silent students who identified with the statement 2 regarding extra credit being a main motivator. Percentiles were high for this statement for both those who increased their participation, 70%, and those who decreased their participation, 52%. This indicated that the minimal grade incentive provided by participation points was enough to motivate most students to answer questions.

In interviews, numerous students gave a similar response regarding why they participate, "Definitely the extra credit points. But also just participating helps me understand it. Because if I answer or intend to answer, I have to think about what I would say and understand it." One student even went as far to state, "In the beginning I was like, oh yeah, we get points... But then actually most of the time I

raise my hand and answer questions, now I don't actually go up and get points after class." This student obviously started out by answering questions for the grade incentive but then realized the value added from participating was worthwhile without even claiming the extra credit.

Most of the vocal students interviewed saw the educational value in answering questions, yet they most often stated it was the participation points that encouraged them to start trying to answer. This interview data corresponded with the survey data, which indicated extra credit was a major initial motivator for students to become vocal in class.

3.4.3.3. Preparation for Class

Most of the students, 75% of vocal and 63% of silent, felt their ability to participate was impacted by the time they had to prepare for class by identifying with statement 4. Most of the students who increased participation, 79%, and decreased participation, 81%, also felt participation was affected by time to prepare. When students had time to prepare for class, their ability to participate improved. The converse must then have also been true; when students were overwhelmed by other classes or activities, they did not have time to prepare for chemistry class and were unable to participate.

In interviews, some students felt that they could still participate without having read the assignments before class, but most did not. One student stated, "Without reading, I won't answer; but because others answer, I still understand." A

number of students expressed that as their semester got busier, their time to spend reading for class diminished, with their participation following. One student said, "At the beginning, I was more likely to have done the reading, so I participated more at the beginning. Then it varied if I'd done the reading." Thus, the Socratic method did provide motivation for students to read the material before class. One student said, "Asking the questions challenged the students to go back and read and to understand. And definitely with the way you get extra points if you answer questions, I think that really encouraged people to go more in depth in their reading." Making time to read and prepare prior to class did impact participation levels and, most probably, also performance.

A very high percentage, 83%, of the vocal students, but only 34% of the silent students, identified with statement 5 indicating that they felt that as they understood chemistry better, they were better able to answer questions. Survey data also showed that 88% of students who reported that their participation increased over the course of the semester also identified with the statement E. Thus, understanding of the material was definitely a motivational factor for answering questions.

The way most students who were interviewed said they were able to understand the material was by reading and studying. One student said she always read before class because if you did not, "Then you can't get the participation extra credit. So, it was kind of a motivation to read before class, but then it also made a lot more sense if you read before class." Multiple students expressed that their

participation depended upon the amount of time they had to prepare for class by reading, as also seen from the survey data. This also adds some explanation to the vocal students' greater learning gains, as students were vocal if they were keeping up with the course and making sure they understood the content.

Students did see preparation for class as valuable and, for most, essential to being able to be vocal in class. And those students who did participate recognized the impact of preparing and participating on their learning by being engaged and getting feedback on top of staying current with their studies.

3.4.3.4. Studying in Groups

One hypothesis tested was whether students who studied and talked together about chemistry in groups outside of class had a higher degree of participation in class. As shown in Table 3.9, the amount that students said they studied with others was relatively consistent between vocal and silent students. Thus, there was no correlation between talking about chemical concepts with other students outside of class and talking about them in front of the class.

Table 3.9. Vocal and silent students divided by how often they study chemistry in groups

Frequency of Group Study	At least once a week	Occasionally	Only before exams	Never
<i>Vocal</i>	40%	32%	17%	10%
<i>Silent</i>	41%	24%	24%	11%

3.1. Conclusions

The primary conclusion of the first phase of this study was that students who chose to remain silent in this active learning classroom did, in general, participate in the active learning environment despite their silence. The data revealed that both silent and vocal students engaged in this active classroom and thereby increased their understanding of the content. While the self-reporting of students indicated that the vocal students may have benefited more than the silent students from this active learning environment, both groups indicated that Socratic questions and discussion questions were valuable. Even though not all students chose to be vocal due to learning styles or other preferences, generally all students were motivated to participate by engaging with the content and striving to understand. One silent student summed up this large active learning classroom with: "By seeing other people participate, [it] makes me want to do the same. [This] way of teaching is really, really amazing... and makes it very simple to understand."

The second phase of the study incorporated assessments to extend the understanding of the impact of active learning on vocal and silent students. The behavioral dimension of actually participating in class, or even just attempting to participate by raising a hand, did differentiate students by level of learning performance. The CCRT post-test and assess the accuracy exam questions showed vocal students to perform at a higher level than silent students on measures of chemistry knowledge. Because both silent and vocal students started out the semester at the same measured conceptual understanding in chemistry, the

differences at the end of the semester must have been due to differences that had impact over that semester.

Interviews and survey data together also indicated that students were more likely to be vocal in class when they had time to prepare for class and read the assigned material. Students have a great deal of schoolwork and other activities throughout the semester, and time management is one of the great life skills acquired in college. Students were very honest that having time to prepare for class directly impacted whether or not they could participate. Preparing for class would of course impact understanding the material as it was presented in class. It follows that those students who regularly prepared for class often participated and were classified as vocal. Thus, prepared and vocal students benefited both from preparing for class and the engagement and feedback of being vocal, making the greater learning gains of vocal students an obvious consequence of everything involved in being vocal.

This suggests a model for why vocal students outperformed silent students. Because they were more likely to prepare for class, vocal students were more likely to participate. By participating, they understood the material more deeply. Having once participated successfully, they were more likely to want to do so again. As such, they were more likely to prepare for class. Thus, vocal students were better prepared because they participated, and they participated because they were better prepared. How then does a student begin this cycle?

Extrinsic motivation was provided for participation in the form of minimal extra credit. Despite the minimal impact on the course grade, the participation points made a major impact on students' motivation to be vocal. Both survey and interviews showed that participation points encouraged students to attempt to answer questions in class. The motivation was not great enough to overcome inhibitions for some students, but it did get the majority of the class raising their hands.

As discussed earlier, once students answered questions they did see educational value of answering Socratic questions aloud. Students also realized the necessity for preparing for class by reading in advance, as without preparation they had limited opportunities to participate. Students learned from the challenge of putting chemical concepts into words, appreciated the feedback from the instructor, and used the drive to answer questions as a way to keep them on top of completing their reading assignments before class. Thus, vocal students who were initially motivated by extra points seemed to then transition to being motivated by the educational benefits of participation and preparing for participation. Extra credit for participation started off a "virtuous cycle" for students who started to participate in the active learning environment by being vocal, enjoyed the engagement, benefited from feedback, and were motivated to continue to prepare for class so that they could continue to gain all the benefits of being vocal.

Participation points encouraged students to start being vocal, and the immediate feedback and extra motivation to stay on top of the material kept

students answering questions. One student stated that, "Questions are like stepping stones to a whole answer." And I feel the "stepping stones" completed the beneficial active learning experience for students who started with an extrinsic motivation of points and continued with the intrinsic motivation of increased understanding. Thus, future courses should be designed with not only active learning experiences available to students, but obvious motivation to get as many students as possible to participate actively.

General Chemistry Laboratories

This chapter details a longitudinal study in the General Chemistry Laboratories at Rice University. As students enter the field of science at the beginning of their collegiate careers, many participate in General Chemistry Laboratories as their first lab experience. The laboratory should be a place of hands-on data collection and physical manipulation in order to further understanding in chemistry. This study focuses on phases of changes implemented in an effort to improve the quality of educational experience provided by the General Chemistry Laboratories.

4.1. Literature Review

Teaching laboratories first developed in the early 1800s out of a need to train apprentice chemists in composition analysis (Elliott et al., 2008). By the late 19th

century, American universities and high schools had incorporated laboratories as required elements of chemistry instruction but had moved from an apprenticeship experience to the more traditional expository laboratory still used by many today (Elliott et al., 2008). The goals and purposes of those early laboratories diverged as the field of chemistry grew (Lagowski, 1989). Schlesinger (1935) outlined what he believed to be the goals of laboratory instruction:

1. To illustrate and clarify principles discussed in the classroom, by providing actual contact with materials.
2. To give the student a feeling of the reality of science by an encounter with phenomena which otherwise might be to him no more than words.
3. To make the facts of science easy enough to learn and impressive enough to remember.
4. To give the student some insight into basic scientific laboratory methods, to let him use his hands, and to train him in their use.

While Schlesinger gave suggestions and called for successful achievement of these goals, in recent history these goals have not been internalized as the motivation and priority for undergraduate teaching laboratories. The necessity and value of laboratories as part of chemistry education have been taken for granted, and a review of the objectives put forth for laboratory courses leads to the conclusion that laboratories do not generally achieve their purposes (Reid and Shah, 2007). Because of this lack of evidence that laboratories aid in understanding

chemistry and the expense of time and money necessary to administer laboratory courses, some academic scientists have explicitly argued that chemistry laboratory courses should be removed from undergraduate curriculums completely (Hawkes, 2004).

In an effort to show that laboratories can be effective, there has also been much discussion about the utility of the different formats that laboratory courses could assume. A “taxonomy of laboratory instruction styles” was put forth which includes describing the outcome, approach, and procedure in order to determine whether a laboratory is considered expository (traditional), inquiry, discovery, or problem-based (Domin, 1999). In a survey representative of the institutions with American Chemical Society accredited chemistry programs, 91% responded that laboratory guides often or almost always provided step-by-step directions indicating a traditional laboratory format, and only 8% self-reported using inquiry laboratories (Abraham et al., 1997).

Research on the methods for effective chemistry laboratories research has continued in many directions. One such route has been to understand students’ attitudes, beliefs, and perceptions about chemistry and their learning in order to better understand how different teaching practices impact learning (Bauer, 2008; Grove and Bretz, 2007; Russell and Weaver, 2008). The underlying assumption is that if students perceive chemistry as positive and expect certain aspects of how they can come to understand and internalize knowledge in chemistry, they will be better able to learn chemistry. Students’ expectations of how they will learn

chemistry vary significantly from what instructors perceive as students' expectations, and this gap increases through the first two undergraduate general chemistry courses (Grove and Bretz, 2007).

4.2. Research Questions

The goal of this study was to develop a novel and effective General Chemistry Laboratory curriculum via an active research process of assessing student expectations, perceptions, and experiences as changes were implemented. To achieve this goal, the following questions were addressed.

1. What do students expect to learn in General Chemistry Laboratory?
2. How can student expectations be modified to meet the expectations of the instructor?
3. How can the laboratory be structured so that students effectively construct knowledge of chemistry through laboratory experiences?

4.3. Setting

The population for this study was the General Chemistry students concurrently enrolled in the two-semester class and laboratory at Rice University. Each year, about 350 to 400 students were enrolled during the fall semester and approximately 300 students in the spring. About 90% of the students in General Chemistry were freshman. The lecture portion of the course consisted of three 50-

minute classes per week taught by instructors other than the lab instructor. Students attended laboratory sessions once a week in sections of less than 50, led by the laboratory instructor and assisted by teaching assistants. The fall semester lab was CHEM 123, and the spring semester lab was CHEM 124. The study began in Fall 2009 and was continued for three years through Spring 2012.

4.4. Methods

4.4.1. Survey Instruments

Surveys were administered via OwlSpace, Rice University's online course management system. Students accessed the surveys online during specified windows of time and completed the questions confidentially. Surveys were voluntary with minimal extra credit awarded for participation. The extra credit was equal to the amount students could receive for participating in lecture. Surveys were available during the first one or two weeks of the fall semester, last week of the fall semester, and last week of the spring semester from Fall 2009 through Spring 2012, with the exception of the first week of classes in Fall 2011. A total of eight sets of survey data were collected, as shown in Table 4.1, with survey response rates of greater than 80% for each administration. Survey instruments were approved by the Rice University IRB.

The main portion of the survey included 25 Likert-scale questions from CHEMX, a validated instrument used to assess cognitive expectations in learning

Table 4.1 - Participation in surveys and interviews/focus groups in General Chemistry (GC) from Fall 2009 through Spring 2012

	Surveys	Interviews and Focus Groups
Fall 09 PreGC1	339	19
Fall 09 PostGC1	331	15
Spring 10 PostGC2	265	15
Fall 10 PreGC1	357	24
Fall 10 PostGC1	330	15
Spring 11 Post GC2	262	15
Fall 11 PostGC1	286	20
Spring 12 PostGC2	264	13

chemistry (Grove and Bretz, 2007). The questions were taken from five of the seven categories used in the original 47-question instrument. Eight of the selected questions were regarding the laboratory, five from the concepts category, and four each about effort, outcome and visualization, as listed in Table 4.2. The statements that made up the questions were worded either positively or negatively, with the favorable responses determined by the expectations of chemistry faculty (Grove and Bretz, 2007). These questions were selected to probe what the students believed regarding different facets of chemistry courses, including course goals, requirements, expectations, and learning objectives. This set of questions was used at each administration of a survey, and other sets of questions were added depending on the phase of the study.

Table 4.2 - Survey questions by category listed with number and orientation

Laboratory		
1	-	I can do well in the chemistry laboratory (C grade or better) without understanding the chemical principles behind the labs.
6	-	It really doesn't matter how hard I work in the laboratory; the most important thing is to get the right answer.
7	+	It is important that I learn proper laboratory techniques in this course.
11	-	I really don't expect to understand how laboratory instruments work – they are just tools that help me complete the lab.
16	-	It is important that I finish a lab as quickly as possible – I'll figure out what the data mean later.
19	+	When doing lab calculations, I attempt to work through them myself before looking for help from the lab manual or instructor.
22	-	When I do an experiment in the laboratory, it is not important that I understand what is happening. I should just follow the directions carefully.
24	-	I don't expect to use what I learn during one lab experiment in another experiment.
Concepts		
2	-	Problem solving in chemistry means matching problems with facts or equations and then substituting values to get a number.
14	-	The most crucial thing in solving a chemistry problem is finding the right equation to use.
17	+	When I solve most exam or homework problems, I explicitly think about the concepts that underlie the problem.
18	-	Understanding chemistry means being able to recall something you've read or been shown.
21	+	To be able to use an equation in a problem (particularly in a problem I haven't seen before), I need to know more than what each term in the equation represents.
Effort		
4	+	I read the text in detail and work through many of the examples given there.
10	+	After I numerically solve a chemistry problem, I check my answer to see if the answer makes sense.
15	-	Chemical demonstrations do not provide me with useful information although they can be fun and exciting.
20	+	I use the mistakes I make on homework and on exam problems as clues to what I need to do to understand the material better.
Outcome		
3	+	Learning chemistry made me change some of my ideas about how the physical world works.
8	-	Knowledge in chemistry consists of many pieces of information, each of which applies primarily to a specific situation.
23	-	It is possible to pass this course (get a "C" or better) without understanding chemistry very well.
25	+	Learning chemistry requires that I substantially rethink, restructure, and reorganize the information that I am given in class and/or read in the text.
Visualization		
5	+	When I see a chemical formula, I try to picture its structure.
9	+	When I do an experiment in the laboratory, I try to picture the chemistry that is happening.
12	+	Solving a chemistry problem may require me to be able to draw molecules in more than one way.
13	+	After I have watched a chemistry demonstration, I should be able to explain what I saw in terms of the reactions of atoms and molecules.

4.4.2. Interviews and Focus Groups

Interviews and focus groups were performed with approximately 5% of the class population throughout the study, as shown in Table 4.1. Interview participants were selected from those who responded as willing to be interviewed as part of the first survey each fall. These students were grouped according to the amount of time they reported spent doing laboratories in high school. From each group, a random number generator was used to select which students to contact via email for participation. The number of students contacted from each group was proportional to the percentage of the group from the population surveyed. For Fall 2011 when the initial survey was not administered, the students who were asked for an interview were selected at random from all those who had agreed to participate. The students' interviewed were assumed to be representative of the class as a whole.

I performed all interviews and focus groups following an open-ended interview guide approved by the IRB. Questions probed students' previous experiences in chemistry and laboratories, as well as their current academic experiences at Rice University. Students were asked about how they approached the General Chemistry Laboratories, as well as how they thought about chemistry, visualization of chemistry, and how their learning was impacted by lab experiences. Specific questions relating to the phase of the study were added as appropriate. Interviews were recorded when approved by the students, and notes were taken to document responses for each interview. Interviews were conducted with most

students. However, some focus groups were formed, as allowed by students' scheduled, in order to create a more discussion-based atmosphere and elicit student-to-student dialogue in responses.

The first set of interviews was performed within the first month of the semester for Fall 2009 and Fall 2010. Follow-up interviews with the same students were done at the end of the fall and spring semesters of each of those academic years. In Fall 2011, the initial interviews were done at the end of the semester, and second interviews with the same students occurred at the end of Spring 2012.

Interviews were also completed with the lab instructor and teaching assistants for the discussion sessions in CHEM 124 for Spring 2012.

4.4.3. Phase 1: Assess

The first phase of the three-year longitudinal study included an initial assessment of the General Chemistry Laboratories in Fall 2009 with minor changes in Spring 2010 and Fall 2010. The schedule of weekly labs meeting for two and one half hours was in place for each of these semesters. Initial organizational adjustments were implemented at the start of Fall 2009 as compared to the standard way of teaching CHEM 123 and 124 at Rice University. Namely, the laboratory instructor was present in at least one section of the lecture course for the majority of instruction time. Labs were also planned ahead of time in order to correspond with the lecture material. The lab instructor incorporated student interaction in the pre-lab lectures through awarding participation points modeled

after the convention used in lecture. Pre-lab quizzes were assigned, performed and graded through an online course management system.

In Spring 2010, minor changes were made to the format of the laboratories. Pre-lab lectures were moved to class lecture time on Fridays so that more of the two and one half hour laboratory time was available for students to discuss and fully understand their lab experiences. Students were asked to finish their experimentation and data collection so that at least 15 minutes of class time remained. The students then gathered in a classroom for an interactive discussion of the present laboratory exercise facilitated by the professor. Motivation to receive participation credit was again used to encourage student dialogue. However, this practice of post-lab discussion was discontinued after only one or two attempts at implementation without notification by the lab instructor to the researchers. Further changes to promote student learning involved the inclusion of an open-ended laboratory where students designed their own procedure and use it to determine the identity of unknown gases and the addition of an exercise with Legos to demonstrate equilibrium (Cloonan et al., 2011). Changes to the laboratory format were minimal. Besides the movement of pre-lab lectures, the students were not expected to notice changes in the lab format, except the one or two times the post-lab discussions were actually implemented.

In Fall 2010, I was a participant observer serving in the role of teaching assistant for CHEM 123. I performed all the duties of a teaching assistant while also making observations of students during lab, student work as evidenced by their lab

reports and student interactions during lab help sessions. No interviews were performed with students in my particular lab section to reduce any anxiety of impact of the study on student grades.

Changes in the CHEM 123 curriculum during Fall 2010 were minor, with no changes to the standard schedule of labs. The lab professor introduced the course with the specific aims “think scientifically, think visually, and gain the tools necessary to join a research group.” Lab reports were slightly updated in an attempt to ask more probing questions related to understanding the chemical phenomena observed during the laboratories. However, no drastic changes were implemented in Fall 2010.

The initial surveys in Fall 2009 and Fall 2010 included questions about the chemistry experiences of students during high school, as well as 25 questions from CHEMX. Subsequent surveys included the portion of CHEMX as described previously.

4.4.4. Phase 2: Pilot Study

In Spring 2011, a pilot study was implemented in one of the eight sections of CHEM 124. I was the instructor of record for this class. The same laboratories were performed in all eight of the lab sections, but significant changes were implemented in my pilot section. Changes were reflected in the pre-lab, the lab procedures and reports, and lab management. The laboratories themselves were modified on the

basis of the lecture professor's input, yet were still standard labs. The schedule of weekly two and one half hour lab sessions was still in place for all sections.

In addition to the standard practice of requiring students to read the lab procedures before coming to lab, students were also required to make predictions before lab. A one to two page "Predictions" assignment was created for each lab. Questions in the assignment required students to describe the premise behind portions of the lab procedure, predict the outcome of the experiment often by drawing trends of expected results, or perform calculations necessary for the lab procedure. The "Predictions" were designed so that students found it necessary to read and understand the lab procedure in order to successfully complete the assignment. The "Predictions" assignment was due as students entered the lab.

The changes to the pre-lab lectures included a focus on defined learning objectives for each lab. Students clearly heard and saw the objectives for the lab before performing the experiments, and this reinforced the practice of making predictions. The instructions were focused on making observations and understanding and visualizing the chemistry at the particulate level. To facilitate this focus, pre-lab quizzes were given using electronic-response clickers. The clickers allowed for immediate feedback and class discussion regarding each of the five questions of each quiz. While the quiz was being administered and discussed, the teaching assistants graded the "Predictions" assignment and provided feedback to the students so that any misconceptions could be clarified before students started the lab procedures.

The lab procedures were clarified as much as possible so that students could focus more on making observations than understanding what procedures to perform. Any possible areas of confusion were discussed during the pre-lab lecture. A specific map of the location of all supplies and equipment needed in the lab was also presented to students during the pre-lab lecture time.

The lab reports completed by students during and after the actual lab procedure were also modified. A deliberate emphasis was placed on making observations and recording actual data during the lab time. Therefore, more space was provided for students to document observations during the lab. Lab report questions also required students to explain their observations using the chemical concepts discussed in class. One addition to the lab reports was that students were required draw a particulate representation of at least one portion of each lab. Students were encouraged to visualize the molecules and use symbolic representations in their drawings. Grading of the particulate diagrams was based on scientific accuracy rather than artistic ability.

The teaching assistants for the pilot lab section were guided in their interactions with students. They were asked to provide guiding questions to students to help them develop their understanding of the chemical concepts rather than directly answering questions. The teaching assistants were also directed to focus their grading on the completion of detailed observations and data collection during lab as well as coherent and valid demonstration of chemical understanding

shown on the particulate diagrams and lab report questions. Specific grading keys were provided to teaching assistants in order to achieve this focus.

Students were informed of all the modifications present in the pilot lab section during the first week of the course and given the option to switch to another section. There were 20 students were enrolled in the pilot lab section for the course of the semester. The lab instructor for the other seven sections of CHEM 124 was present for all the pilot section pre-lab lectures and laboratories. Lab trials with teaching assistants and both lab instructors were held simultaneously prior to each lab, as the actual experiments were consistent among all lab sections.

An additional survey was given to students in the pilot lab section that included open-ended questions regarding the pre-lab predictions, pre-lab quizzes, pre-lab lectures, particulate level diagrams, and general feedback. The CHEMX survey was made available to students in all sections of CHEM 124.

4.4.5. Phase 3: Full Implementation

In Fall 2011, a new laboratory professor taught CHEM 123. The new instructor modified any previously written laboratories, included different laboratories, and reduced lab sessions to 2-hour weekly meetings. She continued the practice of attending class lectures and coordinating lab material with lecture. However, as this was her first experience as an instructor, data collection was suspended for the beginning of the Fall 2011 semester. Standard lab procedures of online quizzes and traditional lab reports were continued in Fall 2011. Surveys and

interviews were performed at the end of Fall 2011 in order to be able to assess the changes for Spring 2012. The CHEMX survey was administered, and questions were added to address when students performed components of the lab such as reading the lab handouts, making predictions, reflecting on observations, visualizing at the molecular level, analyzing data, making interpretations of data, completing the lab report, and incorporating lab knowledge with class content.

For CHEM 124 in Spring 2012, changes were implemented in the General Chemistry Laboratories. The laboratory time was increased to 3.5-hour sessions meeting every other week with discussion sessions meeting for one hour on the weeks in between labs. Pre-lab quizzes were replaced by pre-lab assignments that required students to outline the data they needed to collect and the equipment they would need, perform any preliminary calculations, and create a workflow outlining the lab procedure. During the first week of each laboratory experience, students turned in the pre-lab assignment, performed the lab and collected the data to be recorded in a format of their own design. Short pre-lab lectures were still held prior to students performing the lab.

In the first week after performing the lab, students were required to complete pre-discussion exercises. These exercises included initial data analysis such as calculations or graphing, as well as some basic interpretation of results. The pre-discussion exercises were due at the beginning of the one-hour discussion session that met one week after the lab was performed. In the discussion sessions, a teaching assistant led students through a discussion of the concept demonstrated in

the lab, guided students in data interpretation, and gave students time to compare and discuss results. Students sat with their lab partners and other students in their lab section at circular tables designed for small group discussion. For some labs, class data was collected so that students could do further analysis. Attendance at discussion sessions was required, and students were assessed on their participation.

In the second week, students were required to further analyze the data and draw conclusions by completing post-discussion and post-lab questions. These questions focused on students' providing explanations and demonstrating understanding of the chemistry. Students were also asked to extend their knowledge to situations beyond what was experienced in the lab. Lab reports were then due two weeks after the completion of the lab and prior to the start of the next lab.

At the end of Spring 2012, the CHEMX survey, along with additional questions regarding when students completed components of the lab course were administered. Survey questions were also added to assess students' opinions of the discussion sessions and its impact on their understanding of content, connection of the lab and the class, use of time, perception of learning, and preferences. Students, the lab instructor, and the discussion session teaching assistants were interviewed and asked for their perceptions of discussion sessions.

4.5. Results

4.5.1. CHEMX Results

The CHEMX results for the entire study are presented separate from the rest of the data collection. The CHEMX portion of each survey was analyzed by determining the percentage of students responding as would be desirable according to previously surveyed chemistry faculty (Grove and Bretz, 2007). The favorable percentage indicates the students responding as would be expected by chemistry professors, no matter if the question statement is positively or negatively oriented, as indicated in Table 4.2. Likewise, the unfavorable response is the opposite response expected by instructors, and neutral is the selection of undecided on the Likert-scale. For each administration of the CHEMX survey, a data table as shown in Table 4.3 was created. Analysis of the administrations of the survey at the different time points each year showed that student responses varied slightly for some questions and constructs. No distinct trend was observed, as some questions had significantly different responses between semesters, while others did not.

The average results of the 25-question CHEMX survey from Fall 2009 to Spring 2012 were comparable with the full CHEMX results from General Chemistry students at a highly selective liberal arts college from the validation of the instrument (Grove and Bretz, 2007). Overall averages are listed for students at the beginning of the first semester of General Chemistry (Pre GC1), end of the first semester (Post GC1), and end of the second semester (Post GC2), as shown in Table

Table 4.3 - Representative CHEMX results, Fall 2009 pre-General Chemistry 1

		Favorable	Neutral	Unfavorable
Total Average		68%	16%	15%
Standard Deviation		21%	9%	14%
Question	Category	Favorable	Neutral	Unfavorable
1	Lab	51%	28%	21%
6	Lab	67%	21%	11%
7	Lab	98%	1%	1%
11	Lab	87%	8%	4%
16	Lab	83%	10%	7%
19	Lab	85%	9%	5%
22	Lab	86%	7%	6%
24	Lab	93%	5%	1%
Average		81%	11%	7%
Standard Deviation		15%	9%	6%
Question	Category	Favorable	Neutral	Unfavorable
2	Concepts	49%	28%	22%
14	Concepts	30%	26%	43%
17	Concepts	62%	24%	14%
18	Concepts	39%	20%	40%
21	Concepts	85%	10%	4%
Average		53%	22%	25%
Standard Deviation		21%	7%	17%
Question	Category	Favorable	Neutral	Unfavorable
4	Effort	63%	15%	21%
10	Effort	89%	6%	3%
15	Effort	69%	19%	12%
20	Effort	96%	2%	2%
Average		79%	11%	9%
Standard Deviation		16%	8%	9%
Question	Category	Favorable	Neutral	Unfavorable
3	Outcome	70%	21%	9%
8	Outcome	31%	29%	40%
23	Outcome	63%	25%	12%
25	Outcome	83%	10%	6%
Average		62%	21%	17%
Standard Deviation		22%	8%	16%
Question	Category	Favorable	Neutral	Unfavorable
5	Visualization	29%	21%	50%
9	Visualization	60%	19%	20%
12	Visualization	72%	22%	6%
13	Visualization	70%	18%	12%
Average		58%	20%	22%
Standard Deviation		20%	2%	20%

4.4. Students at Rice University responded with a slightly higher percentage of favorable responses and slightly lower percentage of neutral responses as compared to literature. The percentage of unfavorable responses was slightly higher each year after General Chemistry 1 but similar at the other time points. These minimal differences were not unexpected due to Rice's strong reputation in science and engineering. The strong similar trends in overall averages across the year of General Chemistry indicate that the use of only 25 of the 47 questions provided suitable data.

Table 4.4 - Overall averaged CHEMX results

	Favorable	Neutral	Unfavorable
Literature (47 questions; Grove and Bretz, 2007)			
Pre GC1	64%	21%	15%
Post GC1	65%	18%	17%
Post GC2	58%	19%	23%
General Chemistry at Rice University (25 questions)			
2009 Pre GC1	68%	16%	15%
2009 Post GC1	67%	14%	20%
2010 Post GC2	62%	14%	23%
2010 Pre GC1	69%	16%	14%
2010 Post GC1	63%	15%	22%
2011 Post GC2	60%	15%	24%
2011 Post GC1	65%	13%	22%
2012 Post GC2	60%	19%	21%

The percentages of favorable responses averaged over the questions within each construct are presented in Figure 4.1. The averages for questions pertaining to concepts and visualization (see Table 4.2) slightly increased after the first semester

of General Chemistry and slightly decreased after the second semester. For questions relating to effort and the laboratory, favorable averages decreased after both semesters, with a more noticeable decline for the lab questions. The averages of the questions about outcome increased over the first semester in 2009 and decreased over the first semester in 2010, but the favorable averages were steady for each year across the second semester. The overall averages decreased across each semester, indicating less alignment with the expectations of chemistry professors, as also shown in Table 4.4.

Results are shown specifically for each of the lab category CHEMX questions in Figure 4.2, with reference to Table 4.2 for the question statements. The overall favorable averages for that construct declined across both semesters each year, as shown in Figures 4.1 and 4.2. A surprisingly high percentage of incoming students felt learning lab techniques was a main goal of the course (Q7), and this decreased only slightly over the year. Significantly more students felt that they could make a passing grade in CHEM 123 without understanding chemistry (Q1) after the first semester than at the beginning of the course. The responses changed less before and after the second semester. A similar trend was seen with students' agreement with the statement regarding finishing the lab as quickly as possible and figuring out the meaning of the data later (Q16). Slight declines were seen across the year in students' need to understand the lab (Q22), working hard over a focus on the right answer (Q6), and the cumulative nature of the labs (Q24). Student perceptions

regarding understanding lab instruments (Q11) and approaching calculations (Q19) did not change significantly across each semester.

Figure 4.1 - Favorable averages by category of CHEMX along the year of General Chemistry (GC) from Fall 2009 to Spring 2012

Figure 4.2 - Percentage of favorable response to lab CHEMX along the year of General Chemistry (GC) from Fall 2009 to Spring 2012

4.5.2. Phase 1 Results

The initial phase of the study allowed for a baseline of data before significant changes were implemented in the pilot study during Spring 2011 and discussion sessions during Spring 2012. Data was also collected in Fall 2009 and 2010 to gain a better understanding of the students' previous experiences in chemistry, as well as their expectations for chemistry in college. Students did report they had experience with labs from high school chemistry, with 92% in Fall 2009 and 97% in Fall 2010

reporting that they did labs at least a few times per semester. Figure 4.3 shows student responses regarding the impact of high school chemistry labs on their understanding and interest in science. More students reported increased interest in science rather than understanding as a result of labs.

Figure 4.3 - Incoming General Chemistry student responses regarding high school chemistry courses

During interviews at the beginning of Fall 2009 and Fall 2010, students elaborated on their experiences in high school chemistry and distinct trends were apparent. In general, high school labs were viewed as fun experiences rather than a main means of learning or furthering one's understanding of chemistry. While students' high school chemistry experiences spanned a wide array of scenarios, such experiences impacted students' perceptions of General Chemistry Laboratories in a similar fashion. If a student had a negative experience in high school laboratories, he or she expected undergraduate laboratories to be better in whatever area the high school experience was lacking. For example, if a teacher did not provide enough background for labs, students expected to have more than adequate preparation and prior knowledge for labs in college. Students with positive high school experiences also had higher expectations for college labs. Most incoming students did not have an understanding of visualization at the molecular level or why it might be important; thus they had little to no expectations regarding visualization in college labs. The majority of students did fully expect that learning proper laboratory techniques was an important part of the lab course, but they had very little concept of what that entailed or the equipment and instruments that are used in chemistry laboratories.

Further interviews were held with the same students at the end of Fall 2009 and Fall 2010. The main theme from the interviews after students had completed CHEM 123 was the idea that the most students do not view the laboratory as a place for learning. They see the lab as an exercise to obtain the required data and think

about the lab itself afterwards if and only if it was necessary to think about the chemistry in order to complete the lab report. Most students focused on completing the required steps of each lab without thinking about what they were doing or why they were doing it. While there were some students who wanted to understand the chemistry behind each step as it was completed, they were in the minority. Most students really did view the lab as an exercise in manipulating materials in order to obtain data so that they could complete the lab report at a later time. While students felt that the labs coincided with the lecture portion of the course, most students did not gain understanding in chemistry from traditional lab experiences. The labs that were viewed as the most helpful in understanding concepts were the “dry” labs that focused on molecular modeling or solid state structure. These were intentionally included within the lab curriculum to provide the students hands-on and intrinsic visualization of the particulate level, yet they were not traditional data collection labs with chemicals. Very few students used the traditional lab experiences as a platform for visualizing at the particulate level. Those students who did find visualization helpful felt it was something they did more often during lecture or while reading the class textbook.

Interviews at the end of the Spring 2010 and Spring 2011 semesters were also held with as many of the same students as possible. Students generally felt that they did better in CHEM 124 than in CHEM 123. They indicated that this confidence was mainly due to being more comfortable in the lab and using lab equipment. However, most students still did not see thinking in the lab to be necessary, and

some found it to be mutually exclusive to think about the chemistry that was happening while they were performing an experiment. This was true, especially during laboratories that used spectrophotometers in order to collect data. Students rarely visualized at the particulate level in the spring semester labs. Discussion with students elucidated that most students would only attempt to visualize on a particulate level in lab if they were asked to do so and if they already had a solid understanding of the chemical phenomenon being studied.

The minimal changes that were incorporated in CHEM 124 in Spring 2010 were discussed with students during interviews. Feedback on the open-ended laboratory suggested that it was a beneficial exercise in understanding how experimental science is performed. The Lego activity gave students macroscopic representations of the particulate factors in dynamic equilibrium and reaction rates that were seen as both illuminating and memorable by most students. The students also indicated that having discussion time at the end of lab, the few times it happened, did not turn out to be beneficial for multiple reasons. Mainly, students were ready to leave and were not willing to wait for everyone to finish the lab. The discussion time was a change that was made in the middle of the semester after the norm had been to be released from lab after data collection was complete. Also, students indicated that they were not prepared to discuss the lab immediately after completion, as they had not yet starting to think about their data and observations. Most students preferred to wait to think about the lab when necessary to complete the lab report and attempted to leave the lab as quickly as possible each week. Many

students expressly stated that they tried to complete data collection as fast as they could in order to spend less time in lab.

Discussions during interviews in Spring 2010 brought to light that one laboratory was performed by all students before discussion on that topic had begun in the lecture portion of the course. While this is counter to the model of learning first in lecture and having background knowledge to then explore the concepts in the laboratory, the model of observation first does align with the philosophy of the *Concept Development Studies in Chemistry* (Hutchinson, 2007). In this instance, most students expressly stated that performing the lab on electrochemistry before covering the topic aided in their perceived understanding of the material.

The interviews served to validate and further explain the survey responses, as well as serve as a baseline for the study.

4.5.3. Phase 2 Results

The second phase of the study was the implementation of changes within a pilot lab section of 20 students in CHEM 124 during Spring 2011. Due to the small comparison sample size in a class of over 300 students, statistical comparisons of the CHEMX survey results between the pilot study and the rest of the class could not be made. However, the survey given to the pilot study participants did yield a great deal of data. Students responded to open-ended questions regarding how each major change implemented in the pilot study enhanced or detracted from their understanding of chemistry. The written results were analyzed as either positive -

meaning the student indicated an enhancement of learning chemistry, negative - meaning the student felt that aspect detracted from their learning, or neutral - meaning no impact. The results of this categorization are represented in Figure 4.4. The vast majority of students, 17 of the 20, felt the inclusion of the “Predictions” assignment added value to their learning in the lab. Pre-lab discussions were seen as positive enhancements to understanding by 16 of the 20 students. Students indicated the encouragement to participate helped them to learn more during pre-lab. However, awarding credit for participation during pre-lab was a standard practice implemented in Fall 2009. The majority of students, 13, also indicated the updated format for the pre-lab quizzes aided in their understanding of the chemistry experienced in lab; yet 4 students felt the quizzes detracted from their experience. Multiple of the students who felt that quizzes helped them indicated the need to prepare beforehand in order to take the quiz. Those who felt the quizzes were not helpful indicated various reasons without consistency. Slightly less than half, 9 of 20, of the students felt the required drawing of particulate diagrams helped them understand chemistry, and 5 students felt the diagrams had a negative impact. Almost all of the students indicated that drawing particulate level diagrams was challenging.

The survey results also included a variety of responses from students about what they felt was the most helpful component of the pilot lab section. Multiple students mentioned that the format of turning in predictions and taking lab quizzes forced them to prepare beforehand, which helped them understand the lab itself.

Figure 4.4 - Categorization of pilot section students' written responses to: "How did *this part of lab* enhance or detract from your understanding of the chemical phenomenon you experienced in lab?"

Multiple students also mentioned that the smaller class size allowed greater accessibility to the instructor and teaching assistants, although this was not a planned aspect of the pilot study.

Interviews were performed only with students who were not part of the pilot study. Similar results were found in interviews as during the baseline phase of the study. Students generally preferred to think about the lab afterwards, if required to do so in order to complete the lab report. The inclusion of different labs instigated the following new responses. For multiple weeks in a row, spectrophotometers were used to collect data to demonstrate Beer's Law, observe equilibrium, and observe reaction rates. However, the majority of students were not able to

differentiate between the concepts being illustrated by the labs. They felt they were repeating the same procedure over and over rather than realizing they were looking at examples of very different concepts in chemistry.

4.5.4. Phase 3 Results

The full implementation of changes in the General Chemistry Laboratories was made in CHEM 124 Spring 2012. Survey questions beyond the CHEM X questions were administered at the end of CHEM 123 in Fall 2011 and the end of CHEM 124 in Spring 2012 to allow for comparisons. Specific questions regarding the main change of including discussion sessions were also included in Spring 2012.

Students were surveyed regarding when they found it most valuable to read and when they actually read the lab procedure. Students provided similar responses at the end of both semesters, as shown in Table 4.5. Most students find it most helpful to read the procedure *the day before* or *the day of lab* and actually do so. Interviews indicated the timing of the lab and schedule of other classes often dictated whether reading the day before or the day of was preferred.

Students did change their responses regarding when they made predictions about what they would observe in lab between Fall 2011 and Spring 2012, as seen in Table 4.6. In Fall 2011, about a third of the class, 32%, made predictions *while reading the lab handout*, and only 9% of students did so *while taking the online pre-lab quiz*. When the pre-lab quizzes were converted to pre-lab assignments in Spring 2012, fewer students, 13%, responded that they made predictions *while reading the*

Table 4.5 – Student responses to survey questions regarding reading at the end of General Chemistry in Fall 2011 and Spring 2012

When do you find it most valuable to your lab experience to read the lab procedure?					
	During the week before lab	The day before lab.	The day of lab.	I only read enough to complete the online quiz/prelab.	I don't read the lab procedure.
FALL	12%	52%	29%	7%	0%
SPRING	5%	58%	30%	7%	0%
When do you actually read the lab procedure?					
FALL	10%	42%	41%	7%	1%
SPRING	6%	43%	42%	10%	0%

Table 4.6 – Student responses regarding predictions at the end of General Chemistry in Fall 2011 and Spring 2012

When do you make predictions about what you expect to observe in lab?						
	While I am reading the lab handout prior to lab.	While I am taking the online prelab quiz/completing the prelab	Before the start of lab.	During the prelab lecture.	While I am performing the lab.	I don't make predictions.
FALL	32%	9%	15%	20%	18%	6%
SPRING	13%	30%	9%	18%	20%	9%

lab handout, and almost a third responded that they made predictions while completing the pre-lab assignment.

Due to the addition of discussion sessions in Spring 2012, some survey questions were altered in order to incorporate the changes. The survey responses were also changed so that students could select their top two options of when they completed components of the lab. The survey data with students top two choices are

presented in Tables 4.7, 4.8, 4.9, 4.10 and 4.11 as SPR: 1st and SPR: 2nd. As the difference between first and second choices for students would be individual to each student, the data was maintained as separate responses.

Students were asked when they reflected on the observations from lab, as shown in Table 4.7. In Fall 2011, the majority of students, 65%, reflected on observations *while completing the lab report* and 18% *while making observations in lab*. With the inclusion of discussion sessions, 49% of students selected *during the discussion sessions* as one of the top two times they reflected on observations. The choice selected most often was still *while completing the lab report*, with 70% of students choosing this in their top two options. Within both top choices, 25% of students reflected on observations *while in the lab*.

Students responded to when they visualized on the molecular level, as reported in Table 4.8. In Fall 2011, if students reported that they visualized, 24%

Table 4.7 – Student responses regarding observations at the end of General Chemistry in Fall 2011 and Spring 2012

		When do you reflect on your observations made in lab?							
		While I am making the observations in the lab.	As soon as I'm finished with the lab, but before I leave lab.	After the lab, usually that evening or the next day.	Right before the discuss. session	During the discuss. session	When I am completing the lab report.	When I am studying for a chem. exam.	I don't reflect on my lab obs.
FALL		18%	6%	7%	-	-	65%	1%	2%
SPR:1 st		22%	3%	3%	8%	25%	30%	4%	6%
SPR:2 nd		3%	3%	2%	7%	24%	40%	13%	8%

Table 4.8 – Student responses regarding visualization at the end of General Chemistry in Fall 2011 and Spring 2012

When do you visualize on a molecular level the observations you made in lab?								
	While I am making the observations in the lab.	As soon as I'm finished with the lab, but before I leave lab.	After the lab, usually that evening or the next day.	Right before the discuss. session	During the discuss. session	When I am completing the lab report.	When I am studying for a chemistry exam.	I don't visualize my lab obs. at the molecular level.
FALL	24%	2%	2%	-	-	35%	10%	25%
SPR:1 st	20%	2%	1%	3%	26%	23%	8%	16%
SPR:2 nd	6%	3%	2%	4%	15%	31%	24%	16%

did so *while making observations in the lab*, and 35% did so *when completing the lab report*. Once discussion sessions were implemented, a total of 41% of students chose *during discussion sessions* as one of the top two times they visualized, with a total of 26% selecting *while in the lab* and 54% *while completing the lab reports*.

Students were also asked when they analyzed their data from lab, as shown in Table 4.9. Prior to discussion sessions, 87% of students analyzed lab data *while completing the lab report*. With the inclusion of discussion sessions, a total of 58% of students chose *right before discussion sessions* as one of the top two times they analyzed data, and 33% chose *during in discussion sessions*. *While completing the lab report* was in the top two choices of 79% of students.

In conjunction with data analysis, students were asked when they interpreted and made sense of their data, as shown in Table 4.10. Again, the vast majority of students, 78% in Fall 2011, reported they interpreted *while completing*

Table 4.9 – Student responses regarding analyzing data at the end of General Chemistry in Fall 2011 and Spring 2012

When do you analyze (e.g. perform calculations on, graph, summarize) the data you collected in lab?								
	While I am collecting the data during lab.	Immediately after completing data collection while I am still in the lab.	After lab, usually that evening or the next day.	Right before the discuss. session	During the discuss. session	When I am completing the lab report.	When I am studying for a chemistry exam.	I don't analyze my lab data.
FALL	4%	3%	5%	-	-	87%	0%	0%
SPR:1 st	9%	2%	6%	40%	11%	32%	0%	0%
SPR:2 nd	4%	3%	4%	18%	21%	47%	4%	1%

the lab report. Once discussion sessions were implemented, 71% of students chose *while completing the lab report* as one of the top two options of when they interpreted data. Students also reported *right before the discussion sessions*, 27%, and *during discussion sessions*, 49%, as common top times for data interpretation.

Finally, students were asked when they took the knowledge gained via the labs and incorporated it with what they learned in class, as seen in Table 4.11. The distribution of responses in Fall 2011 was quite spread among the options, with 26% reporting *while completing the lab report*, and 27% *while studying chemistry* as the most common answers. Once discussion sessions were implemented, 43% of

students selected *during discussion sessions* as one of the top two times they incorporated lab and class knowledge. A total of 74% of students selected *while completing the lab report* in their top two options, and 33% selected *while studying chemistry*.

Table 4.10 – Student responses regarding interpreting data at the end of General Chemistry in Fall 2011 and Spring 2012

When do you interpret (e.g. understand the meaning of, draw conclusions from) the data you collected in lab?								
	While I am collecting the data in lab.	Immediately after I have collected the data in lab, but before I leave the lab.	After lab, usually that evening or the next day.	Right before the discuss. session	During the discuss. session	When I am completing the lab report.	When I am studying for a chemistry exam.	I don't interpret my lab data.
FALL	10%	5%	4%	-	-	78%	3%	0%
SPR:1 st	22%	4%	4%	17%	22%	29%	2%	0%
SPR:2 nd	7%	5%	2%	10%	27%	42%	6%	2%

Table 4.11 – Student responses regarding incorporating knowledge at the end of General Chemistry in Fall 2011 and Spring 2012

When do you incorporate the knowledge you gained in the lab with your chemistry knowledge from class?							
	While I am in lab.	While I am in class.	While I am in discussion.	When I am completing the lab report.	When I am studying chemistry with a group of students.	When I am studying chemistry by myself.	I don't integrate knowledge from the lab and class.
FALL	17%	10%	-	26%	19%	27%	2%
SPR:1 st	15%	3%	28%	40%	2%	11%	0%
SPR:2 nd	12%	7%	15%	34%	8%	22%	1%

Student perceptions of the discussion sessions were assessed with further survey questions as listed in Table 4.12, and the responses are shown in Figure 4.5. The majority of students agreed that discussion sessions helped them understand chemical concepts, helped them connect the class and lecture material, were a good use of time, caused them to learn more chemistry, and were preferred over having no discussion session. More students agreed that they preferred the teaching assistant explain a concept before discussing with their peers than vice versa.

Interviews with students elicited various themes about discussion sessions. Students' responses were very dependent upon which teaching assistant ran their session. The teaching assistants were all provided guidance by the lab instructor as to the topics to cover during discussions, yet they had leeway to structure the sessions how they felt was best and to decide what specific questions to incorporate. Different students responded to the different formats and approaches depending on their level of confidence with the material. Students who more frequently struggled to understand the concepts reported that the discussion sessions that were mainly reiteration of ideas, explanation of portions of the lab, and group discussion of data interpretation were valuable. Students who already felt comfortable with most of the content preferred being asked questions that addressed the concepts beyond the lab and were given more chances to participate in class or group discussions. In general, most students did see the value of the discussion sessions to their education and preferred them over weekly labs. Students did notice a change in the lab reports

being more challenging and requiring more thought in coordination with the implementation of discussion sessions.

The lab instructor and discussion session teaching assistant interviews validated the varying student reports of format and activity during discussion sessions. The lab instructor was often present in discussion sessions, but she did not

Figure 4.5 – Students’ survey responses regarding Spring 2012 discussion sessions, corresponding to question statements listed in Table 4.12

Table 4.12 - Question statements used in Spring 2012 survey regarding discussion sessions, corresponding to data in Figure 4.5

Discussion Session Survey Questions
Q1. The post-lab discussion sessions helped me understand the chemical concepts behind the lab better.
Q2. The post-lab discussion sessions helped me connect the lab material to the lecture material better.
Q3. The discussion session was a good use of lab time.
Q4. I preferred when my TA explained a concept before I talked about it with other students.
Q5. I preferred talking about a concept with other students before my TA explained the answer.
Q6. I learned more chemistry this semester because of the post-lab discussion sessions.
Q7. Overall, I prefer having post-lab discussions to no discussion session.

attend all of them due to labs occurring simultaneously. The multiple formats all addressed the same topics, as provided by the lab instructor. Two of the four teaching assistants spent more time explaining concepts, one regularly gave students more time to work on new problems together, and one actively tried to get the students to explain concepts amongst each other. The teaching assistants all felt that they grew as instructors over the semester and increased in their effectiveness as discussion leaders with practice.

4.6. Discussion

4.6.1. Phase 1 Impact

The initial phase of data collection greatly impacted the progress of this study. The surveys and interviews allowed for a greater understanding of the students' perspectives on learning chemistry and approaching the laboratory. Students entering General Chemistry felt that the lab was a place to focus on learning lab techniques rather than deepen one's understanding in chemistry was a surprising revelation. The fact that most students were unable or unwilling to think about the chemistry they are observing while in lab also set into motion the changes in the later phases of the study.

The initial survey questions gave insight into incoming students ideas about learning chemistry. Students had a wide variety of experiences in high school, but

most had not given much thought to how college chemistry might differ. Students did not have solidly held expectations regarding how they would learn chemistry. The general consensus was that it would be a richer experience than high school and that they would become more proficient in manipulating lab materials and equipment. Most students did not come in seeing the lab as a place to learn chemistry. Instead, they expected learning to come from lectures, working problems, and textbooks.

The minimal changes that were implemented initially could not be compared to previous years, but the data did reflect on their value. Students did appreciate the level to which the lecture and lab coincided and were quick to point out when any deviations occurred. Having the courses aligned was valuable to students' learning of chemistry and helped them to see more potential in the learning experience provided by the lab. However, the emphasis stated by the lab instructor for students to "Think scientifically and think visually" seemed to have no impact on students, as such emphasis was not continued by requiring students to do such in order to complete the lab reports. Students made it clear that they would complete what was required of them in lab, yet most students had no incentive to go beyond the basic course expectations. Despite encouraging participation in pre-lab lectures, students did not see lab as a time for discussion of concepts. They saw lab as a time for presentation of the procedure at hand and as exercises of completion rather than potential experiences in manipulating and understanding chemical phenomena. Spending one or two semesters in the General Chemistry Laboratories seemed to

increase the depth to which students expressed this viewpoint rather than the opposite. The CHEMX survey validated this student belief by showing a decline in the alignment of student expectations with faculty expectations across the first year of chemistry, especially in the laboratory. While this overall decline in expectations was expected according to literature, due to the active research nature of improving the educational value of the course, the hope was to see improvement. Thus, the study continued with a pilot study and further changes.

4.6.2. Pilot Study Impact

The pilot study was a small implementation of changes within the Spring 2011 laboratory. The enrollment in the pilot section was low compared to the other lab sections, which limited any quantitative data comparisons via CHEMX. Changes in the pilot section were only made in how the laboratories were presented to students, as the actual labs could not be modified due to logistics of a large course and lab supplies. Despite these limitations, the pilot study was successful according to written student feedback.

The inclusion of a weekly pre-lab assignment that focused on predictions was found by most students to enhance their understanding in the lab. Students were forced to not only read through the lab procedure in order to complete the "Predictions," but they were also required to think about what they expected to happen in the lab or show their expected trends in data. This requirement to think about what would be going on ahead of time gave students the time they needed to

process the lab procedure and grasp an understanding of the chemical process prior to performing the lab. While students were not graded harshly for incorrect predictions, they did receive feedback on their ideas before beginning the lab. This allowed for students to address misconceptions and test them in the lab.

The requirement of preparation before lab was also mandated by the pre-lab quizzes. The multiple-choice nature of electronic response system questions limited the depth of questions that could be asked, yet the immediate feedback and discussion with students made up for this challenge. While most students found the quizzes to be helpful, they also thought they were challenging. Students did not like losing points in lab because of the quizzes. However, students who were prepared rarely performed poorly. Students' previous experiences in CHEM 123, which required little pre-lab preparation and online quizzes with limited accountability, impacted their willingness to appreciate the need to prepare for lab. However, once students understood the expectations in the pilot section, they were able to be successful on the pre-lab quizzes.

The focus on the pre-lab discussions of understanding the concepts as verbalized by the students, in addition to the instructor, also aided understanding in the lab according to students. Multiple students did note that this discussion time was very helpful to their ability to make sense of the lab. Students need to be able to put their ideas into words, whether on paper in lab reports or out loud during pre-labs. This process allows students to evaluate their thoughts and connect ideas into full concepts. More discussion-based pre-labs and more thought provoking lab

report questions were beneficial to students, as well as taking time each week to discuss the results from the previous lab. It was these findings that most impacted the changes that were implemented in the full Phase 3 portion of this study.

Students were required to visualize on the molecular level via particulate diagrams on every lab report. At first, this was very challenging for students. Later in the semester, some students saw the diagrams as redundant. Inclusion of particulate level diagrams was the change that the fewest number of students found beneficial. While students did have to attempt to visualize in order to complete the drawings, some students circumvented that requirement as best they could by creating the most simplistic diagrams possible. While this process did challenge and enhance those students who took it on completely, the actual implementation may have been better suited for less regular use.

The impact of the pilot study was minimal due to its small size, 20 students, in comparison with a class of over 300 students. Further reaching changes were necessary in order to encourage more students to see the lab as a place for learning. The pilot study was successful in encouraging students to prepare for lab so that they could think about it while it was proceeding and encouraging students to visualize chemistry.

4.6.3. Full Study Impact

The changes implemented in Spring 2012 represented a culmination of the results of the first two phases of the study. The lab was reorganized in order to

incorporate longer biweekly lab periods and biweekly one-hour discussion sessions. Discussion sessions required some preparation for students, mainly data analysis. Pre-lab assignments were included rather than online pre-lab quizzes, and more challenging post-lab questions were included. Each lab became a two-week process rather than one-week.

Data from Fall 2011 allowed comparison of when students completed components of the lab. Students did not change when they read the lab handout between Fall and Spring semesters, but they did utilize the pre-lab assignment as a time for making predictions in Spring 2012. The pre-lab assignments were similar to the “Predictions” of the pilot study, but they also included a listing of the materials, equipment, and workflow of the lab. Specific predictions of data trends were not required, but synthesis of the lab procedure so that students understood what was expected of them did allow for predictions to be made.

Student survey responses indicated that the discussion sessions did offer students time to complete lab activities. Students reported reflecting on observations, visualizing on a molecular level, analyzing data, interpreting data, and incorporating lab and class knowledge during discussion sessions. Prior to discussion sessions students did most of these activities while completing the lab report, which was often done right before it was due. The required discussion sessions gave students structured time to think about the aspects of the lab and gain more from the lab experience. Further survey questions did indicate that students saw discussion sessions as valuable to their learning experiences. They reported the

sessions helped them understand the chemistry of the labs better and connect the lab and lecture material. Students generally felt discussion sessions to be a good use of time, even though the consistency between the discussion sessions led by different teaching assistants was not high. Despite different approaches, students generally preferred having discussion sessions. From interviews, students who were struggling in chemistry benefited more from discussion sessions than students who were excelling. However, the majority of those students who were excelling still saw discussion sessions as valuable learning experiences, whether through discussion concepts and teaching other students or via specific time to think about lab concepts.

The CHEMX survey data from Fall 2011 and Spring 2012 did not show any differences from previous phases of the study. The trends were the same for the overall averages, construct averages, and the individual lab question averages. The CHEMX survey did not illicit quantitative data on the implementation of changes in the General Chemistry Laboratories, yet the survey data showed consistency across the two semester courses from 2009 to 2012. The survey was designed to capture students' expectations in learning chemistry, and showed that these expectations become slightly less aligned with those of chemistry faculty after two semesters of General Chemistry. Student expectations were not changed by this study. Changing expectations is challenging, especially if students do not spend much time or thought understanding their own expectations. Even though the expectations measured by the CHEMX instrument were not affected, student behavior was

changed by this study. Upon implementation of required pre-lab assignments and structured post-lab discussions, students were made to think about the lab experiences and the chemistry involved.

4.7. Conclusions

The chemistry laboratory is a potential place for learning chemistry. However, traditionally structured lab experiences do not create learning experiences for most students. Students will perform labs without thinking or visualizing if such tasks are not required of them. Thus, laboratories must be specifically designed and structured in order to require students to think about the chemistry by discussing the data, visualizing the particles, and being required to address the concepts rather than simply follow a cookbook procedure.

Students' expectations in learning chemistry change and become less aligned during the first two semesters of college chemistry both at Rice University and in previous studies (Grove and Bretz, 2007). Despite active changes focused on requiring students to think in lab, their expectations remain unchanged. One possible conclusion is that students do not thoughtfully reconcile their expectations with what they actually do in order to complete laboratories. Students might still expect to focus on finding the right answer or attempting to finish as quickly as possible, yet they are required to also provide meaning for their data in lab reports and attend discussion sessions to spend time interpreting data and understanding

the concepts. Thus, student expectations are not synonymous with the activities the students actually complete.

The modifications made to the lab experiences within this study did add to the educational value of the labs for the students. The challenges faced with implementation of minor changes in the initial phase and limited ability to make changes in the pilot study informed the final phase of changes. The ability to make structural changes, changes in the labs themselves, and changes in the requirements given to students are all necessary in order to create quality lab experiences. Students need to be encouraged to think, visualize and make meaning from labs. Performing manipulations within the lab is not the main point of the lab experience, yet gaining greater understanding of the chemical phenomena being observed is what makes labs valuable. While students might still expect that the actual lab performance is the main process in the lab, they can be required to enhance their conceptual understanding in chemistry through actively discussing the lab. While this study was focused on General Chemistry Laboratories, the conclusions are also informative for high school and upper level college labs. Students must be required to think about labs and be given the structure and time needed to do so.

Novel General Chemistry Laboratories

In an extension of my work in assessing, understanding, and improving General Chemistry laboratories, I have also created new laboratories that exemplify the experiences that provide the basis for a relevant lab. Two such laboratories have been created and shared via the *Journal of Chemical Education* (Cloonan et al., 2011a, 2011b). They are both presented within this chapter, and a plethora of supplemental material is available online via the *Journal* to assist teachers with the actual implementation of these activities.

5.1. A Simple System for Observing Dynamic Phase Equilibrium

This section describes an activity that can be used as an inquiry-based laboratory or demonstration for either high school or undergraduate chemistry

students to provide a basis for understanding both vapor pressure and the concept of dynamic phase equilibrium (Cloonan et al., 2011a).

5.1.1. Background

Inquiry-based activities and pedagogies are promoted by the American Association for the Advancement of Science and incorporated into the National Science Education Standards (USA Research, Inc., 1984; Minstrell and Van Zee, 2000). Inquiry-based teaching follows from a constructivist understanding of how people learn and focuses on building understanding of a concept initially from experiences, observations, or existing knowledge (Bodner, 1986; Bransford et al., 1999; Kipnis and Hofstein, 2008). This focus on learning is especially important when commonly held misconceptions are present and must be challenged directly to prevent dichotomous and inconsistent lines of reasoning within an individual's knowledge base. Numerous researchers have revealed an array of misconceptions in chemistry at all level of students (Kind, 2004; Horton 2007). Although a number of studies have focused on how students understand evaporation (Bodner, 1991; Johnson, 1998; Osbourne and Cosgrove, 1983), only a few studies have concentrated on perceptions of vapor pressure and liquid-gas phase equilibrium (Canpolat, 2006; Canpolat et al., 2006). These studies have shown that the majority of third-year undergraduates in a science teacher preparation program have misconceptions about the definition of vapor pressure and how vapor pressure is affected by changes to a closed system (Canpolat, 2006; Canpolat et al., 2006). The authors call for a focus on improving the quality of chemistry instruction and increasing the

depth at which basic concepts such as vapor pressure and phase equilibrium are covered (Canpolat, 2006; Canpolat et al., 2006).

This section presents an activity that can be used as an inquiry-based laboratory or demonstration for either high school or undergraduate chemistry students to provide the basis for understanding vapor pressure as well as grasping the concept of dynamic phase equilibrium. To understand equilibrium, students must be able to think on the particulate level. This activity presents data to illustrate that a system at equilibrium is not static. Although the macroscopic properties are constant, molecular motion is incessant. Students are challenged to see how equilibrium is achieved and maintained. The concept of equilibrium is a central theme throughout all of chemistry and important in understanding not only phase transitions but also chemical reactions. A related activity created to help students understand reaction equilibrium using a more tactile experience with interlocking building blocks will be discussed in the next section of this chapter (Cloonan et al. 2011b).

The measurement of the vapor pressure of a liquid at a certain temperature is a common chemistry laboratory experiment for physical chemistry classes; however, specialized equipment is often necessary (Dunell and Werner, 1955; Frigerio, 1962; Iannone, 2006). The idea of phase equilibrium is easy to show in a textbook, but recreating such a system with common substances helps students understand the concepts of phase equilibrium and vapor pressure. Furthermore, creating a setup in which the volume can be varied while maintaining a degassed

system can become complex and require vacuum pumps. Even so, varying the volume provides an illustration of how phase equilibrium is maintained, as vapor pressure does not change with volume. This counteracts the common misconception that vapor pressure depends on the volume of a closed system (Canpolat et al., 2006).

The activity described here forces students to reconcile the differences between a liquid-vapor system of a single substance versus a system that only includes a gas. Although this is a subtle difference to students, altering the volume of the systems results in totally different sets of behaviors. Thus, students must conclude that the liquid-vapor system maintains constant pressure due to phase equilibrium; yet the system with only a gas is dominated by Boyle's law. Students must realize the rate of vaporization changes only with temperature, while the rate of condensation adjusts with volume. When the volume is reduced, the frequency of gas molecules colliding with the liquid surface increases, which increases the rate of condensation. This increase is only temporary, and then the rate of condensation stabilizes for the new volume to again equal the rate of vaporization and reestablish equilibrium. Through this line of reasoning, the idea of dynamic equilibrium is illustrated, and students come to see that particles are in constant movement within a system even though they appear stationary from the macroscopic view.

5.1.2. Experiment

The setup of a closed system of one substance, water, void of air is described. To contrast this setup of liquid and vapor in equilibrium, the same setup can be used with only air to provide an example of Boyle's law. Detailed instructions for students and instructors were made available in relation to the publication of this activity (Cloonan et al., 2011a).

5.1.2.1. Degassing

A small volume of water is boiled in a small Erlenmeyer flask to purge the flask of air. After a few minutes of boiling, the flask is closed with a two-hole rubber stopper fitted with Luer connectors. A plastic syringe is connected to one Luer connector and fully depressed. After the connectors in the stopper are purged by a few more minutes of boiling, a pressure sensor is connected to the second Luer connector to create a sealed system, and the flask is removed from the heat source. The flask is immersed in an ice-water bath for a few minutes to expedite cooling to room temperature. An image of the complete setup in use is shown in Figure 5.1.

Other substances can be used for this activity. Methanol was successfully used with this setup, but boiling was performed in a ventilated hood. However, acetone was not compatible with the tubing used, so selection of other substances should be done with compatibility of plastics in mind.

Figure 5.1 - Experimental setup

5.1.2.2. Pressure Sensor

This experiment has been performed using both Vernier and MicroLab pressure sensors and their associated software. The pressure can be observed while the temperature drops, which provides an illustration of the temperature dependence of vapor pressure. The most interesting measurements are made once temperature is constant. It may take as long as 45 minutes for the temperature of the system to be completely equilibrated, but measurements can usually be made as soon as 20 minutes after the system is set up. Once the pressure is steady near the vapor pressure of water at room temperature (23.8 Torr at 25°C), the system is

ready for volume manipulation and measurements. This setup was found to maintain vacuum for several days with an increase in pressure of only a few Torr per day due to air leaking into the system.

5.1.3. Results

A sample of data obtained in this experiment is shown in Figure 5.2 with the corresponding times and changes in volume in Table 5.1. The pressure of the water system shown in Figure 5.2(A) is relatively constant with an average of 24.8 Torr and standard deviation of 0.7 Torr as the volume is changed by up to about 30%. There were slight changes in pressure that ranged from 23.7 to 25.8 Torr throughout the variations in volume. Those changes were due to a small quantity of air still present within the system. The water system is in stark contrast to the same system containing only air, as shown in Figure 5.2(B) with the same corresponding changes in volume. The air system in Figure 5.2(B) has an average pressure of 678 Torr with a greater standard deviation of 84 Torr, ranging from 555 to 794 Torr. These changes in pressure and volume follow the ideal gas law within less than a 1% error.

Figure 5.2 - Pressure of systems including (A) only liquid and vapor water and (B) only vapor air at room temperature upon volume changes at times noted in Table 5.1

Time (s)	Syringe Volume (mL)	Equilibrium Pressure (Torr)	
		Water	Air
0	0	25.4	773
15	14	25.0	704
30	35	24.2	622
45	58	23.8	561
60	35	24.3	622
75	14	25.1	706
90	0	25.6	774
105	58	23.9	562
120	0	25.6	774
135	0	25.6	774

Table 5.1 - Volume changes and equilibrium pressures of the two experimental setups

5.1.4. Discussion

The activity was performed as a laboratory by 35 teachers in the continuing education course for secondary science teachers at Rice University. The teachers enjoyed the laboratory and provided positive feedback noting it was both simple and illustrative. It challenged their thoughts on vapor pressure and helped them confront their misconceptions, especially the dependence of vapor pressure on volume. Multiple teachers plan to use this activity in their high school chemistry classrooms.

The activity was also performed as a demonstration for chemistry and Advanced Placement chemistry high school students. The use of this demonstration and the discussion that ensued was recorded and is available in podcast format via an online school webpage (Cloonan et al., 2011a). The high school students

examined the gaseous air system before the liquid-vapor water system as a review of Boyle's law and to provide a stark contrast to the vapor pressure setup. Thus, when the volume of the air system changed, Boyle's law prevailed, and the pressure of the system changed inversely with the volume. When the setups were compared, the lack of pressure change with volume change in the water setup provided a discrepant event that forced students to reconcile the differences and challenge their misconceptions. Discussion with the students was guided to help them understand what was changing in the systems on a molecular level. Students were able to conclude that the rate of condensation momentarily changes as volume is changed, but equilibrium is attained again when the rate of condensation returned to equal the rate of vaporization.

Undergraduate General Chemistry students at Rice University were presented with the liquid-vapor water system as a demonstration during lecture in Spring 2010 and as a station in laboratory in Spring 2011. The students provided positive feedback about the activity and responded that they were able to see, "The book come to life." Students found the demonstration memorable and helpful to understanding dynamic equilibrium. In Spring 2010, some students replied it would have been better if they could have done it themselves in lab; therefore the activity was incorporated into the laboratory curriculum the following year.

Through discussion with each of these groups, students and teachers reasoned through the molecular basis for the lack of pressure change upon volume change in the water system. In the specific case of the volume of the system

increasing, more space is available to the gaseous water particles. The gas particles then collide less frequently with the walls of the container, so there is an initial decrease in pressure. The gas particles also collide less frequently with the surface of the liquid, so there is also a decrease in the rate of condensation. However, the rate of vaporization does not change as it is dependent on temperature, which is constant in this situation. Therefore, since the rate of vaporization is greater than the rate of condensation, there soon are enough particles in the gas phase to balance the two rates, and equilibrium is established again. Through this understanding, the students and teachers were able to see that dynamic equilibrium must be occurring due to the constant motion of particles, as represented diagrammatically in Figure 5.3. Condensation and vaporization are continual even if there is no overall change in the volume of liquid or the pressure. In this setup, the interplay of dynamic equilibrium happens very quickly as is seen by no change in pressure.

Figure 5.3 - Dynamic equilibrium within a system of liquid and vapor water

5.2. Understanding Chemical Reaction Kinetics and Equilibrium with Interlocking Building Blocks

This section presents an activity that provides a discovery-based method to help students visualize simple reactions at the molecular level using small, plastic brick interlocking building blocks (LEGOS) to represent atoms and molecules (Cloonan et al., 2011b).

5.2.1. Background

A major goal of any chemistry laboratory is to help students connect the molecular concepts introduced in class with macroscopic observations seen through experiments (Hofstein and Lunetta, 2004; Reid and Shah, 2007; Schlesinger, 1935). However, research has shown that most students do not visualize the microscopic level when performing laboratory experiments or thinking about their observations unless specifically challenged to do so (Lazarowitz and Tamir, 1994). An activity was designed that uses small interlocking plastic building blocks to allow for visualization and to demonstrate chemical reaction kinetics and dynamic equilibrium by building on an idea initially proposed by Stacy (2010). Other building block activities have been developed for chemistry classes (Mind and Hand Alliance, 2007; Sharma, 2001; Witzel, 2002), but there are no published reports of building blocks being used to model chemical reaction kinetics and equilibrium. Stacy (2010) has suggested that by using building blocks to simulate elementary reactions, the concepts of concentration and collision rates will also come into play. By using small, macroscopic objects to represent atoms and molecules, this activity encourages students to visualize on the molecular level by putting the particles in their hands (Rhodes and Daly, 1977). This activity also goes beyond the static visualization that occurs when model kits are used to represent a single molecular structure. Through hands-on macroscopic experimentation, students can discover the concentration dependence of the reaction rate, observe a reaction system in

dynamic equilibrium through competing reaction rates, and dispel some of the common alternate conceptions regarding equilibrium.

Equilibrium is a core concept throughout chemistry, and the underlying concept of dynamic equilibrium permeates the discussion of all chemical reactions, as well as phase equilibrium. However, students often have misconceptions about chemical equilibrium because of vocabulary issues (e.g. the meaning of “shift,” “balance,” “reversibility” in chemistry vs. everyday usage), confusion about the difference between rate constants and equilibrium constants, misinterpretation of Le Chatelier’s principle, and lack of knowledge about the dynamic nature of equilibrium (Banerjee, 1991; Berquist and Heikkinen, 1990; Ozmen, 2008; Quílez, 2004; Wheeler and Kass, 1978). A variety of approaches have been developed to help elucidate the nanoscopic world of chemical equilibrium including macroscopic analogies, writing assignments, and hands-on activities (Raviolo and Garritz, 2009; Rudd et al., 2007; Wilson, 1998). In general, students find concrete examples more helpful than the abstract symbols that are traditionally used to illustrate chemical equilibrium.

Students are often particularly challenged by the concept of dynamic equilibrium, and only a few lab protocols exist to help them examine this concept (Harrison and Buckley, 2000). The activity presented here helps students dispel some of these misconceptions by allowing them to actually see and experience a dynamic model for how reactions depend on concentrations of reactants and come to equilibrium. Students can see that equilibrium is not a static state on the

particulate level but one in which the macroscopic properties are not changing, even while the microscopic particles are in continuous motion. The activity in the previous section of this chapter also encourages students to understand dynamic equilibrium via constancy of the vapor pressure equilibrium of a liquid-vapor system as volume changes (Cloonan et al., 2011a).

5.2.2. Activity Overview

The purpose of this activity is to demonstrate the concept of the dependence of the reaction rate on concentration and to illustrate how the rates of the forward and reverse reactions become equal when those reactions compete and come to equilibrium. The basic system is an elementary reaction involving synthesis and decomposition in equilibrium, as shown in Equation 3.1.



In Equation 3.1, A is a green (or any color) building block atom, B is a yellow (or any other color) building block atom, and AB is a molecule of connected green and yellow atoms. First, the bimolecular reaction of the synthesis of molecules from atoms is performed, and the reaction rate is monitored. Then, the unimolecular reaction of the decomposition of molecules into atoms is performed, and again the reaction rate is recorded. The kinetics of both bimolecular and unimolecular reactions will become apparent as students perform the reactions themselves and reconcile the differences between the two. Finally, both reactions are performed simultaneously to simulate competing forward and reverse reactions. This provides

a vivid illustration of how equilibrium occurs when the forward and reverse rates are equal and gives the students context upon which to build their understanding of equilibrium as macroscopically static but microscopically dynamic.

5.2.3. Activity Details

Detailed guides for students and teachers were made available upon the publication of this activity (Cloonan et al., 2011b). Materials include boxes containing 50 small interlocking plastic building blocks in two colors for a total of 100 bricks similar in size. Each building block represents an individual atom. Elements are distinct by color. When multiple building blocks are combined, they represent a molecule made of those particular atoms. Students work in teams, each with different tasks. The tasks are as follows:

- *Assembler:* Reach two hands into the box and pull out two particles without looking. If the particles are individual atoms (unattached building blocks) of different colors, they are assembled into a molecule and returned to the box. If the particles are the same color or if already a molecule, both are returned to the box with no changes. Repeat for the duration of the reaction time.
- *Disassembler:* Reach one hand into the box and pull out one particle without looking. If the particle is a molecule, it is disassembled, and the individual atoms are returned to the box. If the particle is an individual atom, it is returned to the box. Repeat for the duration of the reaction time.

- *Agitator*: Shake the box of building blocks to mix them during the reaction time. This is necessary as the most recently assembled or disassembled pieces will otherwise always be at the top.
- *Timer*: Indicate start and stop times to the team.

5.2.3.1. Procedure 1: Kinetics of Bimolecular Synthesis

Students perform a synthesis reaction by starting with all individual atoms and only having Assemblers work to make molecules with no Disassemblers. The reaction runs for one minute, then the numbers of atoms and molecules are counted. The reaction is performed again starting from the previous number of molecules for two additional one-minute intervals.

5.2.3.2. Procedure 2: Kinetics of Unimolecular Decomposition

Students perform a decomposition reaction the same as above but starting with all assembled molecules and no individual atoms. For a decomposition reaction, only Disassemblers work, and there are no Assemblers. The reaction is performed for three one-minute intervals, as per Procedure 1.

5.2.3.3. Procedure 3: Competing Reactions and Equilibrium

Students perform both synthesis and decomposition reactions simultaneously to represent competing forward and reverse reactions. The starting number of molecules can be varied, or students can predict what they expect will be equilibrium and start at that point. The reactions are best performed in two-minute

intervals when both reactions occur together. Equilibrium is typically attained after three two-minute intervals.

5.2.4. Results

After completion of the reactions, students compute “mole fractions” (in this case, simple fractions of particles of each type) to represent a concentration of each type of particle as shown in Equation 3.2, where X_i is the mole fraction of species i , N_i is the number of i particles, and N_T is the total number of particles.

$$X_i = N_i / N_t \quad (3.2)$$

The mole fractions are calculated after each reaction interval. Students are asked to compare and contrast the synthesis and decomposition reactions, their reaction rates, and the time required to get to completion. For the forward and reverse reactions together, students are asked if they achieved equilibrium. They are also directed to calculate an equilibrium constant, K , using mole fractions, as shown in Equation 3.3.

$$K = X_{ab} / X_a X_b \quad (3.3)$$

Students can then compare their observations to theoretical concentrations and equilibrium constant under the simple assumption that the forward and reverse reaction rate constants are equal, in which case $K = 1$. Calculations of the equilibrium constant and equilibrium concentrations are feasible and highlight the fascinating aspect that if $K = 1$, there would be 15 molecules and 35 of each atom at

equilibrium. Thus, even if we assume $K = 1$, the result is an unequal number of molecules and particles. Moreover, the data will differ if the reaction rate constants are not equal.

Actual student data varied, but many groups found an equilibrium number of molecules to be between 10 and 12. This is because the forward and reverse rate constants are not equal for this system, since, as students find out quickly, it takes less time to pull two connected building blocks apart than to put two pieces together. As noted below, however, this observation challenges students' preconceptions about dynamic equilibrium and what it means to have equal forward and reverse reaction rates.

5.2.5. Discussion

The equilibrium activity was performed by General Chemistry students at Rice University during a laboratory period. After completing the activity, some students did not understand that their system had reached equilibrium even if the number of molecules remained constant after each reaction period. Through the students' written responses and discussion, we discovered the students were unable to let go of their alternate conceptions regarding equilibrium. The main misconception students struggled to reconcile was their belief that at equilibrium, the concentration of reactants equals the concentration of products. Students were also encountering confusion regarding the difference of the chemistry definition of

“equilibrium” with the everyday meaning of “equal.” Thus, they expected equilibrium to only be achieved if they found 25 molecules and 25 of each atom.

While not all students understood equilibrium immediately after the activity and some expressed disappointment even when the numbers of particles of each type became static after multiple trials, guided discussions helped clarify misconceptions. Students came to understand the dynamic aspect of equilibrium at the particulate level while the macroscopic state appears static. Conversation forced students to reconcile that equilibrium was represented by the building blocks when the number of molecules remained constant while both the forward and reverse reactions continued. Students reconciled that equilibrium means equal forward and reverse reaction rates. After discussion in lecture, the majority of students showed understanding on the following exam question shown in Figure 5.4 on equilibrium that referenced the building blocks activity.

Assess the following analysis of equilibrium. In your assessment, you must determine what information is correct or incorrect, provide the correct information where needed, explain whether the reasoning is logical or not, and provide logical reasoning where needed.

For a reaction to achieve equilibrium, the forward and reverse reaction rates must be equal. In some reactions, the rates are always unequal so that the reaction cannot come to equilibrium. For example, in the building block activity, the rate of assembly was always slower than the rate of disassembly, so we never achieved equilibrium. This is why weak acids only dissociate a little because the forward reaction: $HA + H_2O \rightarrow A^- + H_3O^+$ is much slower than the reverse reaction, so the reaction cannot reach equilibrium.

Figure 5.4 - Exam question relating to equilibrium with building blocks

Feedback from interviews with students also revealed the building blocks lab to be successful for illustrating equilibrium (these students only did the equilibrium activity, not the kinetics, as that topic came later in the sequence of the semester). Students were able to understand reactions and equilibrium on a molecular level when the molecules were big enough to be in their hands. When asked to respond about the effectiveness of the building blocks lab, one student gave the following response:

“It really helped me understand the equilibrium thing and that it depends on the rate of forward and reverse reactions and the number of reactants...The whole equilibrium thing made sense.”

Both the kinetics and equilibrium activities were performed with 35 secondary science teachers as part of the professional development course, CHEM 570: Nanotechnology for Teachers, at Rice University. The teachers enjoyed the activity and saw its value for illustrating principles of reaction rates, dependence on concentration, and equilibrium. In those curricula where mole fractions are not discussed, the alternative can be to use percentage of particles or refer somewhat loosely to the mole fractions as concentration. In one instance where a teacher from the cohort took this activity back to the classroom, the students found the experience valuable and understood concentration dependence by looking at percentages. That same teacher also noted that the students seemed to gain the most understanding when performing the role as Agitator, as they were able to watch how the reactions occurred. Thus, the ideal would be to allow students to

rotate through each of the roles. Other teachers also planned to use this activity in their classrooms using building blocks or cheaper materials such as paper clips.

5.2.6. Further Student Activities

These building blocks activities could be modified in various ways to look more at reaction rates and equilibrium by starting with differing amounts of molecules or using differing sets of atoms. Enzyme kinetics could be simulated by including another building block piece as an enzyme. Also, other reactions could be performed rather than merely the combination of two distinctly colored bricks. The possibilities are vast and offer an informative way to visualize at the molecular level.

High School Chemistry

This chapter details the study of the impact of professional development for teachers on the high school chemistry classroom. While the fundamentals of science are introduced to students at a young age, it is in high school when most students have the cognitive ability to delve into the abstract world of unseen molecules and forces (Woolfolk, 2010). High school is a prime arena for capturing the hearts of future scientists and creating the basis for a scientifically literate population. Creating quality chemical education in high school is of great importance for the advancement of science and for our society. This study focuses on understanding the high school level implementation of one method for successfully teaching chemical concepts.

6.1. Literature Review

Reform in science education at all levels has been an ongoing effort for decades (USA Research, Inc., 1984). To address the failings of science education, inquiry-based teaching methods have been promoted by the American Association for the Advancement of Science and incorporated into the National Science Education Standards (Minstrell and Van Zee, 2000; National Research Council, 1996). Inquiry-based teaching draws on a constructivist perspective of how people gain knowledge and make it their own through incorporating previous knowledge with new understanding and experiences (Bodner, 1986; Bransford et al., 1999). Unfortunately, most high school science curricula fail to incorporate inquiry-based teaching, let alone focus teaching in ways that facilitate learning (Roehrig and Luft, 2004). High school chemistry courses cover a wide variety of topics using various techniques, dependent often on state, district and school regulations (Deters, 2006; Tai et al., 2006). Multiple studies have demonstrated that students are not gaining conceptual understanding in traditional chemistry classrooms but are still able to successfully complete algorithmic problems (Cracolice et al., 2008; Nakhleh and Mitchell, 1993). This discrepancy has been suggested to be due to a lack of reasoning skills and the limited emphasis placed on developing such skills in chemistry classes (Deters, 2006). While some instructional strategies, such as most inquiry-based instruction, do provide means for improving cognitive thinking, implementation of such methods in high school chemistry classrooms has been limited (Roehrig and Luft, 2004).

The material that is being included in high school chemistry courses has been assessed via surveys from both the perspective of what college chemistry instructors believe should be taught and what high school chemistry teachers actually teach (Deters, 2003; Deters, 2006). Survey data showed that 82% of the 96 professors responding included basic skills on their list of top five topics that would be most helpful for college chemistry students (Deters, 2003). This suggests that a conceptually focused pedagogy that engages students reasoning skills and focuses on understanding rather than memorization would be of great value to high school chemistry students planning to take chemistry in college.

A survey of high school chemistry teachers found that the majority had used at least one inquiry-based laboratory, but 44.5% did not incorporate any inquiry focused teaching methods (Deters, 2006). A different study reported that instructional approaches utilized by high school chemistry teachers did impact college chemistry course performance with those strategies that encouraged peer teaching having a positive association (Tai and Sadler, 2007). More generally, survey data showed that the experiences of students in high school science does affect college science course performance showing a positive correlation with curriculum that focuses on understanding scientific concepts (Tai and Sadler, 2006). The literature implies that the focus of high school chemistry classrooms should shift from covering a great number of topics to focusing on reasoning skills and inciting interest in science, which suggests that inquiry-based methods would be an appropriate pedagogy for such a goal.

Professional development programs for high school science teachers are an active avenue for promoting the use of inquiry in chemistry classrooms. However, multiple studies on such programs have found limited success in teachers' regular implementation of inquiry-based teaching methods (Laius et al., 2009; Roehrig and Luft, 2004). Even those teachers with training in inquiry-based teaching and strong content knowledge did not often or fully use inquiry in their classrooms (Roehrig and Luft, 2004). The impact of professional development on the classroom must be carefully focused, as it has been found that sometimes teachers do not perceive the intended goals (Lotter et al., 2006). There are expert reports on best practices in professional development for high school chemistry teachers (National Research Council, 2009; Sarquis and Hogue, 2008), yet the research on the efficacy of professional development determined by impact on students is limited. One large scale study involving self-reporting via surveys concluded that teachers got the most benefit from professional development that focused on content knowledge, provided active learning experiences, and included curriculum consistent with school-required objectives (Garet et al., 2001). The assumption remains that when teachers benefit, students benefit. Beasley (1992) calls for such a focus on teacher support via professional development, as it is the teacher that ultimately delivers or provides the learning experiences for the students.

6.2. Theoretical Framework

Inquiry-based teaching is based on the constructivist idea of how people learn by creating understanding of new concepts from previous experiences or knowledge alongside current observations (Bodner, 1986; Bransford et al., 1999). One inquiry-based method to teaching chemistry using inductive reasoning is the “Concept Development Studies” (CDS) approach as developed by John Hutchinson and documented as successful for introductory chemistry at the undergraduate level (Hutchinson, 2000). When used at the college level, the CDS approach turns the standard expository lecture into an interactive experience via Socratic questioning based on data and observations. The corresponding textbook of case studies documents how chemical concepts were historically deduced via experimental observations and allows for the integration of concept development in active classrooms and through individual study (Hutchinson, 2007). The CDS approach gives students the opportunity to learn how to think about science by presenting them with foundations of knowledge, then questions about how the world works, and data to analyze that reveals answers to those questions. By guiding students through the analysis of real data, creation of models and theories, and further questions, the continuous cycle of the scientific process is modeled. Students are able to create their own knowledge and confront misconceptions through this progression of understanding principles in chemistry. Students are empowered by the tools of critical thinking, logical reasoning, and analytical skills that are exercised by use of the inductive process inherent to the CDS approach. Students see

how science works and become confident in their own capabilities as they are initiated into the field. Through the CDS approach, students have access to not only the content of chemistry but also the theoretical basis for such knowledge. The CDS approach goes beyond basic instruction in chemistry to allow for engagement in the inquiry of science itself.

The CDS approach was designed to address the failings of the traditional lecture based chemistry classes that focus on rote memorization and non-conceptual problem solving (Hutchinson, 2000). The corresponding text provides a resource for conceptual development via inductive reasoning using experimental observations that is not beyond the understanding of first year college students (Hutchinson, 2007). Students' feedback was very positive, with 90% of students asserting that the case study textbook contributed to their understanding of chemistry (Hutchinson, 2000). More recent pre and post-test data from the CCRT showed improvement of conceptual understanding with the CDS approach, as presented in Chapter 2. While the CDS approach has been tested at other universities, it was designed for the introductory General Chemistry course at Rice University. Integration of this approach and pedagogy at the high school level had not previously been studied. Understanding how this conceptually focused curriculum, interactive teaching style, and true engagement into scientific inquiry can be integrated at the high school level was the ultimate goal of this study.

6.3. Professional Development Setting

6.3.1. Nanotechnology for Teachers

Rice University offered secondary science teachers a one-semester course to encourage the inquiry-based teaching and facilitate in their professional development. The course, CHEM 570: Nanotechnology for Teachers, was funded through the Center for Biological and Environmental Nanotechnology. The two-fold program focused on nanotechnology and the CDS approach during evening classes one night a week during the spring semester and follow-up workshops in the summer and fall. One strand of the course was the presentation of cutting edge nanotechnology based in chemistry, biology, and physics. The nanotechnology research was ongoing at Rice University and presented by the researchers themselves. The researchers facilitated discussion through the use of electronic-response clicker discussion questions during their talks, open forums for questions, as well as time for individual interaction with the teachers. Teachers became students again as they learned the latest technologies and applications in science. They then brought the excitement of nanotechnology back into their classrooms and received inspiration for teaching the basic principles of science.

The other focus of the professional development course was the modeling of the CDS approach by John Hutchinson on essential topics in chemistry. Teachers again played the role of students as Hutchinson lead Socratic dialogue and inquiry into understanding the data upon which foundations of chemistry are based. Topics

included atomic molecular theory, kinetic molecular theory, and chemical bonding. For the majority of teachers, the content was expected to be review; however, the approach to understanding the concepts as based in data and scientific reasoning was novel. Teachers were given the opportunity to be engaged as scientists within the confines of a chemistry classroom and more fully reason through the basic epistemologies of chemistry. Teachers were to come to appreciate the fundamentals of the CDS approach through the modeling of the roles of teacher, guide and scientist.

6.3.2. Study from Previous Participants

Participants from CHEM 570 cohorts prior to this study provided insight on the implementation of the CDS approach and interactive style lecturing at the high school level. A survey was administered to participants from 2007 to 2009 with a 60% response rate. Of the 52 teachers who responded, 94% agreed that the *Concept Development Studies in Chemistry* textbook (Hutchinson, 2007) deepened their understanding of chemistry. Data showing teachers' self-reported use of the CDS approach is shown in Figure 6.1. Almost 80% of the teachers had at least attempted to use the CDS approach, with almost 70% of teachers trying it more than once. Figure 6.2 shows teachers' self-reported changes in their teaching practices as a result of CHEM 570. The majority of teachers reported that they used passive lecturing less often and tried new pedagogical tools more often. The current study finds its basis in the positive response towards the CDS approach reported by past professional development participants.

Figure 6.1 - Responses from 52 previous CHEM 570 participants to "I have used the Concept Development Studies approach in my class"

Figure 6.2 - Responses from 52 previous CHEM 570 participants to "Please indicate which of the following instructional strategies may have changed as a result of your participation in the Nanotechnology Programs"

6.3.3. Houston-area High Schools

CHEM 570 drew participants from as far as 45 miles from Rice University, yet all were considered to be part of the greater Houston area. While each school within each district had its own mode of operation, they function similarly. What follows is the general hierarchy for chemistry classrooms within these schools.

Each teacher generally has his or her own classroom and teaches all but one period each day. Teachers who are also coaches usually teach half the day and share their classroom with another coach/science teacher. The conference period is for lesson planning, meeting with other teachers, and taking care of the high volume of administrative tasks. Traditionally, teachers used to have two conference periods, one for planning with other teachers and one for managing their own classrooms. Teachers ideally meet with their teams on a regular basis. Teams are formed by the classes taught; for example, all teachers for Advanced (Level) Chemistry form a team or all teachers for Honors Chemistry form a team. Each team has a team leader who is responsible for managing the curriculum plans and making final decisions regarding lesson planning. Some teachers teach more than once course, so they are part of more than one team. Some teachers are the only one to teach a course, so they are a team of one.

The teams of teachers combine by subject into departments. Each school has a science department that includes chemistry, physics, biology, as well as any other science course. Some departments also had subsection heads, such as one teacher

who is the lead for chemistry. Each science department had a chair, who was also one of the science teachers, most often one with an advanced degree or extensive experience. Department chairs were responsible for the allocation of resources amongst the classrooms and laboratories. Most of the teachers included in this study only taught chemistry courses (Advanced Chemistry, Honors Chemistry, AP Chemistry), but a few also taught Integrated Physics and Chemistry (IPC) or other science courses such as Forensic Science.

Each school also had an overall administration including a principal and vice principals who oversaw curriculum. Administrators evaluated teachers each semester via short, in-class observations. Administrators could also follow up with teachers to be sure their lesson plans reflected the district requirements and wishes of the department and team. Each district had a set of curriculum standards for each course that aligned with, and was an interpretation of, the state standards. Each district also had science specialists who offered workshops and lesson planning guidance, but each to a varying degree.

6.4. Methodology

6.4.1. Research Questions

This study was built upon two main research questions:

1. How does a teacher implement the CDS approach to teaching chemistry in high school?

2. How does the implementation of the CDS approach to teaching chemistry in high school impact the students?

The first question could be answered via survey and interviews, yet that would only give a self-reported perspective from the teachers. The first question also contains many intrinsic questions within, such as how do teachers translate the material from CHEM 570 into their classrooms, what impediments do they face to such incorporation of new ideas, and is the incorporation of the CDS approach within their current curriculum manageable or must this be an overhaul process? Thus, further methods of data collection were needed.

The second question also has multiple facets, as impact on students can come in many forms. Do students show greater performance in chemistry with the CDS approach? Do students enjoy science more with the CDS approach? Do more students feel capable in science and go on to science related fields? These questions regarding student impact were much harder to answer. The methodologies used, data collected, analyzed findings and conclusions follow in an attempt to answer these two broad research questions.

6.4.2. Participants

Teacher participations for this study were initially identified based on criteria drawn from Spring 2010 CHEM 570 applications and a survey sent to accepted CHEM 570 teachers prior to the start of class in January 2010. Only teachers who were currently teaching high school chemistry were considered. The

initial survey assessed potential participants in their interest in the following areas: introducing new materials in their classes, willingness to try new pedagogical techniques, freedom in planning and designing their classes, openness to being observed while teaching, and their ability and interest in participating in the summer programs. From these criteria, a list of twelve potential participants was generated from the CHEM 570 Spring 2010 cohort. After initial in-person contact, seven teachers from four Houston-area school districts agreed to participate. Also included on the basis of the same criteria were two teachers from previous cohorts of CHEM 570.

6.4.3. Initial Study

The study of the implementation and impact of the CDS approach at the high school level was two-fold. First, teachers must implement the approach. Only then could the impact be observed. Thus, the study began with an initial phase to observe and interview teachers and determine how their current teaching practices reflected the CDS approach or if they were planning to incorporate the CDS approach.

The study included observation and interviews as approved by the Rice University IRB and school district research departments. Both initial in-class observation of the participants and one-on-one interviews were conducted with seven of the teachers during Spring 2010 and the final two teachers during the first few weeks of school in Fall 2010. Classroom observation included silent observation

of the proceedings of multiple classes. Constant field notes of the classroom set up, teaching practices, teaching materials, content, and engagement of the teacher and students were recorded in an ethnographic style during the observation with further detail added to the notes immediately following. Interviews were also performed with each participant using a semi-structured protocol. Interviews were focused on understanding the teacher's perception of the CDS approach and active learning, as well his or her thoughts on implementation of such practices in the classroom. Interviews also included asking the teacher's perception of his or her students' learning in chemistry, the barriers their students may be facing, as well as the barriers he or she may be facing, and all the factors of the classroom as viewed by the teacher. Because interviews gave a teacher's perspective and in-class observation gave an outsider's perspective, both were used to create a more valid interpretation of the level of implementation of the CDS approach in high school chemistry classrooms. Interview and field notes were coded and analyzed according to grounded theory (Strauss and Corbin, 1998).

6.4.4. Case Study

The best method of answering the first research question regarding how a teacher implements the CDS approach in his or her own chemistry classroom is a case study. The research design of a case study provides a means of understanding a situation from the perspective of all those involved (Bornam et al., 2006). This chapter includes the case study of a chemistry classroom in which the CDS approach was implemented. The case study allowed for a fine grain analysis of the

development of the CDS approach and what that meant for the teacher, the students, and the chemistry. Multiple qualitative methods including in-class observation, interviews, and analysis of class materials were necessary to create an in-depth description, interpretation and evaluation of the phenomenon of the CDS approach in high school chemistry.

One teacher did implement the CDS approach starting in Fall 2010 in her Advanced Placement (AP) Chemistry courses. Some changes were also implemented in her Honors Chemistry 1 classes. An in-depth case study with this one teacher was performed over the 2010-2011 school year. Two initial classroom visits and an interview were performed in Spring 2010, prior to her incorporation of the CDS approach. Starting in September 2010 through May 2011, classroom visits were made approximately weekly for a total of 22 visits, 11 each semester.

The teacher taught six of the seven 50-minute periods each day with three classes of Honors Chemistry 1 and three classes of AP Chemistry. Each observation visit was for at least one full class period, but the usual visit was three to four class periods and included lunch with the teacher and her colleagues. Observations were also made during after school laboratory periods. The use of a classroom as a case study allowed for the inclusion of the teacher, the students, the curriculum, and all other variables that directly impacted the classroom. Notes on all of these were made in an ethnographic fashion during the observations and immediately following them.

The case study methodology also lends itself to answering the second research question of determining the impact of the implementation of the CDS approach on students. In-class observation of student discussion, verbal answers to Socratic questions, answers to discussion questions, as well as interaction with the teacher were documented in an effort to capture any impact of the CDS approach implementation. Success of students on chemistry exams, both teacher-made and standardized, as well as other student work, allowed for general comparisons of measures of understanding in chemistry with previous cohorts of students from the same teacher.

All papers and handouts used by the students during observation times were collected, as well as the material on each unit for both courses via the teacher's school website. Informal interviews with the teacher were performed at almost every visit in the classroom during her conference period or after school or during after school monitoring duty. Interviews were not conducted with students or other teachers or administrators, as such was not included in the IRB approved protocol.

The teacher also participated in sharing her use of the CDS approach in two venues outside of the classroom, which were documented as part of the case study. In collaboration with John Hutchinson, this teacher presented a workshop on the CDS approach at a state conference in Fall 2010 (Szymczyk and Hutchinson, 2010). The teacher also presented a lesson she created incorporating the CDS approach to the new cohort of CHEM 570 teachers in Spring 2011.

6.4.5. Limitations

The population studied was very small with only nine teachers including a full case study of one of those teachers. However, the goal of the study was to demonstrate the utilization of the CDS approach with high school curriculum and document the impact of such content and pedagogy. The limitation of a small, self-selected sample is intrinsic to the exploratory nature of determining if this method of teaching chemistry can be successful at the high school level. There was no pressure on the participants to change their teaching practices in ways they did not fully understand or ways they felt to be counterproductive to their goals in teaching chemistry. This study does show the ability of one high school teacher to use the CDS approach and interactive style pedagogy with success, thus future studies could be performed with larger samples and more representative populations.

6.5. Results

Research findings are broken down into two categories: initial study and case study results. While implementation of the CDS approach was not observed in the initial study except for the one teacher that became part of the case study, there was still a wealth of information and data worth reporting from those classrooms without the CDS approach. The case study results will be discussed from the perspective of the setting, the curriculum, the teacher, the students, and the dissemination of the CDS approach. Each of these aspects is a piece of the puzzle that allowed for answers to the main research questions of this study.

6.5.1. Initial Study Results

Nine teachers were interviewed and observed, and only one teacher truly attempted to implement the CDS approach. That one teacher was the participant for the case study, however the information gathered from the other eight teachers was still very valuable for informing the case study, planning for future professional development classes, and understanding chemical education at the high school level in context. Each of the eight teachers who did not use the CDS approach faced different barriers that will be discussed in the following section.

The main barriers faced by each of the teachers who were unable to implement the CDS approach were impediments from the hierarchy of schools, lack of content knowledge, and lack of pedagogical knowledge. Also of interest, while the surveys of previous CHEM 570 were extremely positive, as noted previously, classroom observations were necessary due to the limitations of self-reported data from both surveys and interviews, as has been discussed in previous studies (Roehrig et al., 2007). The survey data was illuminating, yet it did not present a detailed view of how the CDS approach was truly implemented in classrooms on a consistent basis. While this as a finding itself does not answer the research question, it did inform the case study and can help in planning future studies.

6.5.1.1. Barriers from Department, School and District

Each classroom functions in its own way within each school. The ideal is for the school to support the classroom, but often the classroom is limited by the school

system. Four teachers in the sample were severely limited by their department, school, or district.

One teacher with a chemistry degree and education background was one of five Advanced Chemistry teachers at her school, however, she was not the team lead for this course. None of the other team teachers had a background in chemistry. Each week the team met to plan the lessons in coordination with the district requirements. My observations included one of these meetings. The other teachers did not display a firm understanding of the objectives from the district and state standards, and they focused their discussion on whether to give the students complete sets of notes or those with fill-in-the-blanks. Yet, they set the daily lesson plans for the whole team. This teacher gave as much input as would be accepted. All five teachers then taught the same lessons on the same day, only alternating when needed for lab supplies. This teacher had no ability to implement the CDS approach or any of its components within her classroom. When she did add to the team-set minimal lessons, she was reprimanded by the administration.

Another teacher was limited by the lack of support from his school. Despite being in a successful district, his school had too many students and not enough teachers or funding. His classes were overflowing, with students sitting on lab stools because all of the desks were full. He also had no budget to buy supplies for his classroom, as the principal had not allocated funds to the departments. This teacher paid for basic supplies such as scissors, markers and tape from his personal money. The teacher did not have enough lab equipment or lab space for his students to

safely perform labs. While some aspects of the CDS approach could have been implemented without any supplies or funding, the atmosphere of the overfilled classroom with no support was a barrier for attempting novel teaching practices.

Each school is governed by a larger district, and two teachers in the same district faced mandates that cut into class-time and instruction focus. This district required students to prepare for the Texas Assessment of Knowledge and Skills (TAKS) on a daily basis. A supplemental curriculum of PowerPoint presentation and worksheets had been given to all science teachers so that the first 10 to 15 minutes of class was focused on a TAKS concept in biology, physics or chemistry. Thus, no matter the course, any of those topics could be covered. Weekly quizzes were also mandated. One of the teachers in this district was at a school with 50-minute periods, so the TAKS curriculum took 20 to 30% of the instruction time on a daily basis. The other teacher in this district had block schedule with longer periods only every other day, yet there was still impact since two sets of TAKS prep were done at most class sessions. Such a focus on preparation for standardized exam severely limits the amount of class time available for real learning in the objectives for that course. This district also had strict curriculum guidelines that limited the amount of flexibility teachers had in their planning. They were required to submit lesson plans directly linked to state objectives online, and they were assessed by school administrators during evaluation on adherence to such plans. The barriers presented in this district limited the possibility of CDS approach implementation.

6.5.1.2. Barriers from Limited Content Knowledge

Science teacher certification in Texas is almost always composite, which means a science teacher is certified to teach any science course for grades 8 through 12. Thus, it happens that teachers are teaching outside of their field of expertise. Two of the teachers included in this study demonstrated a limited foundational knowledge of chemistry during in-class observations. Each of these teachers' lack of content knowledge manifested itself in a slightly different way in the classroom and inhibited implementation of the CDS approach.

One teacher had a biology background and taught both Advanced Chemistry and Advanced Biology. She was taking CHEM 570 for the second year in a row when observations were made in her chemistry classes. She had encouraged another teacher on her team to take CHEM 570 with her the second time and then the whole Advanced Chemistry team at that school was part of the class the following year. This teacher adamantly supported CHEM 570 and stated that she believed in the CDS approach. However, she felt that approach could not work with her students. In her classroom, the main focus was discipline. She used self-described elementary school tactics to attempt to entice students to behave with little success. She was unable to carry on discussions of chemistry with her students due to both her lack of content knowledge and the lack of discipline in her classroom. Students in her classes did not appear to show her respect or seem to care about trying to learn chemistry. She used the materials prepared by her team for lessons and gave the students the answers rather than asking students to discuss. Observations made

during demonstrations and laboratories indicated the teacher lacked basic understanding of acids and bases, and thus she did not relay the concepts to her students. When the students asked valid questions, she led them astray with completely false statements. While this teacher felt like she was faced with challenges from unruly students, the same population of students stayed much more focused and completed work in the adjacent chemistry classroom. This teacher seemed to have created a wall of defense in classroom management due to her limited chemistry knowledge. The students seemed to be aware of their teacher's weaknesses and took advantage where they could. This teacher had no means of implementing the CDS approach, as she did not fully understand even the most basic content in chemistry and could not manage her classroom effectively even with traditional lecture.

Another teacher also had a biology background and adamantly advocated for the CDS approach. She was very excited to have me observe her classroom and made extra time to give me a tour of the school, introduce me to fellow teachers, and sit down for an extended interview. She was the chemistry lead teacher for her school and was very proud of her classroom and teaching. This teacher also served as a coach, so she only taught science in the morning. She planned to take the *Concept Development Studies in Chemistry* text (Hutchinson, 2007) and incorporate it into a text with images and figures in the future rather than use it in tandem with a traditional text currently. She seemed to focus on the CDS approach being solely about the book and not about active learning. She did feel her teaching style was

active due to her regular use of a Smart Board, yet observations showed otherwise. The teacher conducted class in a dark room while sitting in the back behind all the students. She asked questions of the students often, but they were direct fact-based questions rather than discussion-focused questions. She did not foster understanding but focused on getting the right answer. She was constantly talking to the students yet lost their attention quickly. Over two consecutive class periods, she presented inaccurate material to students regarding the concept of the mole. Due to multiple mistakes, which she read from her prepared PowerPoint presentation over both class periods, she did not seem to realize the errors. This teacher did not seem to know the limits of her own understanding of the content. Her implementation of the CDS approach was limited due to her need to drastically manipulate the text before she could use it, but implementation would have been impeded by her focus on getting the right answer and learning facts rather than understanding concepts.

Other teachers included in this study did not show such obvious examples of limited content knowledge, although most of them did appreciate the refresher of General Chemistry included within the CHEM 570 course.

6.5.1.3. Barriers from Limited Pedagogical Knowledge

There were three teachers observed in the initial study who seemed to have strong content knowledge yet limited pedagogical knowledge. Prior to becoming teachers, each of these individuals had been trained in another profession:

engineer, health care professional, and scientist. They were certified as teachers via alternative certification routes. While other teachers in the sample also had other careers and came to teaching via alternative certification, observations of these three indicated a lack of skill in classroom management and minimal understanding of how people learn.

One of the teachers who demonstrated limited pedagogical basis had a great background in chemistry, self-professed his passion for teaching, and taught at a well-recognized school. The only observed means of teaching was via PowerPoint presentation and YouTube videos, yet he stated that was a regular day for his classes. In presenting a new topic, he provided students in inappropriate mnemonic devices and encouraged them to come up with their own. Thus, the whole focus of his class became vulgar phrases rather than the concept at hand. From the students' initial reaction to the teacher, this was not the first time he had shared such crude techniques with his students. While mnemonic devices can be very helpful, teaching trick phrases as concepts are initially introduced indicated a lack of understanding on the teacher's part of the need to assist students in constructing knowledge. He also demonstrated an insensitivity to appropriate language for use with minors and disparaged historically significant scientists in these comments.

Another teacher with great credentials at an outstanding school also managed her classroom in a way that indicated a lack of pedagogical skill. This teacher had taken CHEM 570 the year before and participated in workshops since taking the course, indicating an outspoken adherence to the CDS approach. She had

her classroom set up in a very traditional manner, rows of desks facing the front of the room. She assigned an additional worksheet when she felt students had not mastered the previous material rather than discussing the concepts. She lectured via a PowerPoint presentation that gave the essential formulas, quickly working through a sample, and then requiring silent time for the students to work individually. When she asked for students to give answers, she was rude to students with incorrect responses. She would not let students be excused to the restroom, despite valid reasons. She did not create an environment conducive to learning. The classroom was across the hall from a fully equipped laboratory, however she only had students perform one laboratory the whole semester. She also avoided doing demonstrations due to having to plan beforehand to get materials from across the hall. She spoke in a demeaning manner towards her students because they were in the Advanced Chemistry rather than the accelerated Honors Chemistry course. This teacher did not see her classroom from her students' perspective and did not understand that asking students to give their numerical answers did not qualify as Socratic questioning. Implementation of the CDS approach was not achievable with this teacher having a limited understanding that learning is more than memorizing algorithms.

The third teacher who showed the need for greater skill in the classroom also showed great initial potential. He taught at a school that was working hard to improve its academic image, thus he had access to resources for his classroom and laboratory. Classroom observations indicated that his schedule of lesson plans was

often updated or changed due to assignments, projects and labs frequently taking longer than planned. The students were involved in a project or lab during most of my observations, but they often seemed unsure of what to do and lacked direction. Rather than providing further direction, the teacher would verbally discipline students. Thus, students would continually get off task and non-completion of work was a constant issue. This teacher did not know how to effectively manage his classroom, as was exemplified by him getting in a screaming match with one of his female students. Despite his best intentions to get his students actively engaged in the content, he did not structure his classroom or provide adequate instructions to allow his students to be successful. The CDS approach, if attempted, would have been undermined by the inability to plan appropriately and keep students on task.

Each of these three teachers had different struggles from not using appropriate teaching practices, not providing appropriate feedback for students, and not providing appropriate direction. All of these were barriers to any true implementation of the CDS approach.

6.5.1.4. Need for Interviews and Observation

While the survey data from previous CHEM 570 participants showed high use of the CDS approach, visiting classroom was not as encouraging. Survey data is intrinsically limited due to the nature of self-reporting. However, in-class observation scheduled with the teachers has a caveat, as well. If scheduling a specific time with teachers for observation, one would expect that to be the most

probable time for a teacher to demonstrate success with active learning and inquiry. Yet, active learning and inquiry-focused lessons were not often observed even during scheduled observations.

One teacher from a previous CHEM 570 cohort who was included in this sample expressed that she had changed her teaching practices during a workshop at Rice University. She stated that she was teaching in more conceptual manner, motivating students to learn, and her students now felt like they were the ones leading the class. However, during scheduled observation none of these claims were visible in her strictly managed, rote-focused classroom.

Another teacher exemplified the fact that interviews are also insufficient as lone sources of data. In discussing his background, he indicated his passion for teaching had led him to leave his first career. He had also had experience teaching in multiple venues; thus, he seemed to be a knowledgeable and motivated teacher. He kept a minimal classroom, with conflicting schedules for the week on two separate boards. The periodic table was falling off the wall. He shared no enthusiasm or interest in the subject matter with his students. He did have the buckyball model he had received in CHEM 570 on display, yet he had not told his students what it was or shared its significance. The same teacher seemed like someone different between the interview and the in-class observations.

These findings highlight the necessity of multiple methodologies when attempting to answer a broad research question in education. Surveys and

interviews alone are insufficient to understanding the happenings of a classroom. Observation alone would also be insufficient, as without talking with each of these teachers mentioned, there would be no indication of the teachers perceiving themselves as passionate, motivating or using active learning.

6.5.2. Case Study Results

Observation of students taking on the challenge of thinking in science and being empowered by the idea that they could create sound scientific theories and models was documented within the case study of a single teacher. The case study teacher incorporated the CDS approach in both her Honors Chemistry 1 and AP Chemistry courses, yet the degree of implementation differed between the two. The changes made within each curriculum will be discussed alongside the observations made of the teacher, the students and their reactions to the courses. This view allows for the first research question of how the CDS approach can be implemented and some answers to the impact of the implementation of the CDS approach on students. The impact of the changes on the teacher, as well as how the teacher shared the experiences provided insight on the first research question of how the CDS approach could be implemented. The case study incorporated the school environment, which sheds more light on how this teacher succeeded due to the setting while also overcoming barriers.

6.5.2.1. The Case Study Setting

The case study teacher had a bachelor's degree in Chemistry and a Masters of Education. She started her teaching career in a Houston area school, and the case study took place during her 6th year of teaching at that same school. The teacher had a passion for teaching that was observed by her classmates and professors while she was in college, and she was encouraged and excited to go into teaching. The dual background of content and pedagogy along with the motivation for teaching made this teacher well-equipped for the chemistry classroom.

The teacher managed her classroom avidly, with regular systems of distribution of assignments to the students in the class and online, consistency in posting and meeting daily objectives in "learning, language and activity," and focus to keep students on task during class. Her organization of the materials allowed her class to be efficient and productive. Students were rarely disruptive, as they always knew what was expected of them. The teacher also had organized systems in place for laboratory procedures, whether held during class or after school. Formative assessments were also used regularly via individual student dry erase boards to show results, diagrams or answers and colored-cards to respond to questions in class.

The classroom was a recently remodeled space with a full-sized class area furnished with 14 small tables that each seated two students. Additional desk seating was available for to accommodate the up to 32 students in one of the Honors

Chemistry 1 courses. Beyond the well-designed classroom with a projector system, plenty of white boards, and space for students was a fully equipped laboratory area with seven lab stations. Each lab station had a computer for data collection with Vernier instruments and outlets for natural gas. The laboratory was well-stocked with supplies and was conveniently designed for both the teacher and the students.

The students in Honors and AP classes were all being tracked to go to college and had personal goals to go to highly ranked colleges and universities. The vast majority of the students within the case study were Asian, followed by white students and only a minority of black or Hispanic students. The proportion of females and males was approximately equal in most classes in the case study. Exact percentages were not calculated due to the changes in class rosters over the first month of school, changes at the semester break, and the commonplace absences of students due to illnesses or school activities. All students in Honors Chemistry 1 could have taken an Advanced (Level) Chemistry 1 course, yet elected to take a more challenging course that also offered a higher GPA incentive. The case study teacher and one other teacher offered the only Honors Chemistry 1 courses with an aligned curriculum they co-developed. The case study teacher was the only teacher offering AP Chemistry. All students in AP Chemistry had successfully completed Chemistry 1, and most students had taken the honors version of the course.

The Houston area school was a large, high-performing, comprehensive high school in an affluent area. The school had garnished an outstanding academic reputation in the area under the direction of its longstanding principal. However,

during the 2010-2011 academic year of this case study, a new principal had just taken over the school's administration, and the school culture was in flux due to the cancellation of all but three faculty meetings during the year and stresses of budget cuts within the district. The school placed a great deal of emphasis on students taking AP courses and doing well on AP tests, which indicated the school's focus was on getting students into good colleges.

6.5.2.2. Transformation in Advanced Placement Chemistry

From the 2009-10 school year, the AP Chemistry program had grown from 25 students to over 80 students initially enrolled in 2010-11. While the enrollment dropped to less than 60 students, the growth was still tremendous and required three sections of AP Chemistry. The case study teacher had taught AP Chemistry the year before and was excited for the growth. She did not mind the initial attrition, as she felt and heard from students that AP Chemistry was the hardest course offered at the school. However, students were being strongly encouraged by the school to take as many AP courses as possible. This teacher taught a very rigorous course and had a history of success with the AP format. The curriculum was based on the AP Chemistry requirements (College Board, 2012). Three sections of the course were offered, along with three days of after school laboratory. Each student was required to select one day a week to stay after school for laboratories that were based on the designated AP curriculum.

During the summer before the 2010-11 school year, the teacher started the transformation of her version of the AP Chemistry curriculum to incorporate the CDS approach. She incorporated the CDS text (Hutchinson, 2007) into her lesson plans and rewrote the notes she provided to her students in order to align with the CDS chapters. She rearranged the initial portion of the course on reactions and revised the first four units of the course, which went through mid-October. The chapters of the CDS text that were incorporated into the course as required reading were “The Atomic Molecular Theory,” “Relative Atomic Masses and Empirical Formulae,” “The Structure of an Atom,” “Quantum Energy Levels in Atoms,” and “Energetics of Chemical Reactions” (Hutchinson, 2007). While some students ordered a copy of the printed text, all students were able to read the chapters as files available from the Connexions website and the teacher posted the updated versions of each chapter even prior to their published availability (Hutchinson, 2012).

The AP Chemistry students took on the challenge of reading the college level text and were observed discussing it in class. The most common daily “language” objective posted on the board was, “TSW (the students will) speak in class discussion.” Students were held accountable for the reading by regular questioning in class. The teacher incorporated Socratic questioning by posing questions to students, not only to describe the data presented in the reading, but also so students could explain the observations. Students were able to successfully meet this expectation and orally provided scientific reasoning for observations. The teacher

focused on guiding the students to explanations by providing the premise, showing data if necessary and asking leading questions to promote critical thinking. When students responded incorrectly, she continued questioning by incorporating more ideas from other students until the class self-corrected the misconceptions with scientific reasoning. She encouraged students to challenge their own ideas and hardly ever answered student questions with actual answers. She instead turned student questions back to the class for further discussion. Generally, students were active in discussions and were able to share relevant thought processes and lines of reasoning verbally. While not every student responded orally each day during observation, the teacher did have regular participation from most students. Some students did respond regularly, while the teacher also called on the less verbal students.

Incorporated within each discussion, the teacher had both prepared and spontaneous opportunities for students to engage in think-pair-share, respond to multiple-choice questions with colored cards, or provide responses on individual dry erase boards. All students were required to participate in these questions, which were often ones aimed at confronting commonly held misconceptions. Students were encouraged to answer and taught that wrong answers were okay as they provided good learning opportunities for the class. Students saw that assessing each others' answers enhanced analytical skills. The teacher used these full-class response questions to springboard further discussion and provide a means of

formative assessment in order to gauge how well students were understanding concepts.

The lengthy class discussion time was mostly observed during the first few months of the school year as the teacher was implementing the modified curriculum. During these discussions, the students exhibited reasoning skills and the ability to think in science. After that time, the teacher reverted to using the previously prepared curriculum due to a lack of time to continue modifications. Without the modified curriculum, the teacher relied more often on lectures with PowerPoint. However, she continued to use think-pair-share, colored-card response questions, and dry erase boards to supplement her lectures with active learning. She had also already created an atmosphere of understanding why and providing explanations for observations. Thus, even though the course readings were no longer focused on inductive reasoning from data, students continued to have opportunities to discuss the basis of chemical understanding and lectures were focused on such. The basis for understanding chemistry as science and the creation of models to explain phenomena rather than chemistry as a set of predetermined facts was a culture created by the teacher's initial implementation of the CDS approach.

Throughout the school year, the teacher promoted student understanding rather than simply problem solving skills. Students responded by providing more in-depth answers to practice AP questions than the teacher had seen in previous years, asking questions beyond the scope of a introductory college-level chemistry

course, and explaining how to solve problems in unique and valid ways without formulaic processes. The success of the students of teacher-created assessments was unable to be compared to previous years, as the teacher did not maintain old grades. However, she did note that she saw increased reasoning skills and performance on free-response questions. Students did successfully learn chemical concepts within this implementation of the CDS approach. The AP Chemistry Test average remained high with the 25 students in 2009-10 achieving an average score of 4.67 before the implementation of the CDS approach and the 49 students who took the test in 2010-11 obtaining an average score of 4.49. Both averages demonstrate the high quality of the AP Chemistry course over both years. The case study teacher expected the slightly lower average for double the number of students due to her perception that not all the students enrolled in 2010-11 should have been taking AP Chemistry, yet the school offered not other second year option for chemistry.

Overall in the course, the students were very engaged, motivated, and exhibited an interest in science. The teacher's commitment to her class was obvious to the students. The students seemed to enjoy the class and would often come early or stay late. They responded well to her during the full implementation of the CDS approach as well as beyond the use of the CDS text by continuing with the mindset of a goal of understanding the science throughout the school year.

6.5.2.3. Modifications in Honors Chemistry

The case study teacher implemented the CDS approach in her three Honors Chemistry 1 courses at a different level. The teacher felt that the CDS text was too challenging for students in their first course in chemistry and decided it was more beneficial to have discussions regarding scientific reasoning than require the CDS as reading. She used the same physical curriculum components that she and her team teacher had created over the past few years and modified her approach.

She described her change in the classroom as a reversal to provide “data first.” Rather than doing a demonstration after lecture to show a concept in action, she would present the demonstration first so that the students could determine the concept from their observations. Rather than using the notes she provided students as the support for students during lecture, she lead class discussions and provided the notes as a summary. She asked students to recall their prior knowledge in science and make predictions during discussions in order to engage them as scientists. Similar to her approach in AP Chemistry, she challenged her students regularly with questions regarding explanations of concepts. While the concepts were simplified as appropriate for a first year course, the teacher did incorporate inductive reasoning via questioning during lectures on a regular basis. She modeled to students how to use observations to come to ideas, models, and concepts in chemistry, and then asked them to do the same. She often incorporated analogies or stories in her explanations of concepts. The use of think-pair-share alongside

colored-card and dry erase board student responses were also implemented regularly.

Less time was spent on class discussion in Honors than in AP, yet the Honors students also participated in more hands-on activities, guided practice, and group work. Students were regularly engaged in the inquiry of science, although it was not always through discussion. The teacher provided more structure for the students during these activities and more closely monitored during think-pair-share time to make sure their discussions stayed on topic. The Honors stated language objective was more often, “TSW listen to lecture.” However, straight lecture without the incorporation of active components was rarely observed for more than ten to fifteen minute stretches. Even during these stretches, students quickly lost their focus and many would seemingly disengage despite the teacher’s entertaining lecture style. She usually quickly noticed the loss of student attention and addressed it with individual student or full-class questions.

The teacher described the changes in her Honors Chemistry courses as a gradual integration of the CDS approach. She felt she was doing what she had always done, yet in a slightly different order. Her already high-quality course was infused with the idea that students can and should focus on understanding the science behind chemistry by interpreting data. The students became able to explain observations and data more easily and thoroughly as the year progressed, and they became initiated into the field of science. They seemed to feel able to meet the challenges of thinking in science and found success in chemistry.

The teacher discussed student performance in comparison to years past, yet she did not have previous scores for quantitative comparison. She did state that students seemed to perform as well or better than in the past. She did not have to retest students on normally troublesome topics, most notably the concept of the mole. The case study year was the first time she had not given a make-up test due to poor overall performance by students on the first mole test. This antidotal evidence does suggest the “data first” implementation of the CDS approach was successful for Honors Chemistry 1. Further data on how many students continued from Honors Chemistry 1 into AP Chemistry, as well as other measures of success in science and chemistry, were not available.

6.5.2.4. Impact on the Teacher

The case study teacher expressed a desire to implement the CDS approach in her Honors and AP Chemistry classrooms. Due to her freedom to define what she taught on a day-to-day basis and how she approached each topic, she did have the ability to make changes to her curriculum. She stated that the biggest challenge of any professional development for teachers was being able to bring ideas to the classroom in a format that could be used. She addressed this challenge from CHEM 570 by spending time over the summer in 2010 to revise her AP curriculum. Her modifications to the Honors Chemistry curriculum were a more subtle incorporation by a revision of the order of presentation of the ideas. She focused on the “data first” in her Honors courses without needing to revise the materials she provided to the students.

The revisions to the AP curriculum took a great deal of time, and she was only able to update the first four units of an 18-unit course. Once the school year started, the high demands on the teachers' time left her unable to continue to revise the curriculum. She initially expressed disappointment that she was unable to revamp the whole course, as she felt the payoff of the implementation of the CDS approach was worth the investment of time. She felt rejuvenated by the approach and saw her students improving in their understanding of concepts and ability to approach problem solving. Despite her desire to completely overhaul the course in order to fully implement the CDS approach, the teacher was overwhelmed by the administrative and teaching duties required of her by the end of October. She had received no recognition for the improvements she had made in her courses and her motivation to continue had decreased. Her AP class did continue with a focus on understanding scientific reasoning, but she also relied on lecture rather than class discussion more often than during the initial months of the school year.

6.5.2.5. Dissemination of the Implementation

The teacher shared her implementation of the CDS approach in multiple venues. She presented her incorporation of the approach alongside Hutchinson to fellow chemistry teachers at a conference (Szymczyk and Hutchinson, 2010). She also returned to CHEM 570 as a guest speaker to share how she had used the professional development in her own classroom. During both presentations, she highlighted her idea of presenting data to the students first and guiding them through constructing the scientific concept. Her main illustration was the use of

cheese sandwiches as an example from which students could come up with the Law of Multiple Proportions. The bread and cheese slices model the idea that compounds are made of particles of definite mass. She shared her experiences with students having trouble understanding or even remembering the Law of Multiple Proportions. Yet with the use of her cheese sandwich data as an introduction, students were able to translate the knowledge in their own minds and apply the Law of Multiple Proportions to chemistry, as well.

6.5.2.6. Barriers from a Good School

Despite the amazing classroom and laboratory space, the availability of supplies, and the autonomy in creating a curriculum, the case study teacher also faced barriers in her implementation of the CDS approach. Managing the grading for six classes with only one conference period put a great deal of strain on the teachers' time. The lack of time made it impossible for her to continue to revamp her curriculum after the school year had started. Preparing for, monitoring, and grading the laboratories for the AP students also required a great deal of time and effort for the teacher, especially since the labs were held after school. She received a minimal stipend for teaching after hours, yet she did not feel the compensation was proportionate to the effort required.

Other factors from the school environment also presented challenges to the teacher. Technical difficulties and increased administrative duties for teachers took time away from her ability to innovate in the classroom. The teacher was also very

isolated from the rest of the chemistry team besides the one other Honors Chemistry 1 teacher. She received no recognition for the changes she made to her curriculum, thus she did not feel validated enough to disseminate her experiences within her own department or school.

Despite the strains on her time, the barriers she faced, and the lack of recognition for her hard work, this teacher continued to strive to improve her chemistry courses. However, towards the end of the school year when teacher morale was at a low due to teacher layoffs, this teacher took the opportunity to interview for a job outside of the high school classroom. Despite not wanting to leave the students, the teacher accepted a job with Rice University as part of the team that teaches CHEM 570. While her implementation of the CDS approach would no longer be continued in her own classroom, she would have the appropriate time and resources to innovate and incorporate the CDS approach by writing and sharing lessons with other high school chemistry teachers.

6.6. Conclusions

This study of the impact of professional development on high school chemistry classrooms presents a varied set of conclusions. First, the impact of CHEM 570 was minimal on most classrooms due to the barriers faced by teachers from their own limited content knowledge, their own limited pedagogy knowledge, or their school environments. Professional development programs should be able to

address the first two barriers, but there are many hurdles to correcting all of the issues presently facing American public education.

Another limitation is that the first full school year of implementation of the new teaching practices may not be the best implementation of these new practices and may limit findings as reported by previous studies that track changes in student performance due to teacher development (Silverstein et al., 2009). Subsequent years may have shown greater success with these methods if this study could have been continued beyond 2011 for the initial cohort.

The case study did demonstrate that the CDS approach could be integrated into high school chemistry classrooms at varying levels with success. In both the AP Chemistry classes with an initially full implementation of the CDS approach to the Honors courses with a “data first” perspective, students were observed discussing chemical concepts on a regular basis. The positive impact on students was not quantified, but the observations suggest students were able to participate in scientific reasoning, were engaged in science, and enjoyed the process of constructing knowledge in chemistry. However, after the first year of attempted implementation, the teacher left high school to disseminate her experience to other teachers through CHEM 570.

6.6.1. Need for Professional Standards

The multitude of barriers faced by high school teachers and students today is tremendous. Schools should be held to basic standards that allow for appropriate

class size, funding for necessary supplies, and proper administrative support. Teachers should also be held to high standards. Teachers should only be teaching subjects that they are qualified to teach. Composite science certification should truly mean that a teacher has a broad and deep knowledge base of chemistry, physics and biology. If teachers do not have the content knowledge, students are limited. However, teachers need more than content knowledge alone. Teachers need to understand how students learn and be able to practice pedagogical methods. Teachers should understand and be able to manage the classroom in a way that promotes learning and does not distract from instructional opportunities. Students need clear directions and expectations in order to succeed.

6.6.2. Need for Professional Development

This study highlights the need for applicable professional development for teachers, especially science teachers. Many science teachers are not prepared or equipped to successfully guide students to a proper understanding of science. They themselves may be unaware of the true epistemologies of science, or they may not know how to share their knowledge with students. Professional development that enhances content knowledge and demonstrates appropriate pedagogical methods can go a long way to improving science education if teachers can successfully translate the ideas into their classrooms.

The case study teacher left the high school classroom in order to provide this translation ability for other teachers. She now leads CHEM 570 alongside professors

at Rice University. She takes her experiences as a high school teacher and draws on her implementation of the CDS approach to create cohesive lesson plans for teachers to take directly to their classrooms. She aligns these lesson plans with the state mandated curriculum but also with her knowledge of how students learn and the dynamics of the high school classroom. She is able to synthesize the content, focus on inquiry learning, and provide the practicality necessary to make it work in order to create usable CDS approach lessons.

In one sense, the case study was a great success, as it highlighted the efforts and accomplishments of the teacher in a way that allowed her to be asked to take on the role of instructor for CHEM 570. Her demonstration of success with the CDS approach in high school in her own classroom and ability to now share her experiences with many Houston area chemistry teachers will positively impact numerous students in their science education.

Conclusion

The body of work represented in this thesis includes advancements in teaching chemistry at a conceptual level in multiple avenues. Each of these projects was based on the theoretical framework provided by constructivism and reflects advancements in teaching chemistry that allow students to construct their own knowledge. The fundamental principle of constructivism is that people learn by connecting previous knowledge and experiences with new observations in a social setting (Bodner, 1986; Bransford et al., 1999; Woolfolk, 2010). This central idea that students must build upon their existing knowledge base by incorporating new ideas as their own is the motivation behind active learning pedagogy and inquiry-focused teaching (Felder et al., 2000; Michael and Modell, 2003). Chemical education teaching practices were advanced by my work in the areas of measuring understanding, actively engaging students, providing beneficial lab experiences, and

improving high school chemistry. Future work and further implementation of my findings will be continued through various avenues. The following sections will summarize my conclusions in each area of study, as well as the continuing impact of my findings.

7.1. Chemistry Concept Reasoning Test

There had been multiple calls for a concept inventory in chemistry, yet no standard exam has been agreed upon (Nurrenbern and Robinson, 1998; Mulford and Robinson, 2002; Krause et al., 2004). None had been provided that filled the need for assessing conceptual reasoning in chemistry. The creation and validation of the Chemistry Concept Reasoning Test provided the chemical education community with an easy-to-administer tool for measuring conceptual understanding and scientific reasoning of fundamental chemistry topics (Cloonan and Hutchinson, 2011). This tool assesses students' ability to construct knowledge of chemistry with challenging conceptual questions in a multiple-choice format. The CCRT is currently being used at Rice University with science teachers enrolled in CHEM 570 and CHEM 570, Teaching Chemical Concepts via Inquiry, to determine initial content knowledge and improvement from the course. Also at Rice University, the CCRT may be used to help incoming students determine which level of chemistry to choose as their first course. The CCRT also serves as a basis for future development of a larger bank of questions. The multiple-choice formats for "assess the accuracy" questions and "select the correct assessment and reasoning" questions provide examples for

making similar questions on other topics or ideas. The CCRT provides a tool and format for instructors to determine if their students have successfully constructed knowledge in their classes. With this assessment available, instructors can determine the need for curricular changes and measure the impact of such changes. Multiple professors across the world received copies of the CCRT and have used it in different ways, whether as a pretest for incoming students or discussion questions in class.

7.2. Silent and Vocal Students

The study of silent and vocal students in General Chemistry provided insight on the engagement and motivation of students in their learning. While both silent and vocal students were engaged by the active learning format of the class, vocal students outperformed their silent counterparts on quantitative measures of understanding, including the CCRT. While active learning is an avenue to constructing knowledge, students must actively participate for the greatest benefit. The structuring of the class allowed for students to choose to participate, while motivating them to do so with grade incentives. While the silent students did perceive the active learning atmosphere as beneficial, the vocal students showed greater improvement. This is an example of the difficulty in creating class experiences that allow for students to construct knowledge. Even if such experiences are available, not all students will take advantage of the opportunities. Based on the findings of this study, the format for General Chemistry at Rice

University is being changed in Fall 2012 so that all students are required to participate. The format will be reorganized from an instructor-guided Socratic dialogue infused with full class discussion questions to a small group guided-discussion of instructor posed questions infused with full-class discussion questions. The new approach is called Student Centered Active Learning at Rice (SCALAR) and its structure is similar to the approach used by others (Belcher, 2001; Gaffney et al., 2008). Students will sit in groups of three at round tables that seat nine. The instructor will provide reading assignments to be completed prior to class and an initial foundation at the start of class time. Students will then work together to discuss questions provided by the instructor. Such questions will focus on the analysis of data, interpretation of observations, and building of models. In these small groups, each student will be able to verbalize his or her thoughts and build his or her knowledge. The SCALAR format deliberately requires that all students participate and motivates students to come to class prepared and able to contribute to discussion. The impact of this curricular change will be assessed with the CCRT, surveys, and other means of student feedback. The findings of my research on silent and vocal students have guided this change, have established a baseline for understanding the impact of this change, and will also inform the broader chemical education community upon their release in publications (Obenland et al., 2012a, 2012b).

7.3. General Chemistry Laboratories

My research related to the General Chemistry Laboratories at Rice University has also advanced the idea that students must construct their own knowledge in order to gain understanding. Through each phase of this study, it was apparent that students must be explicitly required to think about chemistry, even within hands-on engaging activities such as laboratory work. While the nature of labs seems intrinsically inquiry-focused, more than physical manipulation is necessary for students to think or construct knowledge. Traditionally structure labs were not providing educationally rich experiences for students. The reformatting of the labs specifically and intentionally required real student preparation and predictions, forced data analysis and interpretation, and allowed for discussion sessions with reflection and social construction of knowledge. The labs became a place for learning chemistry. The three-year process of understanding the students' perspectives and making a class format to insist that students think will continue. In Fall 2012, the longer labs every other week with discussion sessions will continue. The format of the discussion sessions will be more uniform across sections and build upon the best practices from Spring 2012. While fewer labs can be included, the selection was carefully done to provide students with optimum chances to collect data that will allow for discovery within the lab. My research has allowed for these intentional changes in the lab that carefully structure real learning experiences so that students can construct their own knowledge in chemistry.

The novel general chemistry laboratories that I created and published are examples of experiences that allow students to construct understanding of the chemical concepts of equilibrium (Cloonan et al., 2011a, 2011b). When these labs are used in the format presented, they allow students to discover the concepts exemplified by the data. While these were both incorporated into the CHEM 123 and CHEM 124 curriculum prior to the final phase of implementation, the incorporation of these labs alone did not fundamentally change the experiences of the students. These were experiences designed around the idea that students could observe and collect data to construct ideas about equilibrium. However, more than just a good lab is necessary for this to actually happen for most students. The traditional format of the lab allowed for reporting data with little interpretation; thus even these discovery-based labs could be performed without students building knowledge. The structural change of the labs was necessary to deliberately engage students in the activities required to build knowledge. While I feel the novel labs are great labs, to truly be successful in furthering students' understanding, they must be implemented in intentional ways where students reason through the data, come up with their own interpretations, and make meaning from observations.

7.4. High School Chemistry

My research on the implementation of the CDS approach in high school chemistry classrooms revealed both encouraging and discouraging conclusions. Teachers must have a minimum of good content knowledge, appropriate

pedagogical skill, and an adequate school environment to be successful in incorporating the CDS approach. Beyond those basic requirements, teachers must also be highly motivated to design and structure deliberate changes within their classrooms. While only one teacher was found able to truly implement the CDS approach, her implementation was successful. She carefully restructured her AP Chemistry course and reformatting her Honors Chemistry course to give students the data first. Then she used Socratic dialogue and discussion questions with white boards and colored card responses in addition to her traditional curricular tools. On a regular basis, it was apparent that she was providing opportunities for students to build their own understanding. This intentional focus on active learning and inquiry alongside presenting data first provided an atmosphere of students constructing knowledge. Despite the case study teacher leaving the high school classroom, she will continue to impact high school chemistry classes through her role as instructor of CHEM 570 and CHEM 571, Teaching Chemical Concepts via Inquiry at Rice University. Through this role, she has added to the professional development by creating detailed lesson plans of the CDS approach. She demonstrates these lessons to the teachers in the course alongside presentations of how General Chemistry at Rice University has been taught with the CDS approach. The lesson plans and interactive classes give teachers detailed guidance that should allow for greater implementation within their own classrooms. The deliberate lesson focus of getting students to discuss data in order to make meaning from their observations demonstrates the constructivist philosophy of teaching. Because of the

disappointing findings of my study, except in the case study, the CHEM 570 program was expanded into a two-semester course that follows a week-long summer conference, starting in the 2011-2012 school year. Changes in the program were implemented to improve the quality of professional development and the likelihood of positive impact on students. Studies have been continued by the Rice University School Science and Technology Program (SST) to determine the impact of CHEM 570 and CHEM 571 on teachers and their students. The SST has also expanded their scope of professional development to offer similar courses for physics and biology teachers, creating the Rice Excellence in Secondary Science Teaching program (RESST). Starting in 2012-2013 school year, the RESST program will partner with the Houston Independent School District to offer professional development to all district science teachers over the next few years.

7.5. Academic Future

Throughout each of these projects, the framework of constructivism is evident as best practices in chemical education were furthered. Alongside my pursuit of chemical education research, my personal academic goal in my graduate education has been to develop my own repertoire and abilities as a chemistry teacher. My research focus is analogous to this personal goal, as it has been on developing best practices for helping students construct a conceptual understanding of the basic principles of chemistry at the high school and introductory college level. Young adults are at the formal operational stage of development when they attain

the intellectual capability to grasp abstract ideas (Woolfolk, 2010), which are abundant in introductory chemistry. The initial forays students have into the field of chemistry are extremely critical to whether students maintain an interest in science or decide to leave science to others. Capturing this audience by presenting them with experiences of truly being involved in science, actively understanding chemistry, and constructing their own knowledge will increase the likelihood that more students will pursue and enjoy science in the future. I will continue to pursue my goal as I become a high school chemistry teacher and put to use my depth and breadth of knowledge in chemical education with my own students in the Houston Independent School District at the High School for the Performing and Visual Arts.

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Appendix A

Chemistry Concept Reasoning Test – Version A

1. In the pictures below, solid circles ● represent atoms of element X. Hollow circles ○ represent atoms of element Y. Molecules are represented by adjoining circles; for example, X_2 is . Which equation best describes the reaction shown below?

- a. $X + 3Y \rightarrow XY_3$
- b. $X_2 + 3Y_2 \rightarrow 2XY_3$
- c. $X_2 + Y_2 \rightarrow XY_3$
- d. $4X_2 + 12Y_2 \rightarrow 8XY_3$
- e. The correct equation is not given.

2. If the same reaction as in Question 1 were modified by adding excess X so that the first part of the reaction looked as pictured below, which of the following pictures would best complete the sequence?

a.

b.

c.

d.

e. The correct picture is not given.

3. Amadeo was studying the formation of water. He weighed 10 liters of oxygen; it weighed 10 grams. After reacting the oxygen with an unlimited supply of hydrogen, he was surprised to find that 10 liters of water vapor at the same temperature and pressure as the pure oxygen weighed only 5.6 grams. How could water contain oxygen but weigh less than oxygen?
 - a. Some fraction of the oxygen did not react, because hydrogen was the limiting reagent. The unreacted portion was not weighed in the product.
 - b. The reaction did not go to completion, but instead achieved equilibrium.
 - c. A molecule of water contains only one oxygen atom and therefore weighs less than an oxygen molecule.
 - d. There is much more space between the water vapor molecules compared to oxygen. Therefore, the same amount of water vapor is less dense.
 - e. Hydrogen is a lighter gas than oxygen, so when it binds with the oxygen, the resulting water vapor weighs less than the oxygen itself.
 - f. By the law of conservation of mass, this is only possible if some of the hydrogen or oxygen were lost during the reaction.

4. What is the significance of knowing the number of moles in a given sample of a substance? In other words, why do you try to determine the number of moles?
 - a. If we know the number of moles, we have effectively “counted” the particles.
 - b. If we know the number of moles, we can determine how much of the substance is left over after a reaction.
 - c. If we know the number of moles, we can determine how much mass is present.
 - d. Knowing the number of moles allows for a convenient conversion factor for mass useful for chemical calculations.
 - e. None of these is a good reason.

5. Avogadro’s hypothesis states that, at fixed T and P, two equal volumes of gas contain the same number of molecules. The best data to establish that this is true is:
 - a. At fixed T and P, gas molecules are all about the same volume.
 - b. At fixed T and P, gases react in simple integer ratios by volume.
 - c. At fixed T and P, gases obey the Ideal Gas Law.
 - d. At fixed T and P, gas molecules have the same kinetic energy.

6. What trends are observed as the atomic numbers of the halogens increase? (May have multiple answers.)
 - a. Atomic size increases.
 - b. Electronegativity decreases.
 - c. First ionization energy increases.
 - d. The number of valence electrons increases.
 - e. All of the above are observed.

7. The electron configuration for beryllium is $1s^2 2s^2$ rather than $1s^2 2p^2$. Why is the $1s^2 2s^2$ configuration lower in energy than $1s^2 2p^2$?
- The 2s subshell is full and is thus energetically favorable over the partially filled 2p subshell.
 - The 2s orbital is lower in energy for Be because electron-electron repulsions in the 2s orbital are less than in 2p orbital.
 - The 2s orbital is smaller than the 2p orbital so that electrons in the 2s orbital can get closer to the nucleus and be lower in energy.
 - Spheres (s orbitals) are a lower energy shape than the elongated “dumbbells” of the p orbitals.
 - All of the above.
8. The correct electron configuration for chlorine is $1s^2 2s^2 2p^6 3s^2 3p^5$ (abbreviated as $[\text{Ne}]3s^2 3p^5$). Assess the accuracy and logic of each of the statements below regarding chlorine and select the best choice.
- Every electron in the 3s and 3p shells of Cl feels about the same nuclear charge.
 - There is space for only one more electron in the 3p orbitals of Cl.
 - Therefore, electrons feel a high attraction to Cl so that Cl has a high electronegativity and electron affinity.
 - Statements I and II are true and lead logically to Statement III.
 - Only Statement I is true and Statement II is false, therefore Statement III does not follow logically from I and II.
 - Statement I is false and Statement II is true, therefore Statement III does not follow logically from I and II.
 - Statements I and II are true, but Statement III is only partially true.
 - Statements I and II are false, but Statement III is true.
 - All statements are false.
9. Assess the accuracy and logic of each of the statements below and select the best choice.
- When excited, each atom has a characteristic set of frequencies of radiation that it emits.
 - Each frequency corresponds to a specific energy of the atom.
 - Because there are only specific energies this shows that energy is quantized.
 - All statements are true and logical.
 - Only Statement I is true, but Statements II and III are not logical consequences of Statement I.
 - Statements I and II are true, but Statement III is not a logical consequence.
 - Statements I and III are true even though Statement II is not a logical consequence of Statement I.
 - Statement I is false, yet Statement II is true and the logical consequence is Statement III.
 - All statements are false.

10. The table below shows the successive ionization energies (IE) for which element?

	(kJ/mol)
1st IE	578
2nd IE	1817
3rd IE	2745
4th IE	11575
5th IE	14830
6th IE	18376
7th IE	23293

- a. Ne
- b. Mg
- c. Al
- d. Si
- e. P

13. When a bond is broken,

- a. Energy is added.
- b. Energy is released.
- c. The energetics depend on the circumstances (such as type of atoms bonded, how the bond is broken, and surrounding conditions such as T and P).

14. The reasoning behind your answer above is:

- a. There is energy stored in bonds that is released as heat when the bond is broken.
- b. There is energy stored in bonds that is used to restore the atomic configurations of the components when the bond is broken.
- c. Energy must be added to the molecule to restore the atomic configurations of the components when the bond is broken.
- d. Every bond is different; some require energy and some release energy, so there is no general rule.
- e. Reactions are primarily endothermic at high temperature but primarily exothermic at low temperature.
- f. Reactions are primarily endothermic at low temperature but primarily exothermic at high temperature.

13. Consider the following Lewis structures for HFCO. Which of the following assessments is correct?

A

B

- Structure A is incorrect because a lone pair on oxygen should be shifted to make a double bond between the oxygen and carbon atoms.
 - Structure A is incorrect because it does not account for all of the valence electrons.
 - Structure B is incorrect because the double bond creates a formal charge on the carbon and oxygen atoms.
 - Structure B is incorrect because the double bond should be between the fluorine and carbon atoms rather than the oxygen and carbon atoms.
 - Structures A and B are equally correct resonance structures.
15. Sulfur chloride (SCl_2) and calcium chloride (CaCl_2) have similar chemical formulae. At room temperature, sulfur chloride is a liquid and calcium chloride is a solid. The difference in state between the two chlorides is due to the presence of strong interactions in which substance and why?
- SCl_2 because the difference in sizes (S is smaller than Ca) creates stronger intermolecular interactions.
 - CaCl_2 because the bonds in CaCl_2 are not easily broken, but the bonds in SCl_2 are easily broken.
 - CaCl_2 because of the greater polarity of the bonds in CaCl_2 compared to SCl_2 .
 - SCl_2 because it is covalently bonded.
 - CaCl_2 because it is ionically bonded.
16. The molecule (PCl_5) is observed not to have a dipole moment. This is because:
- There are no lone pairs of electrons on the central atom.
 - There are two lone pairs of electrons on the central atom, but due to repulsion, they are on opposite sides of the central atom and cancel out.
 - P and Cl are close in the periodic table, so they have very similar electronegativities, and as such, the P-Cl bonds are not polar.
 - The polarity of the P-Cl bonds cancel out due to the geometry of the molecule.
 - As a gas and liquid PCl_5 is not ionic, but rather the bonds are covalent.

17. In the nitric acid molecule (H-O-NO_2), the three oxygen atoms are attached to the nitrogen. Of the three O-N bonds, two have the same length and are shorter than the third. The best reason for this observation is:
- There are two double NO bonds and one single NO bond.
 - There are two single NO bonds and one double NO bond.
 - There are two resonance structures with two single bonds and one double NO bond.
 - There are three single NO bonds, but one bond is longer due to the electronegativity of the H atom.
 - There are three single NO bonds, but one bond is longer due to the greater repulsion with a lone pair of electrons on the N atom.
18. Which of the following is the predicted shape of nitrogen bromide (NBr_3)?
- Trigonal planar
 - Trigonal pyramidal
 - Tetrahedral
 - T-shaped
 - See-saw shaped
19. The reason for your answer above is:
- Nitrogen forms three bonds that equally repel each other to form a trigonal planar shape.
 - The polarity of the nitrogen-bromine bonds determines the shape of the molecule.
 - The difference in the electronegativity for bromine and nitrogen determines the shape of the molecule.
 - The geometry is determined by the repulsion of the electronegative bromine atoms.
 - The tetrahedral arrangement of the bonding and non-bonding electron pairs around nitrogen results in the shape of the molecule.
20. If the total bond energy in the starting materials is less than the total bond energy in the products, is the reaction exothermic or endothermic?
- Exothermic
 - Endothermic
 - Cannot be determined from this data

21. If the reaction occurs faster at higher temperatures, is the reaction exothermic or endothermic?
- Exothermic
 - Endothermic
 - Cannot be determined from this data
22. A 100g block of iron at 100°C is placed in contact with a 100g block of iron at 30°C. What will happen?
- Heat transfer does not occur between solids so the temperatures of both blocks remain constant. Another medium for heat transfer (e.g. air) is required.
 - The hotter block contains greater energy, so the final temperature equals the temperature of the hotter block.
 - The hotter block contains greater energy, so the final temperature is closer to the temperature of the hotter block.
 - The cooler block absorbs energy and the hotter block loses energy, so the final temperature is half way in between the starting temperatures.
 - The cooler block absorbs the energy of the hotter block bringing both blocks to the lower temperature.
23. Considering the Question 21, how does the temperature equilibration occur between the iron blocks?
- Heat flows from hot bodies to cold bodies.
 - The greater kinetic energy of the atoms in the hot iron increases the kinetic energy of the atoms in the cold iron by collisions.
 - The lower kinetic energy of the atoms in the cold iron dampens the kinetic energy of the atoms in the hot iron by collisions.
 - All of the above.
 - Solids cannot transfer kinetic energy via collisions – a gas or liquid is required to transfer heat.

24. As shown below, 100 g block of substance X has been heated to 100°C and dropped into a beaker of 100 ml of water at 25°C. A 100 g block of substance Y has also been heated to 100°C and dropped into another beaker of 100 ml of water at 25°C. The final temperature of the water in the beaker containing substance X is greater than that of substance Y. Which substance has the higher specific heat capacity (per gram)?
- Substance X
 - Substance Y
 - The heat capacities are equal.
 - Cannot be determined from the information given.
25. Which of the following accurately describes the relationship between volume and pressure in an ideal gas (temperature and amount of gas held constant)?
- As pressure increases, volume increases.
 - As pressure decreases, volume increases.
 - As pressure increases, first the volume decreases, but then it starts to increase again.
 - There is no relationship.
 - Insufficient information to determine this.

26. Which of the following is the best theoretical explanation for the relationship between volume and pressure that you chose for Question 24?
- As the volume of a vessel decreases, the molecules begin to stick together and therefore collide less with the walls. Fewer collisions with the walls means the pressure decreases as well.
 - As the volume of a vessel increases, the surface area increases. Since the total number of molecules remains the same, the number of molecules hitting a particular area decreases. By the definition of pressure, this means that the pressure is decreasing.
 - As the pressure increases, the molecules are hitting the walls of the vessel with more force. This pushes the walls out, so the volume increases as well.
 - As the volume decreases, the molecules begin to repel each other. This causes them to hit the walls more often. By the definition of pressure, this means that the pressure is increasing.
 - Pressure is how many molecules are hitting the walls, while volume is how much space the molecules are taking up, so there is no relationship between them.
 - None of these is a good explanation.

27. Select from the following pictures a sequence showing increasing temperature. At least one of these picture is not physically realistic and should be excluded from your sequence.

A

B

C

D

E

F

G

H

- a. AHGB
- b. EHGB
- c. EHDF
- d. EHGBC
- e. AEHGBF
- f. EHGBCF
- g. EHGBDCF
- h. EAHGBDF

Consider a closed system with liquid-vapor equilibrium as illustrated in the Figures A and B. By moving the piston up from its position in Figure A, the volume is increased in Figure B.

A

B

28. **After** equilibrium is reestablished in Figure B, which of the following will be true?
- The vapor pressure will remain the same in Figures A and B, since it depends only on the temperature.
 - The vapor pressure in Figure B will be lower, since pressure is inversely proportional to volume.
 - The vapor pressure in Figure B will be higher in order to fill the increased volume.
 - Because the pressure is below the vapor pressure in Figure B, the vapor will condense into the liquid.
 - Because temperature is proportional to pressure, the temperature will be lower in Figure B.
29. The reason for your answer in Question 27 is, **after** equilibrium is reestablished:
- The rates of condensation and vaporization are unchanged even if volume is increased.
 - The rate of condensation is smaller because with greater volume less vapor molecules will come in contact with the liquid surface.
 - The rate of condensation is larger because there are more vapor molecules that come in contact with the liquid surface.
 - The rate of vaporization is larger because there is more space for the vapor molecules.
 - The temperature is lower because the number of collisions molecules have with the wall has decreased.

30. At ambient conditions, water (H_2O) is a liquid and methane (CH_4) is a gas. Why are water and methane found in different physical states at the same temperature and pressure?
- Water can only form half as many hydrogen bonds as methane.
 - The covalent bonds in water are not as strong as those in methane.
 - Water molecules take up less space than methane molecules, so water is easier to condense.
 - Water molecules are heavier than methane molecules, so water is easier to condense.
 - Water molecules have stronger intermolecular interactions than methane molecules.
31. A reaction is at equilibrium, and then temperature is increased. How does an increase in temperature affect a reaction after equilibrium is reestablished?
- The rate of the forward reaction increases.
 - The rate of the reverse reaction increases.
 - The rates of both the forward and reverse reactions increase equally.
 - The rates of both the forward and reverse reactions increase by different amounts.
 - More information is required to compute the rates of forward and reverse reactions.
32. Why does increasing temperature increase the equilibrium constant for an endothermic reaction yet decrease the equilibrium constant for an exothermic reaction?
- Endothermic reactions favor the products and exothermic reactions favor the reactants.
 - Endothermic reactions occur faster at higher temperatures and exothermic reactions occur slower at higher temperatures.
 - The reaction equilibrium always shifts in the direction which absorbs heat when the temperature is increased.
 - This is not the case. Increasing temperature increases the equilibrium constant for both exothermic and endothermic reactions.
 - This is not the case. Increasing temperature decreases the equilibrium constant for both exothermic and endothermic reactions.

33. The following pictures represent aqueous solutions of three acids, HA, HB and HC. Which acids are strong and which are weak? (Water molecules are excluded from the illustrations.)

represents HX (where X is A, B or C)
represents X ⁻ (where X is A, B, or C)
represents H ₃ O ⁺

HA

HB

HC

- HA, HB and HC are all strong acids.
- HA, HB and HC are all weak acids.
- HA and HB are weak acids and HC is a strong acid.
- HA and HC are weak acids and HB is a strong acid.
- HA is a weak acid and HB and HC are strong acids.

33. Assess the accuracy and logic of each of the statements below and select the best choice.

- I. A strong acid is more concentrated than a weak acid.
 - II. As acid concentration increases, the percent ionization of the acid molecules increases.
 - III. With a higher ionization percentage, the pH of a strong acid solution is lower than the pH of a weak acid solution at the same concentration.
 - IV. With a lower pH, a strong acid can fully neutralize a base solution whereas a weak acid only partially neutralizes a base solution.
- a. All statements are true and follow logically.
 - b. Statements I, II, and III are true, but Statement IV does not follow logically.
 - c. Statements I and III are true, but there is no logic in the statements.
 - d. Statements II and III are true and lead logically to Statement IV even though Statement I is false.
 - e. Only Statement II is true and there is no logic in the statements.
 - f. Only Statement III is true and there is no logic in the statements.

34. Why does the entropy of the universe always increase?

- a. Entropy increases as energy is consumed.
- b. Entropy measures probability, which increases.
- c. Entropy means randomness, which increases.
- d. Heat generates entropy.
- e. None of these is a good reason.

35. Why would a reaction come to equilibrium rather than go to completion?

- a. There is insufficient energy for complete reaction.
- b. There is an insufficient amount of one reactant, which is the limiting reagent.
- c. The reverse reaction competes with the forward reaction.
- d. The entropy of the reactants is greater than the entropy of the products.
- e. The entropy of the surroundings is greater than the entropy of the reaction mixture.

36. Why do all reactions require energy to occur?
- For a reaction to occur, the kinetic energy of the molecules must increase which requires heat input.
 - For a reaction to occur, molecules must collide which takes energy input that is known as the activation energy.
 - For a reaction to occur, some of the bonds of the reactant molecules must be broken so that atoms can rearrange to form new bonds, and the energy needed for this is known as the activation energy.
 - This is not true, because exothermic reactions do not require energy to occur as the reaction itself releases heat.
 - This is not true, because it depends on the specific type of reaction.
37. Which metal, sodium or magnesium, has a higher melting point and why?
- Sodium: the metallic bonding is stronger because Na has fewer electrons delocalized in the metallic bond and the nuclear charge is lower.
 - Sodium: the metallic bonding is stronger because Na is smaller and therefore the atoms can pack more closely together.
 - Magnesium: the metallic bonding is stronger because Mg has more electrons delocalized in the metallic bond and the nuclear charge is greater.
 - Magnesium: the metallic bonding is stronger because Mg is larger and has a greater nuclear charge.
 - More information is needed.
38. Consider chlorine and bromine. Which redox reaction will occur and why?
- (i) Br_2 will oxidize Cl^- or (ii) Cl_2 will oxidize Br^-
- (i) because Br has a stronger electron affinity than Cl.
 - (i) because Br is larger than Cl.
 - (ii) because Cl is more electronegative than Br.
 - (ii) because Cl_2 is more reactive than Br_2 .
 - Either reaction will occur depending upon conditions.