EFFECTIVENESS OF GUIDED INQUIRY ON STUDENTS’ COMPREHENSION OF
CHEMISTRY CONCEPTS IN A NON-SCIENCE MAJORS’ COURSE

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Doctor of Philosophy

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ABSTRACT

The inquiry teaching method has been shown to actively engage students in their learning and help them to understand content at a deeper level. The purpose of this research was to determine the effectiveness of guided inquiry activities on students' comprehension of chemistry concepts in a non-science majors' one-semester chemistry course that consisted of lecture and laboratory components. Three topics (bonding, chemical equations, and acid-base chemistry) were chosen to study the effectiveness of guided inquiry teaching and accompanying laboratories in increasing the students' understanding of the chemistry topics. The students' understanding was evaluated based on their percentages of correct answers on assessments and their gain scores on the three topics. A sample of students was also interviewed to determine their understanding of the chemistry topics and to assess their opinions about the guided inquiry activities and their accompanying laboratories. From the students' percentages on post-test questions and gain scores, students taught via guided inquiry performed significantly better than traditional students on the chemical equations topic, while there were not significant differences for the other two chemistry topics and the overall percentage on all three topics. When taught via guided inquiry, freshmen tended to perform
significantly better than juniors, and the high-achieving students and entering freshmen tended to perform better than the lower achieving students. Interviews revealed that students either liked the guided inquiry activities or did not; none of the students was indifferent. Some students felt that the information in the guided inquiry activities was clearly presented and that the activities contained enough information to understand the topic. However, some students felt the activities contained an overwhelming amount of information or were hard to understand. There was almost an even split among the students interviewed regarding the preference of the style of teaching preferred for the chemistry course; guided inquiry, traditional lecture, or a 50/50 mixture of guided inquiry activities with mini-lectures.
DEDICATION

To my husband Jonathan: thank you for all of your support through this long journey of school. You have been my rock and my foundation during the hard and frustrating times; and shared in my joy during the exciting times. I could not have made it this far without you.

To my parents: Thank you for all of your support and guidance; words cannot describe how grateful I am for all that you do for me. I am proud to be your daughter.

To my daughter Togepi: Thank you for your love and affection, and keeping me aware of when I had worked too long.
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CHAPTER I

PROBLEM STATEMENT

This study investigated the use of guided inquiry teaching in a non-science majors’ chemistry classroom at the undergraduate college level. I was interested in looking at the use of guided inquiry in these classrooms because there is a strong push to include inquiry activities in the classroom at all levels of science education. However, there is very little training for instructors or direct data on the impact of guided inquiry activities on student comprehension of chemistry, especially at the college level.

Purpose

In 1996, the National Science Education Standards (National Research Council) were published with the goal of standardizing how science is taught at the K – 12 level in the United States of America. The Standards address the content that should be taught, the pedagogy used to teach it, the professional development available for the science teachers, and the assessment of students’ achievement and opportunity to learn (Nation Research Council, 1996). The intent of the Standards
was to create standards for all students, emphasizing excellence and equity in science. The *Standards* go on to state that learning science should be an active process with inquiry as a central learning tool. In light of these standards, there has been a shift in the way that science is taught at the high school level, shifting away from lectures in a teacher-centered classroom toward inquiry activities in a more student-centered classroom.

With the increased movement to use inquiry in the science classroom at the K – 12 grade levels (American Association for the Advancement of Science, 1993; National Research Council, 1996), the college science classroom has also been changing. Inquiry has also been incorporated into college science lecture and laboratory classrooms (Siebert & McIntosh (Eds.), 2001). This incorporation of inquiry is to prepare future K – 12 educators on how to teach via inquiry by teaching them via inquiry methods; because often we teach how we were taught. Also, using inquiry at the college level will help students learn by continuing to teach them in a style they are familiar with and to build onto their pre-existing knowledge (Siebert & McIntosh (Eds.), 2001). With this shift in teaching style in the lecture classroom, there has also been a shift in the role of the student. Students are no longer passive observers in the classroom, but they have become active participants. Classrooms are now designed be to more student-centered, instead of teacher-centered (Abraham, 2005). The instructor is no longer seen as a presenter of information, but a guide to help students understand the material.
Problem

This study was conducted to determine the effects of using guided inquiry activities in a non-science majors’ chemistry course, compared to the traditional lecture style of teaching. During this study, the two styles of teaching were compared based on the chemistry topic being covered. Students' test scores and students' answers to content questions discussed during an interview were used to determine the students' level of competency on the material, based on the style of teaching used to present the material to the students. Students' opinions were also collected via interviews to determine which style of teaching was preferred.

Research Questions

1. Is there a significant difference, overall and based on topic, between student test percentages based on the style of teaching in a non-science major's chemistry course?

2. Is there a significant difference, overall and based on topic, in test percentages for students in a non-science major's chemistry course taught via guided inquiry based on students' gender, age, race, year in school, major, or cumulative GPA?

3. What are non-science major students' opinions about guided inquiry lessons in chemistry?
Operational Definitions and Variables

Guided inquiry classroom: A classroom where students learn science by using methods, attitudes and skills similar to those used by scientists conducting scientific research. The students must determine the means for answering questions and understanding the material. The teacher acts as a guide only to help students clarify their understanding. Students are provided only with carefully constructed questions and responses to lead them through the process to ensure that they acquire the desired key concepts (National Research Council, 1996).

Traditional classroom: A classroom where the instructor is perceived as the "giver of information." The instructor uses an oral presentation to convey material to the students about a particular subject. There is no interaction between the instructor and the students other than for the instructor to answer questions posed by the students. Students are expected to take notes and listen while the instructor speaks.

Guided inquiry lab: A laboratory where students are not explicitly told how to conduct the experiment or the results of the experiment. Students are given a variety of questions they are to answers on the laboratory material and concepts, and guidelines on the equipment and chemicals they are to use. The students then determine how they will answer the questions being asked. The post-lab discussion questions then ask students to relate the information they obtained to other examples or problems and not just state the answers they determined to the
particular questions being asked in the laboratory (National Research Council, 1996).

Cook-book lab: A laboratory with explicit step-by-step instructions on how to prepare for and perform the lab and often with the results that should be obtained. Students are not allowed to vary from these instructions; therefore this type of lab may not encourage higher order thinking. Cook-book labs are oriented towards gathering and interpreting data, and the students are told what data to collect. The post-lab discussion questions ask students only to reiterate what they directly saw in the laboratory.

POGIL: Process Oriented Guided Inquiry Learning: Activities designed for students to work in groups to “discover” information about the content. The students work through activities that include five stages: orientation, exploration, concept formation, application, and closure (Hanson, 2005).

Gender: An individual’s self-conception as being male or female, as distinguished from actual biological sex. This is a categorical independent variable in this study.

Traditional student: A student who is enrolled in courses, either part-time or full-time, at the undergraduate college level and who is under the age of 24.

Non-traditional student: A student who is enrolled in courses, either part-time or full-time, at the undergraduate college level and who is 25 years of age or older. These students are classified as Adult Learners at the institution of study.
Age group: The age category of traditional or non-traditional that the students fall into based on their age at the time the chemistry course for the study was taken. This is a categorical independent variable in the study.

Year in school: This is the students classification as freshmen, sophomores, juniors, or seniors at the time they took the chemistry course for the study. This level is determined by the number of credit hours the student has completed towards graduation. A freshman has between zero and 31.99 credit hours; a sophomore has between 32 and 63.99 credit hours; a junior has between 64 and 95.99 credit hours; and a senior has 96 or more credit hours at the institution of study. This is a categorical independent variable in the study.

Major: This is the student’s declared major or focus of study at the institution of study. The majors of the students in the study were broken down into eight categories according to the college of the major and the coursework the students need to complete to obtain their degree. These categories were: Education/Intervention, Business/Accounting, Political Science/Economics/Public Relations, STEMM (Natural Science/Nursing/Engineering/Computer), Associates Degrees, Music/Art/Humanities/Language/Mass Media, Social Sciences/Interdisciplinary, and Undecided. This was a categorical independent variable in the study.

Race: The students’ self-reported category of Caucasian, African American, Latino/Hispanic, Asian, or other based on their heritable phenotypical characteristics or their geographic ancestry. This was a categorical independent variable in the study.
Cumulative GPA: The student’s current grade point average at the time the student took the chemistry course for the study. This is a continuous independent variable in the study.

GPA group: Grade point average classifications based on the grade scale at the institution of study. The five categories are as follows: 4.00 to 3.35, 3.34 to 2.65, 2.64 to 1.65, 1.64 to 0, and entering freshmen or transfer students with no GPA at the institution of study. This is a categorical independent variable in the study.

Total percent on content questions: The percent correct the student received on content questions asked during the study. This was calculated for both the total for all of the topics examined during the study and the content questions for each individual topic. These percentages are also broken down by the style of teaching the students were subjected to. This is a continuous dependent variable in the study.

Gain Score: This is the calculated normalized gain score the student received on the content questions. This was calculated for both the total for all of the topics examined during the study and for the content questions for each individual topic. This is a continuous dependent variable in the study.

Delimitations

This study is delimited to the students who self-enroll in the one-semester non-science majors’ chemistry lecture and laboratory course at the institution of study. The course is offered at two separate times in the fall semester (a total of 96
students can enroll), once in the spring semester (a total of 48 students can enroll),
and may be offered up to two separate times in the summer session (up to 24
students can enroll based on the number of times it is offered).
CHAPTER II

REVIEW OF THE LITERATURE

This chapter will define different theories of teaching and learning that this research will utilize for the presentation of chemistry information to non-science majors. This chapter will also discuss some of the specific teaching processes used in the research, such as the inquiry method of teaching and the process oriented guided inquiry learning method of presenting information. A review of the literature in all of these areas is also included to give the reader some background knowledge and the reasoning behind the current study.

Theories of Learning

There is a variety of theories on how humans learn and understand information. According to Driscoll (2005), all of these theories “refer to learning as a persisting change in human performance or performance potential... [and] to be considered learning, a change in performance or performance potential must come
The theories discussed in this section include cognitivism and constructivism.

Cognitivism

Cognitivism, a cognitive learning theory, focuses on how the learner processes information to be able to understand and retrieve it at a later point in time. According to this theory, the learner is thought to be a processor of information, similar to a computer. There are three proposed memory systems that each learner needs to put information through to be able to understand and retrieve it: sensory memory, short-term memory (or working memory), and long-term memory (Dembo, 1994; Driscoll, 2005).

The sensory memory holds information briefly, until it can be processed. It can only hold information for a fraction of a second (Dembo, 1994). This memory is associated with the five senses. Each learner has input from all of his/her senses and the sensory memory holds that information until some of it can be processed by the learner into the short-term memory. The learner has selective control over what information is processed from the sensory memory through selective attention or automaticity depending on the type of information or senses to which the learner is responding.

Selective attention refers to the learner’s ability to select and process information while ignoring other information (Driscoll, 2005). This ability depends
on a variety of factors. One of the most relevant factors is the relevancy of the information to the learner. This is one of the reasons that instructors are encouraged to keep the information they present to the learner relevant to the learner. A second factor that affects the learner’s selective attention is the similarity between the competing sources of information. When two or more of the sensory inputs are similar, it is often hard for the learner to separate or distinguish between the two inputs. A third factor affecting selective attention is the complexity or difficulty of the information or tasks presented to the learner. When a learner is learning something about which he or she has no prior knowledge, the task or information often demands more attention and focus for the learner to comprehend the material. This selective attention is often considered to be a key component in a learner’s problem-solving ability, since this is what helps the learner focus on specific relevant information (Demetriou et al., 2002).

Automaticity occurs when tasks are repeated enough that the learner does not need to think to complete the task or sources of information become habitual, so that the attention the learner needs to give to the material is minimal (Driscoll, 2005). Automaticity often occurs for learners when information is presented in similar fashions. This can help students determine what information is important or where to find important information, regardless of the type of information being presented. This is commonly done in text books and instructors can also support automaticity in their lecture notes or the way they present information in the
classroom. If students automatically know what information is important, they can spend more time focusing on the concept.

Short-term memory, often referred to as working memory, is the second phase in information processing. This is the stage in which sensory information is processed into information that is ready for long-term storage. The short-term memory is the active part of the memory system and is often referenced as a learner’s consciousness (Dembo, 1994; Driscoll, 2005). The short-term memory, as suggested by its name, can only hold a small amount of information and can only hold that information for a short duration of time. Miller (1956) showed that the working memory can only hold 7 ± 2 chunks of information; he called this number the “magic number.” Information is often chunked, or grouped, by the learner so that the learner can hold more information at a time. This chunking is done when people often try to remember phone numbers; they group the numbers together instead of just remembering seven digits. This strategy of chunking can be used by instructors to help students understand complex information or processes by grouping the information in small chunks that the learner can process at one time.

Short-term memory can only hold information for up to about 30 seconds before it is lost, unless active effort is put into understanding the information. The active effort used by the learner can be either rehearsal of the information or encoding of the information (Dembo, 1994; Driscoll, 2005). Rehearsal of the information is when the learner repeats the same information over and over. This repetition of information is often not enough for the information to be converted
into long-term memory, much to a learner’s dismay. Rehearsed information is often lost once the learner stops repeating the information. Encoding is the process of relating new information to information that is already stored in the long-term memory. This strategy of encoding can be used by instructors to help learners with new information by relating the new information to prior information that the learner already knows. There is a variety of different encoding techniques that learners can take advantage of. These include, but are not limited to mnemonics, imagery, self-questioning, and concept organization (Driscoll, 2005).

The long-term memory is the area where encoded information can be stored for long periods of time and can be recalled at a later time (Dembo, 1994; Driscoll, 2005). There are two types of memories that can be stored in the long term memory: episodic and semantic (Dembo, 1994; Driscoll, 2005). Episodic memories deal with specific events that occur in a learner’s lifetime. Semantic memories are memories of general information that can be recalled independently of how it was learned. Semantic memories are the memories with which instructors are most concerned. These are the memories instructors want to access to help the learner encode new information, and the area of memory that instructors hope to increase.

The executive control is the process that coordinates between the short-term memory and the long-term memory. Under the executive control process, the learner uses information or tools from the long-term memory to help encode new information in the short-term memory so that it can be transferred to the long-term memory and retrieved at a later point in time (Glynn, Yeany, & Britton, 1991).
There is a variety of models proposed that account for the storage of information in the long-term memory and a variety of models of how a learner retrieves the information from the long-term memory (Driscoll, 2005). Storage models include: network models, feature comparison models, propositional models, and parallel distributed process models (Driscoll, 2005). Retrieval of information occurs when the learner needs to bring previously learned information back into the short-term memory, either to help understand some new information or to make a response to a sensory input. Retrieval models include, but are not limited to, recall and recognition (Driscoll, 2005).

All of these parts of the information processing system are summed up by Glynn et al. (Eds., 1991) in their proposed cognitive model of scientific reasoning for a learner. The model can be seen in Figure 2.1. This figure shows the sensory memory in the first circle, which is where the learner asks questions and/or makes observations. From here, that information can flow into the working (short-term) memory where the learner encodes the relevant information using encoding techniques through the executive control process. From here, the information can be passed to the learner's long-term memory so that it can be retrieved at a later date. Between the types of memories, there are arrows pointing in either direction; information can flow from the sensory memory to the long-term memory and vice-versa to help the student encode new information. All of the information flows through the executive control process that the learner has developed.
Figure 2.1. A cognitive model of scientific reasoning through the three parts of the memory system; sensory memory, working memory, and long-term memory.


Constructivism

Constructivism is a branch of learning theory that assumes that knowledge is constructed by learners in their attempt to understand the world around them and to make sense of the things they are seeing. This knowledge cannot be constructed
by anyone else, but must be pieced together by the learner. The learner is not an
“empty vessel” that can be filled with information, but has to be actively involved in
the processing of the information (Driscoll, 2005). Glasersfeld (1995) considered
Jean Piaget to be the “pioneer of the constructivist approach to cognition in this
century” (p. 54). He reasons this because “Piaget explains that... knowledge arises
from the active subject’s activity... and that it is goal-directed activity that gives
knowledge its organization” (p. 56).

According to Fox (2001) the main claims that are held together to define
constructivism are:

1. Learning is an active process.
2. Knowledge is constructed, rather than innate, or passively absorbed.
3. Knowledge is invented, not discovered.
4. All knowledge is personal and idiosyncratic, or all knowledge is socially
   constructed (depending on the learning situation involved).
5. Learning is essentially a process of making sense of the world.
6. Effective learning requires meaningful, open-ended, challenging problems for
   the learner to solve.

However, Fox (2001) goes on to state that each of these claims has its own inherent
critiques that may make the all-or-nothing aspect of constructivism seem unfounded
and states that learning is a much more complex process then the above claims
state. Anthony (1996) adds another dimension to the claims of constructivism:
learning is knowledge-dependent and that the learner uses prior knowledge to
make sense of the new material being learned. Confrey (1990) states that the learner is also aware of the constructs he or she is making from the information that was gathered and is able to alter those constructs through reflection.

Bodner, Klobuchar, and Geelan (2001) go on to simplify constructivist theory of learning to two simple assumptions that instructors can reflect upon:

1. Knowledge is seldom transferred intact from the mind of the teacher to the mind of the student.

2. Useful knowledge is never transferred intact.

These two assumptions mean that what the learner constructs at one time is used to construct new information at another time. These constructs are continually being changed and altered to match with new information to which the learner is being subjected.

The ideas of constructivism are then translated into a new way of looking at the learning environment. An instructor using the constructivist theory of learning needs to find ways to help the learner construct information in a more powerful and meaningful way (Confrey, 1990). The learner having to be actively involved in the learning of new information and knowledge not being able to be transferred intact means that the instructor will not be able to simply pass information to the learner and expect that the learner will be able to understand it. Instructors need to find ways to actively engage the student with the new information they present. The learner's awareness of the constructs he or she is making and having the chance to alter these construct results in instructors needing to give the learner a chance to
reflect and process information to form constructs that he or she will be able to later recall.

Since learners make their own constructions of the information, the instructor needs to take time to determine how the learner has constructed the information. The information, as presented by the instructor, is not always clear and interpreted in the same fashion by the learner, since it is the learner that is constructing the new information from prior knowledge (Julyan & Duckworth, 2005). The logical order of presentation for information from an expert (instructor) is not always the best way to order the information from a learner’s perspective (Bodner, 1986). Students should be given time to explore and develop their own understanding of the concept to completely construct the information in a meaningful way. These constructs should then be checked by the instructor to look at “what the person has learned not if the person has learned” (Julyan & Duchworth, 2005).

The learner tries to fit the new information he or she is receiving in into the constructs he or she already has. When the two constructs do not mix, a new construct must be created by the learner that accurately represents and explains the old information as well as the new information (Bodner, 1986). This is often hard for a learner to do and can often lead to misconceptions. Instructors can help students form these new constructs by giving them time to experiment with the information and make the construct change (Bodner, 1986) or asking them to discuss the knowledge they already have with peers, in an instructor-facilitated
fashion, to find ways of connecting the new information and to form new constructs (Bunce, 2001). If learners are not given time to fashion new constructs to incorporate new information, they often revert to the original construct that is wrong in light of the new information.

Krajecik (1991) calls this process of how learners incorporate and change old constructs to match new ones as conceptual change, and he states that instructors can help students through this process. Conceptual change teaching involves students describing their current understanding about some concept and then restructuring that understanding through looking at and talking about the concept under the light of new information. Students are then expected to apply the new information and make links between the new and the old, correcting the old information where it is needed. Figure 2.4 shows the pathway that students would take when being taught with conceptual change teaching. Notice that the pathway can be sequential, but students can also go through various processes more than once or return if proper linkages are not made.
Figure 2.2. Conceptual Change Teaching Sequence for Student Understanding

Figure 2.2. Shows the pathway students can go through when taught via the conceptual change model. Students can alter their previous constructs to form new correct or more elaborate constructs on science information. Adapted from “Developing Students’ Understanding of Chemical Concepts” by J. S. Krajcik in The Psychology of Learning Science edited by S. M. Glynn, R. H. Yeany, and B. K. Britton, 1991, p. 130. Copyright 1991 by Lawrence Erlbaum Associates.

Learners must also be given reasons why the information they are being presented with is important. For learners to construct knowledge in a certain area, they need to be able to see why it is important (Glasersfeld, 1995). When left to themselves, learners often fail to see why they should make an effort to make
constructs of information and understand the information. When this happens students fail to actively participate and they may miscode information (Fox, 2001). To match with this theory of learning, instructors need to explicitly help learners to see why information is important and demonstrate to the learners why the new information is beneficial to learn.

The constructivist theory of learning also changes the role the instructor has in the classroom. The instructor is no longer only disseminating information, but also facilitating the learning of information. This style of teaching requires a bidirectional flow of information between the instructor and the learner, not a one-directional flow of information from the instructor to the learner. A constructivist instructor “questions students’ answers whether they are right or wrong, insists that students explain their answers, focuses the students’ attention on the language they are using, does not allow the student to use words or equations without explaining them, and encourages the student to reflect on his or her knowledge” (Bodner, 1986, p. 877). This style of classroom helps learners make new and meaningful constructs of the information presented so that they can recall the information correctly at a later point in time.

Inquiry Style of Learning and Teaching

The constructivist learning theory has lead to a variety of different teaching techniques in the classroom. One of the classroom techniques is inquiry instruction.
Inquiry, as defined by the *National Science Education Standards* (National Research Council, 1996), has a three-fold meaning: first, students are doing an investigation of a scientific phenomenon; second, students are to learn how to do the process of science; and third, teachers are to use inquiry as an instructional tool to help students understand concepts. The main idea is that the inquiry style of teaching uses an approach where students are actively engaged in the learning process (Hanson, 2006). Active engagement is held by constructivism as an important aspect for students’ construction of knowledge (Fox, 2001). Through inquiry learning, students are thought to gain knowledge and practice in five different areas: curriculum content, information literacy, learning how to learn, literacy competence, and social skills (Kuhlthau & Maniotes, 2010). By going through all of these different types of learning, students gain a broader understanding of science and have a better chance of becoming life-long science learners because of their understanding of how to learn.

Inquiry and traditional classrooms have different instructional strategies to help students learn material. Abraham (2005) suggests that the traditional strategy of teaching is teacher-centered, where students are presented with a concept and then given data to back up that concept. Students are not actively involved in the creating of the concept, but only in the reinforcement of the concept once the instructor has transferred his or her knowledge to the students. Figure 2.3 shows the phases of traditional instruction and how it looks in a classroom. Abraham (2005) suggests that the inquiry instructional strategy is student-centered, with
students being presented with some data and asked to determine a concept that matches the data. In this form of instruction, students are actively engaged in the construction of the concept from the beginning and then work with an instructor’s guidance to understand and evaluate that concept. Abraham (2005) refers to this as the Learning Cycle. The phases of the Learning Cycle and how it looks in a classroom can be seen in Figure 2.4.

Figure 2.3. Traditional Instruction Strategies

<table>
<thead>
<tr>
<th>Phases of Instruction</th>
<th>Goal</th>
<th>Activities</th>
<th>Questions</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inform</td>
<td>Present concept</td>
<td>Lecture/Discussion, Readings</td>
<td>What is the concept</td>
<td></td>
</tr>
<tr>
<td>Verify Concept</td>
<td>Confirm the truth of concept</td>
<td>Laboratory, Demos</td>
<td>How do your observations fit the concept?</td>
<td>Confirm concept with data, Provide evidence</td>
</tr>
<tr>
<td>Practice Concept</td>
<td>Apply, reinforce, extend &amp; understand concept</td>
<td>Readings, Problem sets, Application questions</td>
<td>Using what you know, answer the following...</td>
<td></td>
</tr>
<tr>
<td>Evaluate</td>
<td></td>
<td>Examinations, Quizzes</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Figure 2.3. The table shows the concept to data flow of information from an instructor to a student. Students are told the concepts they are expected to know and then shown how the concepts work in nature. Adapted from “Inquiry and the Learning Cycle Approach” by M. R. Abraham in The Chemists’ Guide to Effective Teaching edited by N. J. Pienta, M. M. Cooper, and T. J. Greenbowe, 2005, p. 43. Copyright 2005 by Pearson Education.*
Figure 2.4. Inquiry Instruction Strategies

Inquiry Instruction (Data → Concept)

<table>
<thead>
<tr>
<th>Phases of Instruction</th>
<th>Goal</th>
<th>Activities</th>
<th>Questions</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Explore</td>
<td>Explore relations and patterns in data</td>
<td>Laboratory, Demos, Lab Simulations, Video, Activities</td>
<td>What did you do? What did you observe</td>
<td>Gathering data</td>
</tr>
<tr>
<td>Invent Concept</td>
<td>Develop and understand concepts with teachers/peers</td>
<td>Lecture/Discussion</td>
<td>What does it mean?</td>
<td>Exploring data</td>
</tr>
<tr>
<td>Apply Concept</td>
<td>Apply, reinforce, review, extend &amp; understand concept</td>
<td>Readings, Problem sets, Application Questions, Verification Laboratory</td>
<td>Using what you know answer the following...</td>
<td>Using data, Provide evidence</td>
</tr>
<tr>
<td>Evaluate</td>
<td></td>
<td>Examinations, Quizzes</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Figure 2.4. The table shows the data to concept flow of information from a student working with data and guided by an instructor. Students are able to explore phenomenon and then figure out concepts to match. Adapted from “Inquiry and the Learning Cycle Approach” by M. R. Abraham in *The Chemists’ Guide to Effective Teaching* edited by N. J. Pienta, M. M. Cooper, and T. J. Greenbowe, 2005, p. 44. Copyright 2005 by Pearson Education.*

Some of the instructional practices that can be used in the classroom to teach with the inquiry strategy include using a lab to introduce a concept, asking students a series of questions as the main instructional technique to get students to look at the concept, having students work through problem-solving activities in the
classroom, and focusing on the process of science as well as the concept in the classroom (Abraham, 2005). Each of these instructional practices puts the students in the center of the learning and makes the students the ones responsible for their learning outcome; the instructor acts as the facilitator of the information.

The inquiry method of instruction is very broad; most researchers actually view it as a spectrum and not an all-or-nothing technique in the classroom. Somerville and Geddes (2005) propose a three-level spectrum of inquiry in the classroom. They base their levels on the types of questions posed in the classroom and who asks the questions, the instructor or the student. The lowest level of inquiry is the traditional approach. In a classroom using this approach, instructional techniques revolve around the correct answers to questions; students are given facts by the teacher and then asked to regurgitate the answers to questions posed on an exam or quiz. The second level of inquiry is called conservative constructivist. Here, students are actively engaged in structuring their own knowledge. The students might be posed with a question or observation and then asked to describe concepts that fit their observation. The first two levels of inquiry in this spectrum proposed by Somerville and Geddes (2005) have the instructor setting the goals of the course and the information that the students are expected to understand. All students go through the same material and have very similar experiences with the concepts and material. The first level is not often classified as inquiry by other researchers because the students are never really actively engaged in the information. The third and final level of the spectrum is guided exploration. In a
classroom using this approach, students not only answer questions, but they are the ones who pose the questions in the first place. The instructor may guide or set a broad category for the students to look at, but ultimately it is up to the students to ask a question and find the answer. Each student in this classroom may not be exposed to the same material or concepts.

Zion, Cohem, and Amir (2007) also follow this three-tiered idea of inquiry. The first tier is classified as structured inquiry. Here the instructor does all of the planning and laying out of the idea, but it is up to the students to implement the plan and learn the information. The second tier is guided inquiry. As in the first level, the teacher is the one to present the problem, but now students have to come up with both the process and the answer to the problem posed. As in the previous model, the first two tiers are teacher-centered, since the teacher is the one that defines the problem. They are both still considered to be inquiry methods of teaching because the students are actively engaged in finding an answer or learning the information, as the teacher is not just simply presenting the information. The last tier of the spectrum proposed by Zion, Cohen, and Amir (2007) is open inquiry. In open inquiry, similar to the above-mentioned guided exploration, students are responsible for determining the problem they wish to study. Again, teachers are expected to facilitate the students with determining the problem and help students focus on certain aspects, but the initial idea of the problem, the process and the information that follows come directly from the students. Zion, Cohen, and Amir (2007) do state that open inquiry is difficult for instructors to implement in the
classroom if they are not given direct guidelines or instruction on how to implement this style of teaching.

Llewellyn (2011) takes the inquiry spectrum further and breaks it down into four different categories. His categories are based on whether the teacher and the student have low/passive or high/active ownership of the material being learned. The four categories Llewellyn describes are demonstrated inquiries, structured inquiries, guided inquiries and self-directed inquiries. In demonstrated inquires, the instructor demonstrates some phenomenon to capture the students’ interest on a topic or concept. The instructor may then explain or talk about the concept that was presented to the students. In structured inquiries, the students actually engage in some hands-on activity, but the activity and all of the parts and outcomes have been planned by the instructor. In guided inquiries, the instructor poses the problem and defines the set of materials and information that students can use to solve the problem, but it is up to the students to figure out how to use the materials and information to solve the problem. In the final state, self-directed inquiries, the students generate their own questions and processes to obtain the answers to those questions. Figure 2.5 shows the four different categories of inquiry proposed by Llewellyn (2011) and the different levels of ownership the instructor or the student have in each one.
Figure 2.5. Four levels of inquiry teaching based on the level of ownership both the instructor and the student have in the style of teaching. Adapted from Differentiated Science Inquiry by D. Llewellyn, 2011, p. 12. Copyright 2011 by Corwin.

Wenning (2005, 2007) breaks down the spectrum of inquiry teaching even more finely, using seven levels. He bases his levels not only on the level of student or instructor control, but also the level of intellectual sophistication the student needs to have to be able to accomplish and function at the different levels of inquiry teaching. Wenning also breaks down the difference between classroom lessons and laboratories. Wenning’s (2005) seven levels of inquiry are discovery learning, interactive demonstrations, inquiry lessons, guided inquiry labs, bounded inquiry labs, free inquiry labs, and pure or applied hypothetical inquiry. Discovery learning has a focus on learning from experiences; the teacher provides experiences from which the students form meaning. In interactive demonstrations, the instructor demonstrates some phenomenon while asking students questions about what
happened or why it happened. From their observations, students come to some conclusion or form some meaning about the phenomenon. For inquiry lessons, the instructor leads students through guided questions to come to some conclusion. The goal of inquiry lessons is to get student thinking in a scientific manner before they start to encounter laboratories where they perform as well as plan. The three guided inquiry labs are then broken down by how much ownership the student has in the laboratory. For the guided inquiry labs, the teacher defines the problem and gives the students a list of questions to answer. For the bounded inquiry labs, the teacher again defines the problems and only asks one overarching question. The students then determine how to answer that question and any underlying questions they may ask. In free inquiry labs, students determine the questions they want to answer and how to go about answering those questions. In hypothetical inquiries, students are required to come up with a question and a hypothesis and then determine ways to test their hypothesis. The difference between pure and applied hypothetical inquiries is that pure inquiry is just for the sake of learning, while applied inquiry is used to find an application of prior knowledge to new applications. Figure 2.6 shows the seven levels of inquiry described by Wenning (2005, 2007), differences in the levels of control that the teacher or the student has for each level, and the level of intellectual sophistication students need to function at each level. Wenning (2007) recommends that during a course, the instructor progress from the low end of the inquiry spectrum to the high end of the inquiry spectrum as students advance in their knowledge and their inquiry ability.
Figure 2.6. Seven Levels of Inquiry Based on Control and Sophistication

<table>
<thead>
<tr>
<th>Discovery Learning</th>
<th>Interactive Demos</th>
<th>Inquiry Lessons</th>
<th>Guided Inquiry Labs</th>
<th>Bounded Inquiry Labs</th>
<th>Free Inquiry Labs</th>
<th>Pure Hypothetical Inquiry</th>
</tr>
</thead>
</table>

Low ←----------------- Intellectual Sophistication ←----------------- High
Teacher ←----------------- Locus of Control ←----------------- Student

*Figure 2.6.* This figure shows the seven levels of inquiry: the level of sophistication the student needs to function and the level of control the student has over the teacher increases from left to right along the chart. Adapted from “Levels of Inquiry: hierarchies of Pedagogical Practices and inquiry Processes” by C. J. Wenning, 2005, *Journal of Physics Teacher Education Online*, 2(3), p. 10. Copyright 2005 Illinois State University Physics Department.

With the wide variety of breakdowns of levels and categories of inquiry, many instructors are not sure how to go about teaching via inquiry methods or what levels are appropriate for different classrooms. There is also a discrepancy among instructors on how they define the different levels of inquiries used in the classroom (Anderson, 2002). Much attention has been focused on the laboratory component of the science classroom and the level of inquiry in laboratory situations. According to Omer (2002), it is commonly held that unless students understand the language associated with science knowledge, they will not be able to retain information and will fail to gain a mastery of science knowledge, and that during inquiry-based laboratories, students have the best opportunity to understand and retain this science knowledge. Buck, Bretz, and Towns (2008) created a rubric to characterize
the level of inquiry used in undergraduate laboratory activities or exercises. The level of inquiry for the laboratory or activity is based on six different characteristics that each of the laboratories or activities contain and whether or not the information for that characteristic is provided by the instructor. The six different characteristics are problem/question, theory/background, procedure/design, results analysis, results communication, and conclusions; the fewer characteristics that are provided by the instructor the higher the level of inquiry. Buck, Bretz, and Towns (2008) also classify five levels of inquiry for the laboratory: confirmation, structured inquiry, guided inquiry, open inquiry, and authentic inquiry. Each of these levels of inquiry and the characteristics provided by the instructor can be seen in Figure 2.7. Based on this rubric, any laboratory that an instructor is using can be placed at a specific level of inquiry.
Figure 2.7. Rubric to Characterize Inquiry in the Undergraduate Laboratory

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Confirmation</th>
<th>Structured Inquiry</th>
<th>Guided Inquiry</th>
<th>Open Inquiry</th>
<th>Authentic Inquiry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Problem/Question</td>
<td>Provided</td>
<td>Provided</td>
<td>Provided</td>
<td>Provided</td>
<td>Not Provided</td>
</tr>
<tr>
<td>Theory/Background</td>
<td>Provided</td>
<td>Provided</td>
<td>Provided</td>
<td>Provided</td>
<td>Not Provided</td>
</tr>
<tr>
<td>Procedures/Design</td>
<td>Provided</td>
<td>Provided</td>
<td>Not Provided</td>
<td>Not Provided</td>
<td>Not Provided</td>
</tr>
<tr>
<td>Results Analysis</td>
<td>Provided</td>
<td>Provided</td>
<td>Not Provided</td>
<td>Not Provided</td>
<td>Not Provided</td>
</tr>
<tr>
<td>Results Communication</td>
<td>Provided</td>
<td>Not Provided</td>
<td>Not Provided</td>
<td>Not Provided</td>
<td>Not Provided</td>
</tr>
<tr>
<td>Conclusions</td>
<td>Provided</td>
<td>Not Provided</td>
<td>Not Provided</td>
<td>Not Provided</td>
<td>Not Provided</td>
</tr>
</tbody>
</table>

Less Inquiry  More Inquiry

Figure 2.7. This figure shows a rubric that can be used to determine the level of inquiry in any laboratory exercise or activity based on what is provided by the instructor. If it is not provided by the instructor, then the students need to determine that information for themselves. As one progresses from left to right across the figure a higher level of inquiry is involved. Adapted from “Characterizing the Level of Inquiry in the Undergraduate Laboratory,” by L. B. Buck, S. L. Bretz and M. H. Towns, 2008, *Journal of College Science Teaching, 38*(1), p. 54. Copyright 2008 National Science Teachers Association.

The guided inquiry method of teaching seems to be in the forefront of many of the inquiry teaching strategies. The inquiry approach, with students being the makers of their own knowledge, seems to be embraced by many instructors. However, instructors often still want to be the ones to determine the information that the students will be presented with. Students are either asked to complete a
laboratory on some concept or are given data on some concept; from there the students use the data to construct some knowledge about the concept. This concept is then refined through practice and instructor input (Cracolice, 2009). In this style of inquiry, the instructor still has a lot of input into what constructs the students form, but it is the students who are actively involved in the creation of the construct, not the instructor. Many different forms of the guided inquiry teaching style exist today.

Process Oriented Guided Inquiry Learning

One type of guided inquiry method of teaching is the Process Oriented Guided Inquiry Learning (POGIL) method of teaching. The POGIL method of teaching involves students going through the learning cycle of exploration and concept formation followed by an application of that material (Hanson, 2006). There are two broad goals of this style of teaching; (1) students are to develop content mastery, and (2) students are to develop and improve their learning skills (Moog & Spencer, 2008). For the first goal, students will not just be able to regurgitate information, but will have an in-depth understanding of the information so they will be able to apply it to new and different things. The second goal suggests that students will enhance their learning skills, developing into life-long learners. The POGIL style of teaching can be adapted to work in a classroom or in a laboratory setting.
The three key elements that characterize a POGIL classroom, as defined by Moog and Spencer (2008) are:

1. The use of self-managed student teams, which employs the instructor as a facilitator of learning and not a source of information.
2. The activity guides students through exploration to construct understanding.
3. The activity uses content to facilitate the development of higher level thinking and the ability to learn and apply concepts to new contexts.

The materials that are designed for POGIL classrooms are carefully developed and contain questions that help students view and understand the content being presented. Figure 2.8 shows how a POGIL activity is laid out in the classroom to include all of these different characteristics.
Since most of the class time is spent with students working in small groups of three to four, each member of the group is often assigned a role for the day (Moog et al., 2009). The roles assigned include the manager, recorder, reflector or strategy analyst, and the presenter. Assigning roles to each member of the group encourages all the members of the group to be actively involved in the activity.

The instructor also has an important role while students are working on the POGIL activity. The instructor needs to move among the groups, listening to their comments and dialogs and examining their answers on the activity. The instructor may even pose questions to the group members to make sure they are grasping the
concepts being presented. If questions are answered incorrectly or if the group dialogue shows a misconception, the instructor may choose to intervene. The instructor is encouraged to intervene as little as possible; well-designed activities often help students see their misconceptions and work through them to get to the right concept themselves without instructor input (Moog et al., 2009). Some skills that instructors need to have when implementing a POGIL activity include the ability to listen to and rephrase students’ questions, to ask critical questions, and to recognize student emotions (Moog & Spencer, 2008). Instructors also need to be able to recognize when students have encountered a roadblock and need some extra guidance. Student frustrations can be turned into learning outcomes by instructor intervention and encouragement (Kuhlthau & Maniotes, 2010).

The design of the POGIL activity is very specific in its components. Each activity has five stages or sections: orientation, exploration, concept formation, application, and closure (Hanson, 2005). The orientation section prepares the student for learning, providing the motivation for the activity, creating student interest, and making connections with prior knowledge. The learning objectives and the criteria for success are also stated so that the student knows what to expect during the activity and once the activity is completed. The exploration stage gives students the opportunity to make an observation or to analyze some data or information. Students are then encouraged to propose, question, and test hypotheses they create. In the concept formation stage, concepts are invented by the student or introduced by the activity. This is often done by having students
answer critical thinking questions and analytically engaging with the data. The goal of the questions is to lead the students to appropriate connections or conclusions. In the application stage, students use their new knowledge to work through exercises, problems or research situations. In the final closure stage, students validate their results, reflect on what they have learned, and assess their performance.

Literature Pertaining to Inquiry Learning and Teaching

Many studies have been conducted on the effectiveness of the inquiry style of teaching. Researchers have looked at a variety of different components to assess their effectiveness, such as the scores students received on standardized exams, the test scores students received in the classroom, the number of questions posed by teachers and students and other classroom observations, and the attitudes held by both students and teachers. This section of the literature review will look at examples of the research done on inquiry teaching. This research helped to guide the current researcher's questions and hypotheses.

Inquiry classrooms have been shown to help students score higher on standardized exams in many of the science disciplines. In the chemistry classroom, students who were taught via peer-led guided inquiry techniques outscored their traditional lecture classroom counterparts on American Chemical Society exams given at the end of the semester (Lewis & Lewis, 2008). Regardless of the students'
level of scientific literacy, guided inquiry classrooms have helped students obtain higher mean achievement scores on the Biology Achievement Test than their traditional classroom counterparts (Nwagbo, 2006). Students who were taught information via guided inquiry laboratories relating to forensics showed higher knowledge gains and retention as shown through standardized test scores than students who were taught the same information via verification laboratories (Blanchard et al., 2010). Tretter and Jones (2003) found the opposite effect on the end of course standardized exam in a high school physical science class. The mean for the inquiry students was not as high as the traditional lecture students mean for the exam; although, they did find that fewer of the inquiry students were classified as not-proficient on the course material compared the their traditional student counterparts.

It has also been shown that students who are taught via an inquiry method tend to score higher on classroom exams. When taught via inquiry methods, students appeared to have a better understanding of the concepts being taught and were more able to describe in detail certain chemistry topics than when taught via traditional lecture (Sanger, 2007). When taught via the POGIL method in an introductory chemistry course, students tended to have much higher exam scores than traditional students and higher retention and conceptual understanding of the material as shown by the final exam scores for the course (Rajan & Marcus, 2009). Students in an active learning environment for chemistry also outperformed their peers on exams and the bottom 25 percent of the student population in the active
classroom outperformed their peer equivalent in the traditional classroom on the exams (Oliver-Hoyo, Allen, Hunt, Hutson, & Pitts, 2004). These studies show that an active learning method is beneficial even for the lower-achieving portion of students in a classroom. Students who were taught via an inquiry method for introductory chemistry also tended to outperform their peers on organic chemistry midterm exams (Gutwill-Wise, 2001). When the POGIL method was used in a preparatory chemistry course, students were found to perform lower on exams than when traditional lecture was used, but when the POGIL method was mixed with mini-lectures the students outscored their traditional lecture peers on exams (Murphy, Picione, & Holme, 2010). All of these results show that the students had a better grasp on the concepts of chemistry when taught via inquiry than their peers who were not.

In the physics laboratory environment, students tended to gain more understanding about the content when taught via inquiry laboratories than from traditional laboratories when tested on the content. This proved to be true even when the students did not completely finish the laboratory successfully or meet all of the laboratory objectives (Bryant, 2006). In organic chemistry, when students were taught via the POGIL method in the lecture and used an active learning style in the laboratory, they scored significantly higher on exams than students that were taught traditionally. Students also felt more confident with organic reaction mechanisms when taught via inquiry as expressed by their attempting to answer
more mechanism exam questions than traditional students (Schroeder, Greenbowe, 2008).

A study conducted by Yager, Abd-Hamid, and Akcay (2005) showed that in-service science teachers asked more questions about the content and its relationship to previously learned material during laboratories as inquiry involved in the lab increased; three types of laboratories the in-service teachers participated in were structured inquiry, guided inquiry and full inquiry. The researchers concluded that full inquiry works best when it is not preceded by structured or guided inquiry activities. This contradicts many of the other guidelines for teaching with inquiry that state that the level of inquiry should progress as the course progresses (Wenning, 2007). Yager, Abd-Hamid, and Akcay believe that full inquiry should stand alone from structured or guided inquiry because these two types of inquiry limit the number and type of questions that the in-service teachers proposed when those two types preceded the full inquiry activity. The in-service teachers were influenced by the initial structured and guided inquiry activities and did not get the full experience of the full inquiry activity. Students in an active learning environment tend to ask more content questions and have more interaction with their peers and the instructors than students in non-active classes. Instructors in the active classroom also tended to ask more questions of the students instead of giving direct answers (Gutwill-Wise, 2001).

In an inquiry classroom, students were less likely to give up in the course and tended to attend more of the class days (Tretter & Jones, 2003). Students also
tended to be more attentive in the learning process, spent more time-on-task and learned for the sake of learning versus just for the grade (Cavallo, Potter, & Rozman, 2004; Tretter & Jones, 2003). Students also spent more time discussing the content, working on problems and listening to other students when in an inquiry setting, compared to listening to an instructor, reading class materials and writing things down in a traditional classroom (Cianciolo, Flory, & Atwell, 2006). Teachers in an inquiry setting spent more time helping create opportunities for students to practice critical thinking techniques and guiding students than in a traditional setting (Cianciolo, Flory, & Atwell, 2006).

Research has shown that students have mixed attitudes on the inquiry style of teaching. Some of the negative attitudes include frustration with not getting correct answers and fear of being in control of their own learning (Deters, 2005; Meyer, Hong, & Fynnewever, 2008). Students taught via inquiry may also feel that they do not learn the material as well as they would with a lecture format, although this is often opposite to what test scores showed. (Rajan & Marcus, 2009).

Students also have positive attitudes about the inquiry style of learning. Students may enjoy the group work environment that inquiry methods use and may feel that these types of activities increase their ability to communicate scientifically (Deters, 2005; Mitcher & Hiatt, 2010; Rajan & Marcus, 2009; Schroeder & Greenbowe, 2008). Some students feel that it takes time to get used to the inquiry style of teaching, but once they understand what is expected, they tend to enjoy the activities (Gutwill-Wise, 2001). Many students find the inquiry style of teaching
“hard” but “rewarding”, and some students feel that they actually understand the concepts at a deeper level because of the activities. Students even state they find the inquiry activities more interesting than lecture and more fun to work through (Deters, 2005; Meyer, Hang, & Fynewever, 2008; Oliver-Hoyo & Allen, 2005). However, when given the choice, some students prefer guided inquiry laboratories versus open inquiry laboratories. These students feel that they learn more when there is some guidance versus when they have complete control (Chatterjee, Williamson, McCann, & Peck, 2009). When students were asked the type of learning environment they prefer, the most common response from students was a classroom that consisted of 75 percent inquiry and 25 percent direct instruction. No students preferred a classroom with 100 percent inquiry or 100 percent direct instruction (Meyer, Hong, & Fynewever, 2008). Some students also feel that a class taught completely by the POGIL method of teaching would not be valuable and would prefer a mix of different teaching styles (Mitchell & Hiatt, 2010). These articles lead to the opinion that students enjoy the inquiry style of teaching, but they still want to have some direct instruction to help them comprehend the material.
CHAPTER III

METHODOLOGY

Research Design

This study utilized a pre- and post-test quasi-experimental research design. For each chemistry topic, the control group was the traditional style classroom, and the experimental group was the guided inquiry activity classroom. The groups were not randomly assigned, as the students self-enrolled in the courses. Table 3.1 displays the paradigm for each topic the study covered.

Table 3.1

Study Design

<table>
<thead>
<tr>
<th>Group</th>
<th>Pre-Test Percent</th>
<th>Lesson</th>
<th>Post-Test Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>$O_1$</td>
<td>$T_1$ (guided inquiry)</td>
<td>$O_2$</td>
</tr>
<tr>
<td>Control</td>
<td>$O_3$</td>
<td>$T_2$ (lecture)</td>
<td>$O_4$</td>
</tr>
</tbody>
</table>

The Os stand for the different observations that were made, either the percentages on the pre-test questions or the percentages on the post-test questions. The Ts represent the different treatments to which the classrooms were subjected.
Participants

Since human subjects were used for the study, approval from the Institutional Review Board (IRB) at the college of study was requested. The initial request was made for the classroom analysis and to collect student data. This was approved on January 13, 2009 under the exemption 1 category. For the main study, a protocol change was submitted to the IRB to include the interview portion of the study. This was also approved on August 11, 2009 under the exemption 2 category. The Notices of Approval can be seen in Appendix A. For each portion of the study, the instructor for the course and the students filled out a consent form. The consent forms for the instructor of the course, the students in the classroom, and the students who were interviewed can be seen in Appendix B.

Pilot Study

The participants for the two phases of the pilot study were college students enrolled in a one-semester non-science majors’ chemistry course at the institution of study during the Spring 2009 (phase one) and Summer 2009 (phase two) semesters. There were a total of 116 students enrolled in the course for the two semesters. A frequency summary of the pilot categorical demographic data can be seen in Table 3.2.
Table 3.2

*Frequencies of Demographics for Students in Pilot Study*

<table>
<thead>
<tr>
<th>Variable</th>
<th>Categories</th>
<th>Frequency</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Semester</td>
<td>Spring 2009 (phase one)</td>
<td>88</td>
<td>75.9</td>
</tr>
<tr>
<td></td>
<td>Summer 2009 (phase two)</td>
<td>28</td>
<td>24.1</td>
</tr>
<tr>
<td>Gender</td>
<td>Male</td>
<td>51</td>
<td>44.0</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>65</td>
<td>56.0</td>
</tr>
<tr>
<td>Race</td>
<td>Caucasian</td>
<td>97</td>
<td>83.6</td>
</tr>
<tr>
<td></td>
<td>African American</td>
<td>11</td>
<td>9.5</td>
</tr>
<tr>
<td></td>
<td>Latino/Hispanic</td>
<td>1</td>
<td>0.9</td>
</tr>
<tr>
<td></td>
<td>Asian</td>
<td>1</td>
<td>0.9</td>
</tr>
<tr>
<td></td>
<td>Other</td>
<td>2</td>
<td>1.7</td>
</tr>
<tr>
<td></td>
<td>Not Reported</td>
<td>4</td>
<td>3.4</td>
</tr>
<tr>
<td>Year in School</td>
<td>Freshman/Other</td>
<td>31</td>
<td>26.7</td>
</tr>
<tr>
<td></td>
<td>Sophomore</td>
<td>49</td>
<td>42.2</td>
</tr>
<tr>
<td></td>
<td>Junior</td>
<td>20</td>
<td>17.2</td>
</tr>
<tr>
<td></td>
<td>Senior/Higher</td>
<td>16</td>
<td>13.8</td>
</tr>
<tr>
<td>Major</td>
<td>Education/Intervention</td>
<td>49</td>
<td>42.2</td>
</tr>
<tr>
<td></td>
<td>Business/Accounting</td>
<td>27</td>
<td>23.3</td>
</tr>
<tr>
<td></td>
<td>Political Science/Economics/Public Relations</td>
<td>14</td>
<td>12.1</td>
</tr>
<tr>
<td></td>
<td>STEMM</td>
<td>5</td>
<td>4.3</td>
</tr>
<tr>
<td></td>
<td>Associates Degrees</td>
<td>6</td>
<td>5.2</td>
</tr>
<tr>
<td></td>
<td>Music/Art/Humanities/Language/Mass Media/Dance</td>
<td>6</td>
<td>5.2</td>
</tr>
<tr>
<td></td>
<td>Social Science/Interdisciplinary</td>
<td>3</td>
<td>2.6</td>
</tr>
<tr>
<td></td>
<td>Undecided/General</td>
<td>6</td>
<td>5.2</td>
</tr>
<tr>
<td>Age Group</td>
<td>Traditional</td>
<td>96</td>
<td>82.8</td>
</tr>
<tr>
<td></td>
<td>Non-Traditional</td>
<td>20</td>
<td>17.2</td>
</tr>
<tr>
<td><em>n = 116</em></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
A summary of the continuous demographic data for the two phases of the pilot study can be seen in Table 3.3. The values for skewness and kurtosis are reported along with these data to demonstrate the shape of the curve for the continuous data. To estimate the critical values for which skewness would be within the normal distribution the standard error of skewness (ses) was calculated using the equation:

\[
\text{ses} = \sqrt{\frac{6}{N}}
\]

where \( N \) is the number of subjects. This value was then multiplied by 2 to include both tails of the curve (Tabachnick & Fidell, 2007). To estimate the critical values for which kurtosis would be within the normal distribution, the standard error of kurtosis (sek) was calculated using the equation:

\[
\text{sek} = \sqrt{\frac{24}{N}}
\]

where \( N \) is the number of subjects. This value was then multiplied by 2 to include both tails of the curve (Tabachnick & Fidell, 2007). For age and GPA, the estimated critical value for skewness is \( \pm 0.455 \) and the estimated critical value for kurtosis is \( \pm 0.910 \). For the age distribution, the high positive value for the observed skewness shows that the age data fall mostly to the lower values of age than the higher values. It is not evenly distributed, but a positively skewed distribution. The high positive value for kurtosis means that the data is “peaked” more than a normal distribution; it is a leptokurtic distribution. These results are to be expected, since a majority of
the students who take the course involved in the study are traditional students. This causes a very drastic change in the distribution of the curve of the data. The skewness and kurtosis values for cumulative GPA are both within the estimated critical values, meaning that the data can be assumed to be normally distributed. This normal distribution for the cumulative GPA is also expected, because the course involved in the study is a general education course that a wide variety of students take and there is no pre-requisite for the course.

Table 3.3

*Age and Cumulative GPA Statistics for Students in the Pilot Study*

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>SD</th>
<th>Median</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Skewness</th>
<th>Kurtosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>22.5</td>
<td>6.4</td>
<td>20</td>
<td>18</td>
<td>53</td>
<td>2.572*</td>
<td>6.830†</td>
</tr>
<tr>
<td>GPA</td>
<td>3.105</td>
<td>0.576</td>
<td>3.201</td>
<td>1.755</td>
<td>4.000</td>
<td>-0.384</td>
<td>-0.687</td>
</tr>
</tbody>
</table>

n = 116

*positively skewed distribution
†leptokurtic distribution

Main Study

The participants for the main study were college students enrolled in a one-semester non-science majors’ chemistry course at the institution of study during the Fall 2009, Spring 2010, Summer 2010, and Fall 2010 semesters. There were a total of 224 students involved in the study for the four semesters. A frequency summary of the main study categorical demographic data can be seen in Table 3.4.
### Table 3.4

**Frequencies of Demographics for Students in Main Study**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Categories</th>
<th>Frequency</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Semester</td>
<td>Fall 2009</td>
<td>74</td>
<td>33.0</td>
</tr>
<tr>
<td></td>
<td>Spring 2010</td>
<td>45</td>
<td>20.1</td>
</tr>
<tr>
<td></td>
<td>Summer 2010</td>
<td>18</td>
<td>8.0</td>
</tr>
<tr>
<td></td>
<td>Fall 2010</td>
<td>87</td>
<td>38.9</td>
</tr>
<tr>
<td>Gender</td>
<td>Male</td>
<td>92</td>
<td>41.1</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>132</td>
<td>58.9</td>
</tr>
<tr>
<td>Race</td>
<td>Caucasian</td>
<td>198</td>
<td>88.4</td>
</tr>
<tr>
<td></td>
<td>African American</td>
<td>11</td>
<td>4.9</td>
</tr>
<tr>
<td></td>
<td>Latino/Hispanic</td>
<td>3</td>
<td>1.3</td>
</tr>
<tr>
<td></td>
<td>Asian</td>
<td>2</td>
<td>0.9</td>
</tr>
<tr>
<td></td>
<td>Other</td>
<td>8</td>
<td>3.6</td>
</tr>
<tr>
<td></td>
<td>Not Reported</td>
<td>2</td>
<td>0.9</td>
</tr>
<tr>
<td>Year in School</td>
<td>Freshman/Other</td>
<td>55</td>
<td>24.6</td>
</tr>
<tr>
<td></td>
<td>Sophomore</td>
<td>95</td>
<td>42.4</td>
</tr>
<tr>
<td></td>
<td>Junior</td>
<td>42</td>
<td>18.8</td>
</tr>
<tr>
<td></td>
<td>Senior/Higher</td>
<td>32</td>
<td>14.3</td>
</tr>
<tr>
<td>Major</td>
<td>Education/Intervention</td>
<td>74</td>
<td>33.0</td>
</tr>
<tr>
<td></td>
<td>Business/Accounting</td>
<td>57</td>
<td>25.4</td>
</tr>
<tr>
<td></td>
<td>Political Science/Economics/Public Relations</td>
<td>10</td>
<td>4.5</td>
</tr>
<tr>
<td></td>
<td>STEMM</td>
<td>21</td>
<td>9.4</td>
</tr>
<tr>
<td></td>
<td>Associates Degrees</td>
<td>10</td>
<td>4.5</td>
</tr>
<tr>
<td></td>
<td>Music/Art/Humanities/Language/Mass Media/Dance</td>
<td>19</td>
<td>8.5</td>
</tr>
<tr>
<td></td>
<td>Social Science/Interdisciplinary</td>
<td>15</td>
<td>6.7</td>
</tr>
<tr>
<td></td>
<td>Undecided/General</td>
<td>18</td>
<td>8.0</td>
</tr>
<tr>
<td>Age Group</td>
<td>Traditional</td>
<td>182</td>
<td>81.2</td>
</tr>
<tr>
<td></td>
<td>Non-Traditional</td>
<td>42</td>
<td>18.8</td>
</tr>
</tbody>
</table>

n = 224

A summary of the continuous demographic data can be seen in Table 3.5.

The estimated critical value for the age skewness is ±0.327 and for kurtosis is ±0.655. From the estimated critical values, the age distribution has a positively skewed and leptokurtic distribution. The estimated critical value for the cumulative GPA skewness is ±0.351 and for kurtosis is ±0.702. The cumulative GPA is
considered to be slightly negatively skewed (having more higher values than lower values) and to have a mesokurtic (normal) distribution.

Table 3.5

*Age and Cumulative GPA Statistics for Students in the Main Study*

<table>
<thead>
<tr>
<th>Variable</th>
<th>n</th>
<th>Mean</th>
<th>SD</th>
<th>Med</th>
<th>Min</th>
<th>Max</th>
<th>Skewness</th>
<th>Kurtosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>224</td>
<td>22.5</td>
<td>6.7</td>
<td>20</td>
<td>18</td>
<td>54</td>
<td>2.658*</td>
<td>7.230†</td>
</tr>
<tr>
<td>GPA</td>
<td>195</td>
<td>3.034</td>
<td>0.586</td>
<td>3.077</td>
<td>1.341</td>
<td>4.000</td>
<td>−0.400*</td>
<td>−0.457</td>
</tr>
</tbody>
</table>

*positively or negatively skewed distribution*  
†leptokurtic distribution

Instruments

Pilot Study

A researcher-designed pre-survey was created to collect the demographics of the students and ascertain the students’ prior knowledge of the chemistry content that was studied during the pilot studies. The students were asked demographic questions about their age, race, year in school, major and cumulative grade point average. Students were also asked open-ended questions about any prior math classes or chemistry classes they had taken and their grades in those courses, and why they were taking and what they hoped to get out of the current chemistry course. For the Spring 2009 phase one pilot study, there were four open-ended content questions for each research topic: reduction-oxidation (redox) reactions and acid-base chemistry. For the Summer 2009 phase two pilot study, there were
seven open-ended content questions for each research topic: bonding and acid-base chemistry. Students were also asked to sign a consent form for the researcher to collect their information, test scores, laboratory scores and final grade. The pilot study pre-survey forms can be seen in Appendix C.

The pre-survey content questions in Spring 2009 study for the reduction-oxidation reactions topic were:

1. What is oxidation number of the pure element H₂?
2. Which element is more electronegative, Nitrogen or Fluorine?
3. When electrons are transferred to an atom the charge on the atom changes to what sign, positive or negative?
4. In the following equation what is being oxidized?

\[
\text{Mg}(s) + 2 \text{HCl}(aq) \rightarrow \text{MgCl}_2(aq) + \text{H}_2(g)
\]

The questions for the acid-base chemistry topic were:

1. What is the pH range for acids?
2. In the following reaction what is the base?

\[
\text{H}_3\text{PO}_4(aq) + \text{H}_2\text{O} \rightarrow \text{H}_2\text{PO}_4^-(aq) + \text{H}_3\text{O}^+(aq)
\]
3. What is the pH of a solution that contains \(3.2 \times 10^{-7}\)M hydronium ions?
4. What is the pH of a neutral solution?

In the phase two pilot study in the Summer 2009 the pre-survey content questions for the bonding topic were:

1. How many valence electrons does sulfur have?
2. Draw the Lewis dot symbol for chlorine.
3. What charge does the calcium ion have?

4. What attraction holds ions together to form ionic compounds?

5. What type of bond is present in a substance that has the following properties:
electrons shared between two non-metals, can be a solid, liquid or gas at
room temperature, has a low melting or boiling point, and is usually soft?

6. How do you determine if a covalent bond is polar or nonpolar?

7. Draw the Lewis structure for HCN.

The questions for the acid-base chemistry topic were:

1. What is the pH range for acids?

2. In the following reaction, label the base and the conjugate acid.
   \[ \text{H}_3\text{PO}_4(aq) + \text{H}_2\text{O} \rightarrow \text{H}_2\text{PO}_4^-(aq) + \text{H}_3\text{O}^+(aq) \]

3. What is the pH of a solution that contains \(3.2 \times 10^{-7}\) M hydronium ions?

4. What is the pH of a neutral solution?

5. What is the difference between a strong and a weak acid?

6. How many moles of sodium hydroxide (NaOH) would be needed to
   neutralize 2.0 moles of hydrochloric acid (HCl)?

7. What two products are formed when an acid and a base are mixed together?

The traditional lectures for reduction-oxidation reactions, acid-base
chemistry, and bonding were created by the researcher. The notes were created
with content from the textbook for the course and other chemistry texts, along with
input from a previous instructor for the course. The lecture notes were designed to
give students the information on the content topics being studied in a lecture format using the chalkboard.

The guided inquiry activities were designed from published Process Oriented Guided Inquiry Learning (POGIL) activities on reduction-oxidation reactions, acid-base chemistry, and bonding (ChemQuests, n.d.; Hanson, 2006; Moog & Farrell, 1996; Moog & Farrell, 2002). The researcher incorporated a variety of published material to make an inquiry activity that fit the content material being covered in the course and to fit in the time allotted for a daily class period. The labs to accompany the guided inquiry activities were also designed from the published labs for the course and other published inquiry labs on the content being covered (Abraham & Ravelich, 1991; Herr & Cunningham, 1999; Williams, 2005).

For the phase one pilot study, the researcher used a variety of published activities on reduction-oxidation reactions merged together to accommodate the information covered in the course and the time that the course was allotted. The learning goals for the reduction-oxidation activity were for students to be able to distinguish electron transfer reactions from other kinds of reactions and for students to characterize electron transfer reactions in terms of the changes in oxidation numbers and electron flow. The material covered in the guided inquiry activity consisted of information and questions on oxidation numbers and electron transfer reactions. The activity also included a section on electrochemical cells that contained both information for the students to read and questions for them to answer. The laboratory consisted of a section where students looked at the
reactivity of different metals and a section where students created electrochemical cells. Both sections were designed to help students see and understand reduction-oxidation reactions. The classroom activity and the accompanying laboratory can be seen in Appendix D.

For the phase two pilot study, the bonding and acid-base chemistry activities were written by the researcher using guidelines and information from published material. The learning objectives for the bonding guided inquiry activity were for students to identify types of bonds in a compound and state the properties of a compound based on the type of bonding. The activity consisted of information and questions on ions, valence and core electrons, and the octet rule. The next section consisted of information and questions on ionic bonds, covalent bonds, multiple bonds, and polar covalent bonds. The laboratory to accompany the guided inquiry activity had students testing properties of different compounds and then determining the type of bonding present in the compound based on the properties found in the lab. The learning objectives for the acid-base chemistry guided inquiry activity consisted of identifying the characteristics of acids and bases, using the pH scale and interpreting its meaning and identifying and quantifying the neutralization of an acid or a base. The activity included information and questions on the properties of acids and bases, conjugate acid-base pairs, and strong and weak acids and bases. The next section of the activity consisted of information and questions about pH, the autoionization of water and the p-scale. The lab to accompany the acid-base chemistry guided inquiry activity had a section for
students to look at the different properties between acids and bases. The second section consisted of information on neutralization reactions and then had students complete an acid-base titration. The two activities and the laboratories that accompanied them from the phase two pilot study can be seen in Appendix E.

The post-test questions were instructor designed for the Spring 2009 phase one pilot study and researcher-designed for the Summer 2009 phase two pilot study. For the Summer 2009 phase two pilot study, the post-test content questions were similar to the content questions on the pre-survey. These questions were incorporated into the test to be given after a certain amount of material had been covered. For the Spring 2009 phase one pilot study, the only research topic that the students' post-test scores were given to the researcher was for the reduction-oxidation reactions topic, the acid-base chemistry topic was not used for the purposes of the research.

The post-test questions for the reduction-oxidation reaction topic were:

1. What is the oxidation number of solid sodium (Na)?
2. Which element is more electronegative, oxygen or hydrogen?
3. When electrons are removed from an atom, the charge on the atom changes to which sign, positive or negative?
4. In the following reaction, what is being reduced?

\[ \text{Mg(s) + 2 HCl(aq) } \rightarrow \text{MgCl}_2(aq) + \text{H}_2(g) \]
5. What is the oxidation number of Cl in HClO₂?
The next two questions use Figure 3.1.

6. Write the half reaction occurring in the anode.

7. What would happen if the salt bridge was removed from a voltaic cell?

8. When a clean iron nail is placed in an aqueous solution of copper (II) sulfate (CuSO₄), the nail becomes coated with a brownish-black material.
   a. What is the material coating the nail?
   b. What is the oxidizing agent?
   c. Can this be made into a voltaic cell? If so, what reaction would occur in the cathode?

9. Which would you expect to be a stronger reducing agent based on its position on the periodic table, sodium (Na) or iron (Fe)? Why?

Figure 3.1. Figure from Redox Post-Test

![Electrolytic Cell Drawing](image)

**Figure 3.1.** The electrolytic cell drawing and caption as given to the students on the post-test to answer questions six and seven. Reprinted from the post-test written by the instructor of the Spring 2009 course.

For the Summer 2009 phase two pilot study, the post-test(s) for the two topics consisted of seven questions from each topic. The questions for the acid-base
chemistry topic were the same as the pre-survey content questions. The post-test questions for the bonding topic were slightly different from the pre-survey content questions.

The post-test questions for the bonding topic were:

1. How many valence electrons does oxygen have?
2. What charge does the beryllium ion have?
3. What attraction holds ions together to form ionic compounds?
4. Write the formula for the ionic compound calcium chloride, using the smallest whole number ratio.
5. What type of bond is present in a substance that has the following properties: electrons shared between two non-metals, can be a solid, liquid or gas at room temperature, has a low melting or boiling point, and is usually soft?
6. What do we label a bond that shares 2 pairs of electrons (4 electrons)?
7. How do you determine if a covalent bond is polar or nonpolar?

All of the instruments used in the pilot study were considered to have face-validity because they were designed and edited by the researcher and an expert in the field. Validity is the degree to which the material measures, tests, or teaches what it was designed to measure, test, or teach. Face-validity is determined by an expert judge validating the material or by gauging a group’s reaction to the test to see if it appears to be measuring, testing, or teaching what it was designed to do (Newman, Newman, Brown, & McNeely, 2006).
Main Study

A second researcher-designed pre-survey was created to collect the demographics of the students and ascertain the students’ prior knowledge on the chemistry content that was studied during the main study. The students were asked demographic questions about their age, race, year in school, major and cumulative grade point average. Students were also asked open-ended questions about any prior math classes or chemistry classes they had taken and their grades in those courses, and why they were taking and what they hoped to get out of the current chemistry course. Students were also asked if they would be willing to participate in an interview about the research later in the semester. There were four open-ended content questions for each research topic: bonding (ionic and covalent), chemical equations (writing and balancing), and acid-base chemistry (properties, pH and neutralization). The students were also asked to fill out a consent form for the researcher to collect their information, test scores, laboratory scores, and final grade. Appendix F contains the main study pre-survey.

The content questions that were used for the pre-survey and later as post-test questions for the bonding topic were:

1. What charge does the calcium ion have?

2. Describe the formation of an ionic bond in terms of the electrons.
3. What type of bond is present in a substance that has the following properties:
electrons shared between two non-metals, can be a solid, liquid or gas at
room temperature, has a low melting or boiling point, and is usually soft?

4. How do you determine if a covalent bond is polar or nonpolar?

The pre-survey and post-test questions for the chemical equations topic were:

1. State the type of chemical equation for the following reaction.
   \[ \text{Mg} + \text{Ca}_3(\text{PO}_4)_2 \rightarrow \text{Mg}_3(\text{PO}_4)_2 + \text{Ca} \]

2. List the reactants in the following reaction.
   \[ \text{Mg} + \text{Ca}_3(\text{PO}_4)_2 \rightarrow \text{Mg}_3(\text{PO}_4)_2 + \text{Ca} \]

3. What does the triangle mean above the arrow in the following equation?
   \[ 2\text{CH}_3\text{OH}(\text{l}) + 3\text{O}_2(\text{g}) \xrightarrow{\Delta} 2\text{CO}_2\uparrow + 4\text{H}_2\text{O}(\text{l}) \]

4. Balance the following chemical equation.
   \[ \_\_\_\text{Al} + \_\_\_\text{H}_2\text{SO}_4 \rightarrow \_\_\_\text{Al}_2(\text{SO}_4)_3 + \_\_\_\text{H}_2 \]

The pre-survey and post-test questions for the acid-base chemistry topic were:

1. What is the pH range for acids?

2. In the following reaction label the base and the conjugate acid.
   \[ \text{H}_3\text{PO}_4(\text{aq}) + \text{H}_2\text{O} \rightarrow \text{H}_2\text{PO}_4^{-}(\text{aq}) + \text{H}_3\text{O}^{+}(\text{aq}) \]

3. What is the pH of a solution that contains \(3.2 \times 10^{-7}\text{M}\) hydronium ions?

4. How many moles of sodium hydroxide (NaOH) would be needed to
   neutralize 2.0 moles of hydrochloric acid (HCl)?

The traditional lectures on bonding, chemical equations, and acid-base
chemistry were created by the researcher. The notes were created with content
from the textbook for the course and other chemistry texts, along with input from a previous instructor for the course. The lecture notes were designed to give students the information on the content topics being studied in a lecture format using the chalkboard.

The guided inquiry activities were written by the researcher, but published POGIL activities on bonding, chemical equations and acid-base chemistry were used as guidelines and examples (ChemQuests, n.d.; Hanson, 2006; Moog & Farrell, 2002). An instructor for the course also gave feedback on the design and content in the activities. The researcher designed the activities to match the material to be taught during the course and to fit in the time allotted for a daily class period. The labs to accompany the guided inquiry activities were also researcher-designed, but published labs were used as guidelines and examples (Herr & Cunningham, 1999; Williams, 2005).

The learning objectives for the bonding guided inquiry activity were for students to identify types of bonds in a compound and state the properties of a compound based on the type of bonding. The activity consisted of information and questions on ions, valence and core electrons, and the octet rule. The next section consisted of information and questions on ionic bonds, covalent bonds, multiple bonds, and polar covalent bonds. The laboratory to accompany the guided inquiry activity had students test a variety of properties of different compounds and then determine the bonding present in the compound based on the properties found in the lab. The learning objectives for the chemical equations guided inquiry activity

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consisted of recognizing the types of chemical reactions and balancing chemical
equations. The activity had information and questions on writing chemical
equations, representing states of matter, types of chemical equations, and balancing
chemical equations. The laboratory to accompany the activity had students
complete seven different chemical reactions in the lab and then write complete
balanced chemical equations for those reactions. The acid-base chemistry topic was
divided into two separate guided inquiry activities for the main study. The first
activity was on properties of acids and bases and had learning objectives of
identifying characteristics of acids and bases and determining strong or weak acids
and bases. The activity consisted of information and questions on acid and base
definitions, conjugate acid-base pairs, and strong and weak acids and bases. The
laboratory to accompany the first activity had students test a variety of properties of
different chemicals and then determine if they were an acid or a base. The second
guided inquiry activity on acid-base chemistry was on pH and neutralization
reactions. The activity had learning objectives of using the pH scale and interpreting
its meaning and identifying and quantifying neutralizations of an acid or a base. The
activity consisted of information and questions on pH, the autoionization of water,
and neutralization reactions. The laboratory to accompany the second acid-base
chemistry guided inquiry activity had students completing an acid-base titration for
a known acid concentration and an acid with unknown concentration. See
Appendix G for the guided inquiry and lab activities.
The post-test questions were researcher-designed and matched the content questions on the pre-survey. There were four sample questions for each topic covering the content material being studied (bonding, chemical equations, and acid-base chemistry). These questions were incorporated into the tests to be given after a certain amount of material had been covered.

All of the instruments used in the main study were again considered to have face-validity because they were designed and edited by the researcher and an expert in the field.

Procedure

The general procedure for the study was the same for the two phases of the pilot study and the main study. Before the start of the semester the course instructor was given a verbal description of the study and was asked to sign a consent form to allow the study to occur with the students. The instructor was asked to allow the researcher to take over the course on the days the content material being studied (bonding, chemical equations, and acid-base chemistry) was to be taught.

The students were given the pre-survey and a consent form on the first day of the course. The researcher gave a brief talk about the study; telling students the purpose of the study, what changes the students would see in the classroom and the information the researcher would collect about each student. The researcher did
not state any of the research questions or hypotheses. The students then filled out the pre-survey and the consent form during class. These were collected from the students by the researcher and each student who consented was assigned a code to keep the student data anonymous to everyone but the researcher. The code was assigned randomly to each student, and it matched the course section code used by the researcher. For Spring 2009 the two course sections were coded 1 and 0, and student codes ranged from 1 to 89. For Summer 2009 the two course sections were coded 100 and 101, and student codes ranged from 101 to 128.

For the main study, all the students filled out the pre-survey. The students scores on the content questions were used in forming the lab groups the students would be in for the remainder of the semester. A stratified random sampling based on the pre-survey content question scores was used to make the lab groups. Any student could opt out of the study by not completing the consent form; no further data would be collected. Students who consented to be a part of the study were randomly assigned codes, to keep their data anonymous to everyone but the researcher. The codes that the students were assigned again matched the code used for the course sections. The two course sections in the Fall 2009 were coded 200 and 201 and student codes ranged from 200 to 285; for Spring 2010 the section was coded 300 and the student codes ranged from 300 to 349; for Summer 2010 the section was coded 400 and the student codes ranged from 401 to 418; the two sections in the Fall 2010 were coded 500 and 501 and the student codes ranged from 501 to 595.
On day(s) the content material was covered in the course, the researcher would either give a traditional lecture on the material or would work with students on the guided inquiry activity. In semesters when there were two separate sections of the course, one section would receive the traditional lecture on a topic and the other section would do the guided inquiry activity on the same topic. The sections would switch the teaching styles for the other topics. This way, each section was subjected to both teaching styles. When there was only one section being taught, the style of teaching was switched between the topics, except for the Spring 2010 semester.

During the traditional lecture class periods, students were expected to take their own notes based on what the researcher wrote on the board or said during class. The lecture lasted for about an hour. The students then went to lab and completed a laboratory that accompanied the topic being covered. The lab period lasted for about two hours, but students were allowed to leave as soon as their group had completed the lab.

During the guided inquiry class periods, students worked with their lab groups to complete the guided inquiry activity during the first hour of the class period. The researcher and sometimes the instructor walked around the classroom to answer students’ questions and to make sure students understood the material being presented in the activity as indicated by correctly answering the activity questions. Students then went to lab for the next two hours to work on the laboratory that accompanied the guided inquiry activity. Students were free to
leave after their group had completed the laboratory and were not required to stay for the full two hours. In the next class period, the researcher would conduct a follow-up on the material presented in the previous class period. The researcher would present the answers and explanations to some of the guided inquiry activity questions and also answer any of the questions that the students had about the material. This follow-up would last no longer than fifteen minutes, but the exact time of the follow-up was dictated by the number of student questions. The follow-up for the bonding guided inquiry activity also consisted of a worksheet that summarized the material from the guided inquiry activity and the lab that the students did the following class period. This follow-up worksheet for the bonding topic can be seen in Appendix H.

During the days the researcher was in the classroom with the students, the researcher kept a journal about the day, including information on the length of the lecture and the attentiveness and participation of the students. During the guided inquiry class periods, the researcher recorded the start and stop time of the class period, how much of the activity groups had completed at different times during the class period, students' attentiveness and participation during the activity, and the general classroom atmosphere. During the lab time, both after the traditional lecture and guided inquiry activities, the journal included the timing of the laboratory for the lab groups, the attentiveness and participation of the students, and the lab atmosphere.
The post-test questions on the content material being covered were given to the students on the exam given by the instructor. These exams were given on days following the presentation of the material. The questions for the research study were not identified as research questions on the exam. The students' answers to the post-test questions were photocopied from the exam and graded for correctness by the researcher.

Interviews

Interviews were conducted with some of the students during the main study (Fall 2009, Spring 2010, Summer 2010, and Fall 2010 semesters) to evaluate students' understanding of the content topics covered during the research and to assess their opinions about the guided inquiry activities and laboratories. Students were asked during the pre-survey if they would be willing to participate in an interview for this research study. A random sample of these students was contacted via email to set up an interview time near the end of the semester, after all of the research content topics had been covered. If a response was not received in two weeks, a second email was sent to the same student. There was no further contact made if no response was received from the student after the second email. For the Fall 2010 semester, if a response was not received after another two weeks, another student was randomly contacted. This process continued until a week before the end of the semester or until there was no more students to contact.
In the Fall 2009 semester, a total of twenty students was contacted (27.0 percent of the students); eleven from one section and nine from another. Eight students responded (40.0 percent response rate) and six interviews were conducted. In the Spring 2010 semester, a total of fourteen students was contacted (31.1 percent of the students). Six students responded (42.9 percent response rate) and five interviews were conducted. In the Summer 2010 semester, a total of eight students was contacted (44.4 percent of the students). Four students responded (50.0 percent response rate) and four interviews were conducted. In the Fall 2010 semester, a total of 47 students was contacted (54.0 percent of the students); 16 from one section and 31 from the other. Eight students responded (17.0 percent response rate) and five interviews were conducted. A summary of this data can be seen in Table 3.6.

Table 3.6

<table>
<thead>
<tr>
<th>Semester</th>
<th>Students Contacted</th>
<th>Student Response</th>
<th>Interviews Conducted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall 2009</td>
<td>20 (27.0%)</td>
<td>8 (40.0%)</td>
<td>6</td>
</tr>
<tr>
<td>Spring 2010</td>
<td>14 (31.1%)</td>
<td>6 (42.9%)</td>
<td>5</td>
</tr>
<tr>
<td>Summer 2010</td>
<td>8 (44.4%)</td>
<td>4 (50.0%)</td>
<td>4</td>
</tr>
<tr>
<td>Fall 2010</td>
<td>47 (54.0%)</td>
<td>8 (17.0%)</td>
<td>5</td>
</tr>
</tbody>
</table>

There were 20 students interviewed from the four semesters of the main study. A frequency summary of the categorical demographic data from the interview participants can be seen in Table 3.7.
Table 3.7

*Frequencies of Demographics for Students Interviewed*

<table>
<thead>
<tr>
<th>Variable</th>
<th>Categories</th>
<th>Frequency</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Semester</td>
<td>Fall 2009</td>
<td>5</td>
<td>25.0</td>
</tr>
<tr>
<td></td>
<td>Spring 2010</td>
<td>6</td>
<td>30.0</td>
</tr>
<tr>
<td></td>
<td>Summer 2010</td>
<td>4</td>
<td>20.0</td>
</tr>
<tr>
<td></td>
<td>Fall 2010</td>
<td>5</td>
<td>25.0</td>
</tr>
<tr>
<td>Gender</td>
<td>Male</td>
<td>5</td>
<td>25.0</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>15</td>
<td>75.0</td>
</tr>
<tr>
<td>Race</td>
<td>Caucasian</td>
<td>17</td>
<td>85.0</td>
</tr>
<tr>
<td></td>
<td>African American</td>
<td>1</td>
<td>5.0</td>
</tr>
<tr>
<td></td>
<td>Latino/Hispanic</td>
<td>2</td>
<td>10.0</td>
</tr>
<tr>
<td>Year in School</td>
<td>Freshman/Other</td>
<td>5</td>
<td>25.0</td>
</tr>
<tr>
<td></td>
<td>Sophomore</td>
<td>8</td>
<td>40.0</td>
</tr>
<tr>
<td></td>
<td>Junior</td>
<td>3</td>
<td>15.0</td>
</tr>
<tr>
<td></td>
<td>Senior/Higher</td>
<td>4</td>
<td>20.0</td>
</tr>
<tr>
<td>Major</td>
<td>Education/Intervention</td>
<td>7</td>
<td>35.0</td>
</tr>
<tr>
<td></td>
<td>Business/Accounting</td>
<td>2</td>
<td>10.0</td>
</tr>
<tr>
<td></td>
<td>Political Science/Economics/Public Relations</td>
<td>1</td>
<td>5.0</td>
</tr>
<tr>
<td></td>
<td>STEMM</td>
<td>3</td>
<td>15.0</td>
</tr>
<tr>
<td></td>
<td>Associates Degrees</td>
<td>1</td>
<td>5.0</td>
</tr>
<tr>
<td></td>
<td>Music/Art/Humanities/Language/Mass Media/Dance</td>
<td>1</td>
<td>5.0</td>
</tr>
<tr>
<td></td>
<td>Social Science/Interdisciplinary</td>
<td>2</td>
<td>10.0</td>
</tr>
<tr>
<td></td>
<td>Undecided/General</td>
<td>3</td>
<td>15.0</td>
</tr>
<tr>
<td>Age</td>
<td>Traditional</td>
<td>15</td>
<td>75.0</td>
</tr>
<tr>
<td>Group</td>
<td>Non-Traditional</td>
<td>5</td>
<td>5.0</td>
</tr>
</tbody>
</table>

\(n = 20\)

A summary of the continuous demographic data for the interview participants can be seen in Table 3.8. The estimated critical value for the age skewness is ±1.095 and for kurtosis is ±2.191. From the estimated critical values, the age distribution has a positively skewed and a slightly leptokurtic distribution. The estimated critical value for the cumulative GPA skewness is ±1.155 and for kurtosis is ±2.309. The cumulative GPA is considered to be slightly negatively skewed and slightly leptokurtic in its distribution.
Table 3.8

*Age and Cumulative GPA for Students Interviewed*

<table>
<thead>
<tr>
<th>Variable</th>
<th>n</th>
<th>Mean</th>
<th>SD</th>
<th>Med</th>
<th>Min</th>
<th>Max</th>
<th>Skewness</th>
<th>Kurtosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>20</td>
<td>24.6</td>
<td>9.8</td>
<td>20</td>
<td>18</td>
<td>54</td>
<td>1.897*</td>
<td>2.241†</td>
</tr>
<tr>
<td>GPA</td>
<td>18</td>
<td>3.307</td>
<td>0.684</td>
<td>3.485</td>
<td>1.341</td>
<td>4.000</td>
<td>-1.523*</td>
<td>2.761†</td>
</tr>
</tbody>
</table>

*positively or negatively skewed distribution  †leptokurtic distribution

Before the interview, students were asked to sign a consent form that was designed for the interview. The interview was audio taped and later transcribed and coded. Each interview was given an identification code and the student was identified using his or her ID number for the study. During the interview, students were asked the same content questions as were found on the pre-survey and post-tests. The students were then asked to explain their reasoning for the answer that was given or to elaborate on their answer. The researcher then asked a variety of other questions to determine what the student knew about the material. Students were also asked a series of attitudinal questions about the guided inquiry activities and the laboratories they completed during the course. The researcher asked for positive and/or negative comments or opinions about the activities and any changes the students would make if they did the activities again. Students were also asked whether they would prefer traditional lecture or guided inquiry activities in science courses such as the chemistry course in which they were enrolled. The interview was concluded by allowing students to ask any questions about the research or the content questions and allowing them to give any additional thoughts or comments.

See Appendix I for the interview protocol.
Research Hypotheses

**Research Hypothesis One:** There is a significant difference, overall and based on topic, between students’ test percentages and teaching style in a non-science majors’ one-semester chemistry course, such that students who participate in the guided inquiry activities will have significantly higher test percentages than the students in the traditional lecture classroom.

The null hypothesis states that there would be no statistically significant difference between students’ test percentages and the teaching style.

For the hypothesis of difference between the two teaching styles:

\[ H_0: \bar{x}_t = \bar{x}_g \quad H_1: \bar{x}_t < \bar{x}_g \]

where \( t \) represents the traditional lecture classroom and \( g \) represents the guided inquiry classroom.

For the hypothesis of difference between the two teaching styles based on topic:

\[ H_0: \bar{x}_{ti} = \bar{x}_{gi} \quad H_1: \bar{x}_{ti} < \bar{x}_{gi} \]

where \( t \) represents the traditional lecture classroom and \( g \) represents the guided inquiry classroom; the \( i \) represents the different topics for which the study was conducted.

**Research Hypothesis Two:** There is a significant difference, overall and based on topic, for student test percentages in a non-science majors’ one-semester chemistry course taught via guided inquiry, such that a statistically significant
difference will exist between males and females, between traditional students and non-traditional students, among students of different races, among students with differing years in school, among students of different majors, and among students with varying cumulative GPA groups.

The null hypothesis states that there would be no significant difference between guided inquiry students’ test percentages and gender, age group, race, year in school, major, and cumulative GPA group. Table 3.9 contains the independent variables tested, and the null and alternative hypotheses, between groups based on guided inquiry post-test content percentages.

Table 3.9

<table>
<thead>
<tr>
<th>Independent Variable</th>
<th>Null Hypothesis (H0)</th>
<th>Alternative Hypothesis (H2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>$\bar{x}<em>{mi} = \bar{x}</em>{fi}$</td>
<td>$\bar{x}<em>{mi} \neq \bar{x}</em>{fi}$</td>
</tr>
<tr>
<td></td>
<td>$m = males; f = females$</td>
<td></td>
</tr>
<tr>
<td>Age Group</td>
<td>$\bar{x}<em>{ti} = \bar{x}</em>{ni}$</td>
<td>$\bar{x}<em>{ti} \neq \bar{x}</em>{ni}$</td>
</tr>
<tr>
<td></td>
<td>$t = traditional student; n = non-traditional student$</td>
<td></td>
</tr>
<tr>
<td>Race</td>
<td>$\bar{x}<em>{ci} = \bar{x}</em>{AAl} = \bar{x}<em>{Li} = \bar{x}</em>{Oi}$</td>
<td>$\bar{x}<em>{ci} \neq \bar{x}</em>{AAl} \neq \bar{x}<em>{Li} \neq \bar{x}</em>{Oi}$</td>
</tr>
<tr>
<td></td>
<td>$C = Caucasian; AA = African American; L = Latin; A = Asian; O = other$</td>
<td></td>
</tr>
<tr>
<td>Year in School</td>
<td>$\bar{x}<em>{Fi} = \bar{x}</em>{Soi} = \bar{x}<em>{Ji} = \bar{x}</em>{SrI}$</td>
<td>$\bar{x}<em>{Fi} \neq \bar{x}</em>{Soi} \neq \bar{x}<em>{Ji} \neq \bar{x}</em>{SrI}$</td>
</tr>
<tr>
<td></td>
<td>$F = freshmen; So = sophomore; J = junior; Sr = senior or higher$</td>
<td></td>
</tr>
<tr>
<td>Major</td>
<td>$\bar{x}<em>{Eli} = \bar{x}</em>{Bi} = \bar{x}<em>{PSi} = \bar{x}</em>{STEMMli} = \bar{x}<em>{ADli} = \bar{x}</em>{MI} = \bar{x}<em>{SSI} = \bar{x}</em>{Uli}$</td>
<td>$\bar{x}<em>{Eli} \neq \bar{x}</em>{Bi} \neq \bar{x}<em>{PSi} \neq \bar{x}</em>{STEMMli} \neq \bar{x}<em>{ADli} \neq \bar{x}</em>{MI} \neq \bar{x}<em>{SSI} \neq \bar{x}</em>{Uli}$</td>
</tr>
<tr>
<td></td>
<td>$E = education; B = business; PS = political science; STEMM = science, etc; AD = associates degree; M = Music, etc; SS = social sciences; U = undecided$</td>
<td></td>
</tr>
<tr>
<td>GPA Group</td>
<td>$\bar{x}<em>{1i} = \bar{x}</em>{2i} = \bar{x}<em>{3i} = \bar{x}</em>{4i} = \bar{x}_{Ei}$</td>
<td>$\bar{x}<em>{1i} \neq \bar{x}</em>{2i} \neq \bar{x}<em>{3i} \neq \bar{x}</em>{4i} \neq \bar{x}_{Ei}$</td>
</tr>
<tr>
<td></td>
<td>$1 = 4.00 to 3.35; 2 = 3.34 to 2.65; 3 = 2.64 to 1.65; 4 = 1.64 to 0; E = entering freshmen, etc$</td>
<td></td>
</tr>
</tbody>
</table>

*i* represents the total percent on guided inquiry or the percent on each topic
Research Hypothesis Three: Students’ opinions about the guided inquiry activities used in a non-science majors’ one semester chemistry course will be mainly positive and students will find the activities helpful compared to the traditional lecture style of teaching.

Analysis Procedure

Statistical Treatment

This investigation utilized both descriptive and inferential statistics. The same statistics were calculated for both of the pilot studies and the main study. Descriptive statistics, computed for the demographic variables, included means, standard deviations, medians, ranges, and frequency distributions. Skewness and kurtosis values were also calculated to evaluate the distribution of the data. Descriptive statistics were also computed on the pre-survey content question percentages, post-test content question percentages, and gain scores, overall and by topic, and the final grades in the course. According to Newman, Newman, Brown, and McNeely (2006), descriptive statistics are “used for describing the population or sample on which one has data” (p.5).

A chi-square ($\chi^2$) analysis was conducted by class on the demographic variables and the final grades in the course to determine if any statistically significant differences existed between the class sections for each semester that the
study was conducted or the instructor that taught the course. A chi-square analysis is used to determine if the frequency count between groups is statistically significantly different from the expected frequency count (Newman et al., 2006). An analysis of variance (ANOVA) was also conducted by class on the pre-survey content question percentage correct and student cumulative GPA since these variables were not nominal and a chi-square analysis could not be conducted. A non-significant $\chi^2$-value or ANOVA would show that the classes were not statistically significantly different. These tests were done so that cross-class comparisons could be made across each semester and course due to equivalency of groups (Nurrenbern & Robinson, 1994).

Inferential statistics were computed for the post-test content question percentages. A Levene’s test for equality of variances was first computed before every inferential statistical test. This test is used to see if there are equal variances among the groups; it is fairly insensitive to non-normally distributed data. If the Levene test had significant results, then the assumption that the groups are equal is invalid and alternatives were taken in the statistical test to account for the unequal variance (Wielkiewicz, 2000).

A one-tailed dependent $t$-test was conducted to determine if there was a statistically significant difference between student total post-test percentage correct for the topics covered with the guided inquiry activities and the total post-test percentage correct for the topics that were covered via the traditional lecture. A dependent $t$-test was used on the total percentage based on teaching style because
each student was exposed to both teaching methods over the course of the study. A one-tailed $t$-test was conducted because the researcher predicted that the guided inquiry students would have higher content question post-test percentages than the traditional lecture students. A $t$-test is used to determine if there is a significant difference between two groups of interval data (Newman et al., 2006).

The assumption for a dependent $t$-test is that the distribution is normal for the mean of the sample. This is accomplished by having a sample size greater than thirty. For this test, the pair differences must be independent of each other and also be normally distributed (Pagano, 2001).

A one-tailed independent $t$-test was performed to determine if there was a statistically significant difference between the post-test percentages correct for the students in the traditional lecture classroom and the guided inquiry classroom for each topic. An independent $t$-test was used on the per topic data because each sample group was independent of the other, since each group was only taught each topic via one teaching method. A one-tailed $t$-test was conducted because the researcher predicted that the guided inquiry students would have higher content question post-test percentages than the traditional lecture students.

A two-tailed independent $t$-test was conducted to determine if there was a statistically significant difference between the post-test percentage correct for students based on the students’ gender and age group on the topics taught via guided inquiry. An independent $t$-test was used on the data because each sample group was independent of the other, since groups were mutually exclusive. A two-
tailed *t*-test was conducted because the researcher did not predict which group would have statistically higher post-test percentages than the other.

The underlying assumptions for independent *t*-tests are that the distribution of the sample is normally distributed and that the variances of the two populations are equal. The *t*-test is considered to be a robust test, meaning it is relatively insensitive to violations of the underlying assumptions. When sample sizes are greater than thirty and if the sizes of samples are similar, the *t*-test may be used without significant error when moderate violations in normality and/or homogeneity of variance are present in the data (Pagano, 2001).

An ANOVA (analysis of variance) was conducted to determine if there were statistically significant differences between the post-test percentage correct for students based on their year in school, cumulative grade point average (GPA) group, major, and race on the topics that were taught via guided inquiry. An ANOVA was performed because each variable had more than two categories, and the categories were mutually exclusive. An ANOVA is used to determine if two or more groups are statistically significantly different simultaneously when using interval data (Newman *et al.*, 2006).

If the results of the ANOVA test indicated that a significant difference existed between at least two of the groups compared, then a pair-wise post hoc analysis was conducted to determine between which groups the statistically significant difference existed. A Tukey's Honestly Significant Difference (Tukey's HSD) test was used when there was an assumption of equal variance between the groups; this test
compares all possible means while maintaining Type I error rate at the alpha level specified for the entire set of comparisons (Pagano, 2001). A Games-Howell test was used when an assumption of equal variance could not be made between the groups. This test is robust when the sample size between groups is different and homogeneity cannot be assumed (Hilton & Armstrong, 2006).

The assumptions for the ANOVA are similar to the assumptions for the t-tests. It assumes the samples are normally distributed and have equal variances between the groups. The ANOVA is also a robust test and is relatively insensitive to violations to normality or homogeneity of variance if the sizes of the groups are similar (Pagano, 2001).

Each of the above statistical tests was conducted based on the total percentage correct on all of the topics and the percent correct on each individual topic. Gain scores were also used to calculate each of the above statistical tests. Effect sizes were calculated for each of the categorical variables. All of the statistical tests were performed on the Statistical Package for the Social Sciences (SPSS) version 17.0 at an alpha level of 0.05.

Normalized gain scores were used to look at the maximum possible gain students could have made after the implementation of the teaching style based on their pre-survey content question percent correct. The following formula was used to calculate the gain scores for the students:

\[
gain = \frac{\text{post test\%} - \text{pretest\%}}{100\% - \text{pretest\%}}
\]
where the percentage used for both the pre- and post-test scores were the percentage of questions the student answered correctly (Willoughby & Metz, 2009). Using this calculation helps to account for the differences in the pre-test percentages of the students (Lorenzo, Crouch & Mazur, 2006).

Significance testing shows how groups are different, but it does not always show the degree to which the independent and dependent variables are related. How much the variables are related can dictate how practically significant the results are and not just how statistically significant they are. Effect size ($\eta^2$) shows what proportion of the variance of the dependent variable is associated with an independent variable. The guidelines used to determine the amount of an effect for an experiment in the social/clinical areas are small ($\eta^2 = 0.01$), medium ($\eta^2 = 0.09$), and large ($\eta^2 = 0.25$) effects (Tabachnick & Fidell, 2007).

Interview Analysis

Transcribed interviews were coded in two separate sections. The content questions were coded for the correctness of the answers the students gave and also coded for the reasoning the students gave for the answer. The codes for the content question answers and the reasons the students gave were determined from the responses of the students. The student responses to the attitudinal questions were coded using categories developed from the responses the students presented, as well as categories defined by the researcher in advance. The attitudinal codes were:
helpful/not helpful, like/not like, easy/hard, previous knowledge of material, thoughts on working in a group, how much of the activity was completed/thoughts on time, lab/lecture/activity overlap, changes student would make to activity/lab, student preference to lecture or activity. The interview coding schemes for the content and attitudinal questions can be seen in Appendix J.

Once the codes were developed for both sets of questions, intra- and inter-rater reliabilities were calculated. This was done by having five of the twenty interviews (25.0 percent) coded by the researcher a second time (intra-rater) and also coded by another coder other than the researcher (inter-rater). The agreement between the codes was then calculated by the equation from Miles and Huberman (1994):

\[
\text{intra/inter - rater reliability} = \frac{\text{number of codes agree}}{\text{total number of codes analyzed}}
\]

An intra-rater reliability of 0.80 was viewed as acceptable for both the content and attitudinal coding. An inter-rater reliability of 0.80 was used as an acceptable value for the reliability of the coding schemes for the content questions and an inter-rater reliability of 0.60 was used as an acceptable value for the reliability of the attitudinal coding. An intra-rater reliability of 0.88 was calculated for the content questions and a reliability of 0.83 was calculated for the attitudinal questions. An inter-rater reliability of 0.82 was calculated for the content questions and a reliability of 0.66 was calculated for the attitudinal questions. This was done to show that the coding scheme was a reliable scheme and could be used by others and also used consistently by the researcher (Miles & Huberman, 1994).
Frequency counts for the content question answer codes were tabulated. These tabulated codes were also broken down based on the type of teaching the student received for each topic (guided inquiry or traditional lecture). For questions that showed different results for the frequency count of the answer codes between the teaching methods or showed higher frequency counts for wrong answer codes than correct answer codes, frequency counts were also analyzed for the reasons that the students gave the answers.

For the attitudinal codes, a partially-ordered descriptive matrix was created. This matrix had each row representing a student who was interviewed and the answers they gave to attitudinal questions and the columns represented some of the variables the interviews were coded by that would help answer research question three. The column variables were: previous chemistry, thoughts on group work/group interactions, comments on helpful items, comments on non-helpful items, timing of the activities, lab and lecture connections, changes the student would make, and type of teaching preferred. The researcher then filled in the matrix using summary statements or paraphrases of what the students said in the interview about each of the variables. This was done on general terms and not specific to each topic. If a comment was directed at one topic in particular, the researcher noted this in the matrix. Each summary was also labeled with a code that would lead back to the direct quote in the transcribed interview.

The variables of previous chemistry, thoughts on group work/group, and timing of the activities were then designated a shorter code by the researcher so
that the other variables could be clustered by them. The codes for each of these variables and the decision rules to assign the codes can be seen in Table 3.10. The variables were also clustered by the type of teaching preferred.

Table 3.10

*Attitudinal Interview Matrix Variable Codes and Assignment Rules*

<table>
<thead>
<tr>
<th>Variable</th>
<th>Code</th>
<th>Assignment Rule</th>
</tr>
</thead>
<tbody>
<tr>
<td>Previous Chemistry</td>
<td>No</td>
<td>No prior chemistry course taken</td>
</tr>
<tr>
<td></td>
<td>HS−</td>
<td>Had high school chemistry, but commented they did not remember the material or had to relearn all the material</td>
</tr>
<tr>
<td></td>
<td>HS</td>
<td>Had high school chemistry, but made no comments about remembering or not remembering the material</td>
</tr>
<tr>
<td></td>
<td>HS+</td>
<td>Had high school chemistry, and made comments that they remembered most of the material or that not much new was taught</td>
</tr>
<tr>
<td></td>
<td>AP</td>
<td>Had AP chemistry in high school and the material was all a review</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>Taken a prior college chemistry course (either dropped, failed, or passed)</td>
</tr>
<tr>
<td>Thoughts on Group Work/Group</td>
<td>−</td>
<td>Had negative comments about working in a group or the group they had. Comments like “the group did not help,” or “had trouble working in group”</td>
</tr>
<tr>
<td></td>
<td>−/+</td>
<td>Had both negative and positive comments about the group work or the group they were in</td>
</tr>
<tr>
<td></td>
<td>+</td>
<td>Had positive comments about working in a group or the group they had. Comments like “working in a group was helpful,” or “the group worked well together”</td>
</tr>
<tr>
<td>Timing of the Activities</td>
<td>NA</td>
<td>No comments were made about the timing of the activities in the interview</td>
</tr>
<tr>
<td></td>
<td>−</td>
<td>Had negative comments about the timing of the activities or labs. Comments like “we did not have time to finish,” or “we got done fast with a lot of time to spare”</td>
</tr>
<tr>
<td></td>
<td>−/+</td>
<td>Had both negative and positive comments about the timing of the activities or labs. Comments like “only did not finish one of the activities/labs, but finished the rest”</td>
</tr>
<tr>
<td></td>
<td>+</td>
<td>Had positive comments about the timing of the activities or labs. Comments like “finished all of the packets,” or “did not have any problems with time”</td>
</tr>
</tbody>
</table>
The matrix was then analyzed for different themes and patterns. The data were also broken down into chunks, based on the above categories, to look for more detailed themes. Comparisons and contrasts were made based on the variables in the matrix and the sub-matrices from the chunking.

The variables of comments on helpful items and comments on non-helpful times were partitioned into extra categories to look for more detailed descriptions. These two variables were each partitioned into three other subcategories: items that were activity related, items that were classroom related, and items that were lab related.
CHAPTER IV

RESULTS

Introduction

The purpose of this chapter is to report the results of the statistical and qualitative analyses conducted for this research study. This chapter will be divided into four separate sections including the descriptive and inferential statistics for the quantitative portion of the study (student test percentages) and the descriptive statistics and qualitative analysis of the interviews conducted during the study. The data and analysis were used to either support or reject the following hypotheses:

**Research Hypothesis One:** There is a significant difference, overall and based on topic, between students’ test percentages and teaching style in a non-science majors’ one-semester chemistry course, such that students who participate in the guided inquiry activities will have significantly higher test percentages than the students in the traditional lecture classroom.

**Research Hypothesis Two:** There is a significant difference, overall and based on topic, for student test percentages in a non-science majors’ one-semester
chemistry course taught via guided inquiry, such that a statistically significant
difference exists between males and females, between traditional students and non-
traditional students, among students of different races, among students with
differing years in school, among students with different majors, and among students
with varying cumulative GPA groups.

Research Hypothesis Three: Students’ opinions about the guided inquiry
activities used in a non-science majors’ one-semester chemistry course will be
mainly positive and students will find the activities helpful compared to the
traditional style of teaching.

Quantitative Data Analysis

Descriptive Statistics

Pilot Study Phase One

A summary of the pre-survey content question percentages for phase one of
the pilot study can be found in Table 4.1. The data are for all of the students who
participated in the phase one pilot study during the Spring 2009 and are broken
down by the topic (reduction-oxidation (redox) reactions and acid-base chemistry)
and by the total percentage. The standard error of skewness (ses) and the standard
error of kurtosis (sek) are $\pm 0.522$ and $\pm 1.044$ respectively for each of the variables, since they all have the same sample sizes.

Table 4.1

*Pre-Survey Content Questions Percentage Statistics for Students in the Phase One Pilot Study*

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>SD</th>
<th>Med</th>
<th>Min</th>
<th>Max</th>
<th>Skewness</th>
<th>Kurtosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Redox Reactions</td>
<td>26.1</td>
<td>26.51</td>
<td>25.0</td>
<td>0.0</td>
<td>100.0</td>
<td>0.796*</td>
<td>-0.319</td>
</tr>
<tr>
<td>Acid-Base Chemistry</td>
<td>15.6</td>
<td>20.87</td>
<td>0.0</td>
<td>0.0</td>
<td>75.0</td>
<td>1.170*</td>
<td>0.517</td>
</tr>
<tr>
<td>Total</td>
<td>20.7</td>
<td>17.15</td>
<td>12.5</td>
<td>0.0</td>
<td>62.5</td>
<td>0.560*</td>
<td>-0.443</td>
</tr>
</tbody>
</table>

n=88

*positively skewed distribution

Both of the topics and the total have positively skewed distributions. This is to be expected since many of the students were unable to answer or give correct answers to the content questions on the pre-survey. Both of the topics and the total percent on the pre-survey have mesokurtic distributions.

A summary of the post-test percentages for the phase one pilot study can be seen in Table 4.2. The data are for all of the students who participated in this phase of the study and are broken down by the topic (reduction-oxidation reactions) and by the total percentage based on the style of teaching (guided inquiry and traditional lecture). The students in the phase one trial took the post-test for the reduction-oxidation reactions topic, but not for the acid-base chemistry topic. The standard error of skewness (ses) and the standard error of kurtosis (sek) are represented in the table.
Table 4.2

*Post-Test Percentage Statistics for Students in the Phase One Pilot Study*

<table>
<thead>
<tr>
<th>Variable (Section)</th>
<th>n</th>
<th>Mean</th>
<th>SD</th>
<th>Med</th>
<th>Min</th>
<th>Max</th>
<th>Skewness (±ses)</th>
<th>Kurtosis (±sek)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Redox Reactions</td>
<td>85</td>
<td>50.3</td>
<td>15.97</td>
<td>45.5</td>
<td>18.2</td>
<td>100.0</td>
<td>0.713* (0.531)</td>
<td>0.707 (1.063)</td>
</tr>
<tr>
<td>Guided Inquiry (1)</td>
<td>43</td>
<td>55.0</td>
<td>17.06</td>
<td>54.5</td>
<td>27.3</td>
<td>100.0</td>
<td>0.678 (0.747)</td>
<td>0.292 (1.494)</td>
</tr>
<tr>
<td>Traditional Lecture (2)</td>
<td>42</td>
<td>45.5</td>
<td>13.32</td>
<td>45.5</td>
<td>18.2</td>
<td>81.8</td>
<td>0.391 (0.756)</td>
<td>0.396 (1.512)</td>
</tr>
</tbody>
</table>

*positively skewed distribution

The post-test percentages for the reduction-oxidation reactions topic (redox reactions) are positively skewed; a majority of the students still had low post-test percentages, meaning they did not answer many of the post-test questions correctly. This is an abnormal result from what would be expected. Since this is a post-test after the students had received instruction on the material, one would expect the percentages to have a negatively skewed distribution. All of the distributions in Table 4.2 have mesokurtic distributions.

Class section one was subjected to the guided inquiry method of teaching and class section two was subjected to the traditional lecture style of teaching for the reduction-oxidation topic. This is represented in Table 4.1 in parentheses after the variable. There was only one section for each style of teaching.
For phase two of the pilot study, the two topics studied changed to bonding and acid-base chemistry. Table 4.3 contains a summary of the pre-survey content question percentages for this phase of the pilot study. The data are for all of the students who participated in the phase two pilot study during Summer 2009 and are broken down by the topic (bonding and acid-base chemistry) and by the total percentage. The standard error of skewness (ses) and the standard error of kurtosis (sek) are ±0.926 and ±1.852 respectively for each of the variables, because they all have the same sample sizes.

Table 4.3

*Pre-Survey Content Questions Percentage Statistics for Students in the Phase Two Pilot Study*

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>SD</th>
<th>Med</th>
<th>Min</th>
<th>Max</th>
<th>Skewness</th>
<th>Kurtosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bonding</td>
<td>4.6</td>
<td>11.03</td>
<td>0.0</td>
<td>0.0</td>
<td>42.9</td>
<td>2.470*</td>
<td>5.479†</td>
</tr>
<tr>
<td>Acid-Base Chemistry</td>
<td>4.6</td>
<td>7.83</td>
<td>0.0</td>
<td>0.0</td>
<td>28.6</td>
<td>1.516*</td>
<td>1.518</td>
</tr>
<tr>
<td>Total</td>
<td>4.6</td>
<td>8.52</td>
<td>0.0</td>
<td>0.0</td>
<td>28.6</td>
<td>2.036*</td>
<td>3.320†</td>
</tr>
</tbody>
</table>

n=28
*positively skewed distribution
†leptokurtic distribution

Both of the phase two pilot study topics and the total percentage of both topics combined on the pre-survey content questions are positively skewed. Again, this is to be expected because many of the students were unable to answer or answered the questions correctly. The bonding topic percent and the total percent
have leptokurtic distributions, meaning they are more peaked than a normal distribution.

A summary of the post-test percentages for the phase two pilot study can be seen in Table 4.4. The data are for all of the students who participated in this phase of the study and are broken down by the topic (bonding and acid-base chemistry) and by the total percentage on both topics combined based on the style of teaching (guided inquiry and traditional lecture). The standard error of skewness (ses) and the standard error of kurtosis (sek) are ±0.961 and ±1.922 respectively when the subject number (n) is 26 and ±1.000 and ±2.000 respectively when the subject number (n) is 24. All of the post-test percentage distributions in Table 4.4 have normal distributions.

Table 4.4

<table>
<thead>
<tr>
<th>Variable (Section)</th>
<th>n</th>
<th>Mean</th>
<th>SD</th>
<th>Med</th>
<th>Min</th>
<th>Max</th>
<th>Skewness (±ses)</th>
<th>Kurtosis (±sek)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bonding</td>
<td>26</td>
<td>62.1</td>
<td>21.74</td>
<td>57.1</td>
<td>28.6</td>
<td>100.0</td>
<td>0.244</td>
<td>-0.744</td>
</tr>
<tr>
<td>Acid-Base Chemistry</td>
<td>24</td>
<td>63.7</td>
<td>22.68</td>
<td>57.1</td>
<td>28.6</td>
<td>100.0</td>
<td>0.083</td>
<td>-0.980</td>
</tr>
<tr>
<td>Guided Inquiry</td>
<td>26</td>
<td>57.7</td>
<td>20.79</td>
<td>57.1</td>
<td>28.6</td>
<td>100.0</td>
<td>0.603</td>
<td>-0.428</td>
</tr>
<tr>
<td>Traditional Lecture</td>
<td>24</td>
<td>68.5</td>
<td>22.28</td>
<td>71.4</td>
<td>28.6</td>
<td>100.0</td>
<td>-0.298</td>
<td>-0.587</td>
</tr>
</tbody>
</table>

Table 4.5 contains a summary of the post-test percentages on content questions based on the class section the students were enrolled in for the study. The data are broken down by the topic the post-test content questions covered (bonding and acid-base chemistry), and the style of teaching (guided inquiry or
traditional lecture). Section 100 was subjected to the guided inquiry style of teaching for the bonding topic while section 101 was subjected to the traditional lecture style. The two sections switched the style of teaching for the acid-base chemistry topic. The standard error of skewness (ses) and the standard error of kurtosis (sek) are ±1.477 and ±2.954 respectively when the subject number (n) is 11 and ±1.359 and ±2.717 respectively when the subject number (n) is 13. All of the sections have normal distributions for the post-test percentages.

Table 4.5

Post-Test Percentage Statistics for Students in the Phase Two Pilot Study by Class

<table>
<thead>
<tr>
<th>Section</th>
<th>Topic</th>
<th>Sec</th>
<th>n</th>
<th>Mean</th>
<th>SD</th>
<th>Med</th>
<th>Min</th>
<th>Max</th>
<th>Skew</th>
<th>Kurt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bonding</td>
<td>100</td>
<td>11</td>
<td>66.2</td>
<td>22.38</td>
<td>71.4</td>
<td>42.9</td>
<td>100.0</td>
<td>0.359</td>
<td>-1.283</td>
<td></td>
</tr>
<tr>
<td></td>
<td>101</td>
<td>13</td>
<td>59.3</td>
<td>23.22</td>
<td>57.1</td>
<td>28.6</td>
<td>100.0</td>
<td>0.122</td>
<td>-0.839</td>
<td></td>
</tr>
<tr>
<td>Acid-Base Chemistry</td>
<td>100</td>
<td>11</td>
<td>79.2</td>
<td>16.12</td>
<td>71.4</td>
<td>57.1</td>
<td>100.0</td>
<td>0.118</td>
<td>-1.306</td>
<td></td>
</tr>
<tr>
<td></td>
<td>101</td>
<td>13</td>
<td>50.5</td>
<td>19.00</td>
<td>42.9</td>
<td>28.6</td>
<td>85.7</td>
<td>0.782</td>
<td>0.070</td>
<td></td>
</tr>
<tr>
<td>Guided Inquiry</td>
<td>100</td>
<td>11</td>
<td>66.2</td>
<td>22.38</td>
<td>71.4</td>
<td>42.9</td>
<td>100.0</td>
<td>0.359</td>
<td>-1.283</td>
<td></td>
</tr>
<tr>
<td></td>
<td>101</td>
<td>13</td>
<td>50.5</td>
<td>19.00</td>
<td>42.9</td>
<td>28.6</td>
<td>85.7</td>
<td>0.782</td>
<td>0.070</td>
<td></td>
</tr>
<tr>
<td>Traditional Lecture</td>
<td>100</td>
<td>11</td>
<td>79.2</td>
<td>16.12</td>
<td>71.4</td>
<td>57.1</td>
<td>100.0</td>
<td>0.118</td>
<td>-1.306</td>
<td></td>
</tr>
<tr>
<td></td>
<td>101</td>
<td>13</td>
<td>59.3</td>
<td>23.22</td>
<td>57.1</td>
<td>28.6</td>
<td>100.0</td>
<td>0.122</td>
<td>-0.839</td>
<td></td>
</tr>
</tbody>
</table>

Main Study

Table 4.6 contains the demographic frequencies and percentages of the students' gender, race, year in school, major, cumulative GPA group and age group by the class sections during the main study.
### Frequencies of Demographics for Students in Main Study by Class Section

<table>
<thead>
<tr>
<th>Var</th>
<th>Category</th>
<th>Frequency by Class Section (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>200</td>
</tr>
<tr>
<td>Gender</td>
<td>Males</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>(36)</td>
<td>(45)</td>
</tr>
<tr>
<td></td>
<td>Females</td>
<td>23</td>
</tr>
<tr>
<td></td>
<td>(64)</td>
<td>(55)</td>
</tr>
<tr>
<td>Race</td>
<td>Caucasian</td>
<td>31</td>
</tr>
<tr>
<td></td>
<td>(86)</td>
<td>(84)</td>
</tr>
<tr>
<td></td>
<td>African American</td>
<td>2(6)</td>
</tr>
<tr>
<td></td>
<td>Latino/Hispanic</td>
<td>0(0)</td>
</tr>
<tr>
<td></td>
<td>Asian</td>
<td>0(0)</td>
</tr>
<tr>
<td></td>
<td>Other</td>
<td>3(8)</td>
</tr>
<tr>
<td>Year in School</td>
<td>Freshman/Other</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>(28)</td>
<td>(18)</td>
</tr>
<tr>
<td></td>
<td>Sophomore</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>(36)</td>
<td>(53)</td>
</tr>
<tr>
<td></td>
<td>Junior</td>
<td>9(25)</td>
</tr>
<tr>
<td></td>
<td>Senior/Higher</td>
<td>4(11)</td>
</tr>
<tr>
<td>Major</td>
<td>Education</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>(44)</td>
<td>(32)</td>
</tr>
<tr>
<td></td>
<td>Business/Account</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>(17)</td>
<td>(34)</td>
</tr>
<tr>
<td></td>
<td>PS/Economics/Public Relations</td>
<td>1(3)</td>
</tr>
<tr>
<td>Major</td>
<td>STEMM</td>
<td>1(3)</td>
</tr>
<tr>
<td></td>
<td>Associates Degree</td>
<td>2(6)</td>
</tr>
<tr>
<td></td>
<td>Music/Art/Humanities/Language</td>
<td>4(11)</td>
</tr>
<tr>
<td></td>
<td>Social Science/Interdisciplinary</td>
<td>2(6)</td>
</tr>
<tr>
<td></td>
<td>Undecided</td>
<td>4(11)</td>
</tr>
<tr>
<td>GPA group</td>
<td>3.35 – 4.00</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>(31)</td>
<td>(26)</td>
</tr>
<tr>
<td></td>
<td>2.65 – 3.34</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>(25)</td>
<td>(24)</td>
</tr>
<tr>
<td></td>
<td>1.65 – 2.64</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>(19)</td>
<td>(29)</td>
</tr>
<tr>
<td></td>
<td>0 – 1.64</td>
<td>1(3)</td>
</tr>
<tr>
<td></td>
<td>Entering Freshmen</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>(22)</td>
<td>(19)</td>
</tr>
</tbody>
</table>
Table 4.6 *Continued*

<table>
<thead>
<tr>
<th>Var</th>
<th>Category</th>
<th>Frequency by Class Section (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>200</td>
</tr>
<tr>
<td>Age Group</td>
<td>18 – 24</td>
<td>34</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(94)</td>
</tr>
<tr>
<td>Age Group</td>
<td>25 and older</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(6)</td>
</tr>
</tbody>
</table>

Table 4.7 contains the information for the continuous variables of age and cumulative GPA, excluding entering freshmen or transfer students without a cumulative GPA, broken down by the class sections. The standard error of skewness (ses) and standard error of kurtosis (sek) are also reported in the table to determine the shape of the distribution for the data for each section.
Table 4.7

*Age and Cumulative GPA Statistics for Students in the Main Study by Class Section*

<table>
<thead>
<tr>
<th>Var</th>
<th>Sec</th>
<th>n</th>
<th>Mean</th>
<th>SD</th>
<th>Med</th>
<th>Min</th>
<th>Max</th>
<th>Skew (±ses)</th>
<th>Kurt (±sek)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>200</td>
<td>36</td>
<td>20.0</td>
<td>2.71</td>
<td>19</td>
<td>18</td>
<td>32</td>
<td>2.889* (0.816)</td>
<td>10.676† (1.633)</td>
</tr>
<tr>
<td></td>
<td>201</td>
<td>38</td>
<td>22.7</td>
<td>5.82</td>
<td>20</td>
<td>18</td>
<td>41</td>
<td>1.501* (0.795)</td>
<td>1.551 (1.589)</td>
</tr>
<tr>
<td></td>
<td>300</td>
<td>45</td>
<td>23.6</td>
<td>8.34</td>
<td>20</td>
<td>18</td>
<td>54</td>
<td>2.442* (0.730)</td>
<td>5.702† (1.461)</td>
</tr>
<tr>
<td></td>
<td>400</td>
<td>18</td>
<td>27.1</td>
<td>9.37</td>
<td>22</td>
<td>18</td>
<td>48</td>
<td>1.018 (1.155)</td>
<td>-0.321 (2.309)</td>
</tr>
<tr>
<td></td>
<td>500</td>
<td>42</td>
<td>19.8</td>
<td>1.61</td>
<td>20</td>
<td>18</td>
<td>25</td>
<td>1.427* (0.756)</td>
<td>2.388† (1.512)</td>
</tr>
<tr>
<td></td>
<td>501</td>
<td>45</td>
<td>24.0</td>
<td>8.10</td>
<td>21</td>
<td>18</td>
<td>50</td>
<td>2.385* (0.730)</td>
<td>5.092† (1.461)</td>
</tr>
<tr>
<td>GPA</td>
<td>200</td>
<td>28</td>
<td>3.017</td>
<td>0.7164</td>
<td>3.083</td>
<td>1.388</td>
<td>3.974</td>
<td>-0.558 (0.926)</td>
<td>-0.598 (1.852)</td>
</tr>
<tr>
<td></td>
<td>201</td>
<td>31</td>
<td>2.925</td>
<td>0.6312</td>
<td>2.978</td>
<td>1.341</td>
<td>3.817</td>
<td>-0.403 (0.880)</td>
<td>-0.393 (1.760)</td>
</tr>
<tr>
<td></td>
<td>300</td>
<td>45</td>
<td>3.127</td>
<td>0.5427</td>
<td>3.238</td>
<td>2.000</td>
<td>4.000</td>
<td>-0.289 (0.730)</td>
<td>-0.905 (1.461)</td>
</tr>
<tr>
<td></td>
<td>400</td>
<td>18</td>
<td>3.053</td>
<td>0.6632</td>
<td>3.198</td>
<td>1.940</td>
<td>4.000</td>
<td>-0.257 (1.155)</td>
<td>-1.141 (2.309)</td>
</tr>
<tr>
<td></td>
<td>500</td>
<td>31</td>
<td>3.020</td>
<td>0.5367</td>
<td>3.075</td>
<td>1.857</td>
<td>3.949</td>
<td>-0.210 (0.880)</td>
<td>-0.316 (1.760)</td>
</tr>
<tr>
<td></td>
<td>501</td>
<td>42</td>
<td>3.027</td>
<td>0.5197</td>
<td>3.061</td>
<td>1.736</td>
<td>3.963</td>
<td>-0.450 (0.756)</td>
<td>0.099 (1.512)</td>
</tr>
</tbody>
</table>

*positively skewed distribution
†leptokurtic distribution

Most of the sections have skewed age distributions because a majority of the students enrolled are of traditional age. All of the sections have normal distributions for cumulative GPA when entering freshman and transfer students without a GPA are excluded.

A summary of the pre-survey content question percentages can be found in Table 4.8. The data are for all of the students who participated in the main study.
and are broken down by the topic (bonding, chemical equations, and acid-base chemistry) and by the total percentage on all the topics combined. The standard error of skewness (ses) and the standard error of kurtosis (sek) are ±0.327 and ±0.655 respectively for each of the variables, because they all have the same sample sizes.

Table 4.8

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>SD</th>
<th>Med</th>
<th>Min</th>
<th>Max</th>
<th>Skewness</th>
<th>Kurtosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bonding</td>
<td>7.6</td>
<td>15.28</td>
<td>0.0</td>
<td>0.0</td>
<td>75.0</td>
<td>2.095*</td>
<td>4.064†</td>
</tr>
<tr>
<td>Chemical Equations</td>
<td>10.2</td>
<td>19.09</td>
<td>0.0</td>
<td>0.0</td>
<td>100.0</td>
<td>2.027*</td>
<td>3.895†</td>
</tr>
<tr>
<td>Acid-Base Chemistry</td>
<td>6.0</td>
<td>11.48</td>
<td>0.0</td>
<td>0.0</td>
<td>50.0</td>
<td>1.632*</td>
<td>1.653†</td>
</tr>
<tr>
<td>Total</td>
<td>7.9</td>
<td>11.28</td>
<td>0.0</td>
<td>0.0</td>
<td>58.3</td>
<td>1.787*</td>
<td>3.494†</td>
</tr>
</tbody>
</table>

n=224

*positively skewed distribution
†leptokurtic distribution

All of the topics have a positively skewed distribution. This is to be expected since so many of the students were not able to answer the pre-survey content questions or answered the questions incorrectly. All of the topics also have a leptokurtic distribution. This is because a majority of the students had a zero percent on the pre-survey content questions; therefore, it is peaked at that percentage instead of having a normal curve.

In Table 4.9 a summary of the pre-survey percentages based on the class section the students were enrolled in can be seen. The data are broken down by the topic the pre-survey content questions covered (bonding, chemical equations, and acid-base chemistry) and by the total percent on all the topics combined.
<table>
<thead>
<tr>
<th>Topic</th>
<th>Sec</th>
<th>n</th>
<th>Mean</th>
<th>SD</th>
<th>Med</th>
<th>Min</th>
<th>Max</th>
<th>Skew ($\pm$ses)</th>
<th>Kurt ($\pm$sek)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bonding</td>
<td>200</td>
<td>36</td>
<td>5.6</td>
<td>10.54</td>
<td>0</td>
<td>0</td>
<td>25.0</td>
<td>1.395* (0.816)</td>
<td>-0.060 (1.633)</td>
</tr>
<tr>
<td></td>
<td>201</td>
<td>38</td>
<td>5.9</td>
<td>12.24</td>
<td>0</td>
<td>0</td>
<td>50.0</td>
<td>1.992* (0.795)</td>
<td>3.454† (1.589)</td>
</tr>
<tr>
<td></td>
<td>300</td>
<td>45</td>
<td>11.7</td>
<td>20.37</td>
<td>0</td>
<td>0</td>
<td>75.0</td>
<td>1.828* (0.730)</td>
<td>2.767† (1.461)</td>
</tr>
<tr>
<td></td>
<td>400</td>
<td>18</td>
<td>4.2</td>
<td>9.59</td>
<td>0</td>
<td>0</td>
<td>25.0</td>
<td>1.956* (1.154)</td>
<td>2.040 (2.309)</td>
</tr>
<tr>
<td></td>
<td>500</td>
<td>42</td>
<td>7.7</td>
<td>15.11</td>
<td>0</td>
<td>0</td>
<td>50.0</td>
<td>1.838* (0.756)</td>
<td>2.351† (1.512)</td>
</tr>
<tr>
<td></td>
<td>501</td>
<td>45</td>
<td>7.8</td>
<td>16.70</td>
<td>0</td>
<td>0</td>
<td>50.0</td>
<td>1.938* (0.730)</td>
<td>2.262† (1.461)</td>
</tr>
<tr>
<td>Chemical Equations</td>
<td>200</td>
<td>36</td>
<td>10.4</td>
<td>17.29</td>
<td>0</td>
<td>0</td>
<td>50.0</td>
<td>1.413* (0.816)</td>
<td>0.679 (1.633)</td>
</tr>
<tr>
<td></td>
<td>201</td>
<td>38</td>
<td>12.5</td>
<td>23.07</td>
<td>0</td>
<td>0</td>
<td>75.0</td>
<td>1.852* (0.794)</td>
<td>2.415† (1.589)</td>
</tr>
<tr>
<td></td>
<td>300</td>
<td>45</td>
<td>11.7</td>
<td>18.15</td>
<td>0</td>
<td>0</td>
<td>75.0</td>
<td>1.612* (0.730)</td>
<td>2.417† (1.461)</td>
</tr>
<tr>
<td></td>
<td>400</td>
<td>18</td>
<td>8.3</td>
<td>24.25</td>
<td>0</td>
<td>0</td>
<td>100.0</td>
<td>3.576* (1.154)</td>
<td>13.547† (2.309)</td>
</tr>
<tr>
<td></td>
<td>500</td>
<td>42</td>
<td>11.9</td>
<td>20.83</td>
<td>0</td>
<td>0</td>
<td>75.0</td>
<td>1.539* (0.756)</td>
<td>1.148 (1.512)</td>
</tr>
<tr>
<td></td>
<td>501</td>
<td>45</td>
<td>5.6</td>
<td>12.93</td>
<td>0</td>
<td>0</td>
<td>50.0</td>
<td>2.345* (0.730)</td>
<td>4.878† (1.461)</td>
</tr>
<tr>
<td>Acid-Base Chemistry</td>
<td>200</td>
<td>36</td>
<td>3.5</td>
<td>8.77</td>
<td>0</td>
<td>0</td>
<td>25.0</td>
<td>2.180* (0.816)</td>
<td>2.913† (1.633)</td>
</tr>
<tr>
<td></td>
<td>201</td>
<td>38</td>
<td>3.9</td>
<td>9.24</td>
<td>0</td>
<td>0</td>
<td>25.0</td>
<td>1.954* (0.794)</td>
<td>1.918† (1.589)</td>
</tr>
<tr>
<td></td>
<td>300</td>
<td>45</td>
<td>7.2</td>
<td>11.46</td>
<td>0</td>
<td>0</td>
<td>25.0</td>
<td>0.964* (0.730)</td>
<td>-1.123 (1.461)</td>
</tr>
<tr>
<td></td>
<td>400</td>
<td>18</td>
<td>5.6</td>
<td>13.71</td>
<td>0</td>
<td>0</td>
<td>50.0</td>
<td>2.567* (1.154)</td>
<td>6.363† (2.309)</td>
</tr>
<tr>
<td></td>
<td>500</td>
<td>42</td>
<td>7.1</td>
<td>11.43</td>
<td>0</td>
<td>0</td>
<td>25.0</td>
<td>0.984* (0.756)</td>
<td>-1.085 (1.512)</td>
</tr>
<tr>
<td></td>
<td>501</td>
<td>45</td>
<td>7.8</td>
<td>13.92</td>
<td>0</td>
<td>0</td>
<td>50.0</td>
<td>1.640* (0.730)</td>
<td>1.886† (1.461)</td>
</tr>
</tbody>
</table>
Table 4.9  *Continued*

<table>
<thead>
<tr>
<th>Topic</th>
<th>Sec</th>
<th>n</th>
<th>Mean</th>
<th>SD</th>
<th>Med</th>
<th>Min</th>
<th>Max</th>
<th>Skew  (±ses)</th>
<th>Kurt  (±sek)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-Survey Content Question</td>
<td>200</td>
<td>36</td>
<td>6.5</td>
<td>9.37</td>
<td>0</td>
<td>0</td>
<td>33.3</td>
<td>1.233*</td>
<td>0.554</td>
</tr>
<tr>
<td>Total</td>
<td>201</td>
<td>38</td>
<td>7.5</td>
<td>10.40</td>
<td>0</td>
<td>0</td>
<td>33.3</td>
<td>1.355*</td>
<td>0.639</td>
</tr>
<tr>
<td></td>
<td>300</td>
<td>45</td>
<td>10.2</td>
<td>13.16</td>
<td>8.3</td>
<td>0</td>
<td>50</td>
<td>1.644*</td>
<td>2.531†</td>
</tr>
<tr>
<td></td>
<td>400</td>
<td>18</td>
<td>6.2</td>
<td>13.95</td>
<td>0</td>
<td>0</td>
<td>58.3</td>
<td>3.460*</td>
<td>13.050†</td>
</tr>
<tr>
<td></td>
<td>500</td>
<td>42</td>
<td>8.9</td>
<td>10.48</td>
<td>8.3</td>
<td>0</td>
<td>33.3</td>
<td>0.865*</td>
<td>-0.430</td>
</tr>
<tr>
<td></td>
<td>501</td>
<td>45</td>
<td>7.0</td>
<td>11.09</td>
<td>0</td>
<td>0</td>
<td>50</td>
<td>2.236*</td>
<td>5.670†</td>
</tr>
</tbody>
</table>

*positively skewed distribution
†leptokurtic distribution

All of the sections have pre-survey content question percentages with positively skewed distributions. This is to be expected because most of the students were not able to answer the pre-survey content questions or they answered them incorrectly. Many of the sections also have leptokurtic distributions for the pre-survey content question percentages since the main percentage was zero.

A summary of the post-test percentages can be found in Table 4.10. The data are for all of the students who participated in the study and are broken down by the topic (bonding, chemical equations, and acid-base chemistry) and by the total percentage based on the style of teaching (guided inquiry and traditional lecture). The standard error of skewness (ses) and the standard error of kurtosis (sek) are ±0.346 and ±0.691 respectively for the variables with a subject number (n) of 201 and ±0.380 and ±0.760 respectively for the variable with a subject number (n) of 166.
Table 4.10

*Post-Test Percentage Statistics for Students in the Main Study*

<table>
<thead>
<tr>
<th>Variable</th>
<th>n</th>
<th>Mean</th>
<th>SD</th>
<th>Med</th>
<th>Min</th>
<th>Max</th>
<th>Skew</th>
<th>Kurt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bonding</td>
<td>201</td>
<td>59.2</td>
<td>29.09</td>
<td>50.0</td>
<td>0.0</td>
<td>100.0</td>
<td>-0.273</td>
<td>-0.697†</td>
</tr>
<tr>
<td>Chemical Equations</td>
<td>201</td>
<td>75.5</td>
<td>29.06</td>
<td>75.0</td>
<td>0.0</td>
<td>100.0</td>
<td>-1.117*</td>
<td>0.422</td>
</tr>
<tr>
<td>Acid-Base Chemistry</td>
<td>201</td>
<td>72.9</td>
<td>27.69</td>
<td>75.0</td>
<td>0.0</td>
<td>100.0</td>
<td>-0.859*</td>
<td>0.043</td>
</tr>
<tr>
<td>Guided Inquiry</td>
<td>201</td>
<td>70.9</td>
<td>25.15</td>
<td>75.0</td>
<td>0.0</td>
<td>100.0</td>
<td>-0.678*</td>
<td>-0.145</td>
</tr>
<tr>
<td>Traditional Lecture</td>
<td>166</td>
<td>68.6</td>
<td>28.36</td>
<td>75.0</td>
<td>0.0</td>
<td>100.0</td>
<td>-0.712*</td>
<td>-0.212</td>
</tr>
</tbody>
</table>

*negatively skewed distribution
†platykurtic distribution

All of the topics, except bonding, have negatively skewed distributions; this is expected since many of the students had high percentages on the post-tests. The bonding topic has a platykurtic distribution, meaning it is much flatter than a normal distribution.

Table 4.11 contains a summary of the post-test percentages on content questions based on the class section the students were enrolled in for the study. The data are broken down by the topic the post-test content questions covered (bonding, chemical equations, and acid-base chemistry).
### Table 4.11

**Post-Test Percentage Statistics for Students in the Main Study by Class Section**

<table>
<thead>
<tr>
<th>Topic</th>
<th>Sec</th>
<th>n</th>
<th>Mean</th>
<th>SD</th>
<th>Med</th>
<th>Min</th>
<th>Max</th>
<th>Skew (±ses)</th>
<th>Kurt (±sek)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bonding</strong></td>
<td>200</td>
<td>36</td>
<td>58.3</td>
<td>38.72</td>
<td>50.0</td>
<td>0.0</td>
<td>100.0</td>
<td>-0.304 (0.817)</td>
<td>-1.242 (1.633)</td>
</tr>
<tr>
<td></td>
<td>201</td>
<td>27</td>
<td>51.9</td>
<td>29.36</td>
<td>50.0</td>
<td>0.0</td>
<td>100.0</td>
<td>0.001 (0.943)</td>
<td>-0.964 (1.886)</td>
</tr>
<tr>
<td></td>
<td>300</td>
<td>45</td>
<td>66.1</td>
<td>22.71</td>
<td>75.0</td>
<td>0.0</td>
<td>100.0</td>
<td>-0.737* (0.730)</td>
<td>0.635 (1.461)</td>
</tr>
<tr>
<td></td>
<td>400</td>
<td>18</td>
<td>69.4</td>
<td>27.86</td>
<td>62.5</td>
<td>25.0</td>
<td>100.0</td>
<td>-0.083 (1.155)</td>
<td>-1.538 (2.309)</td>
</tr>
<tr>
<td></td>
<td>500</td>
<td>36</td>
<td>54.2</td>
<td>30.18</td>
<td>50.0</td>
<td>0.0</td>
<td>100.0</td>
<td>0.029 (0.817)</td>
<td>-0.838 (1.633)</td>
</tr>
<tr>
<td></td>
<td>501</td>
<td>39</td>
<td>57.1</td>
<td>22.90</td>
<td>50.0</td>
<td>25.0</td>
<td>100.0</td>
<td>0.041 (0.784)</td>
<td>-0.879 (1.569)</td>
</tr>
<tr>
<td><strong>Chemical</strong></td>
<td>200</td>
<td>36</td>
<td>74.1</td>
<td>31.99</td>
<td>100.0</td>
<td>0.0</td>
<td>100.0</td>
<td>-0.887* (0.817)</td>
<td>-0.420 (1.633)</td>
</tr>
<tr>
<td></td>
<td>201</td>
<td>27</td>
<td>60.2</td>
<td>34.85</td>
<td>75.0</td>
<td>0.0</td>
<td>100.0</td>
<td>-0.530 (0.943)</td>
<td>-0.912 (1.886)</td>
</tr>
<tr>
<td></td>
<td>300</td>
<td>45</td>
<td>83.3</td>
<td>19.94</td>
<td>100.0</td>
<td>25.0</td>
<td>100.0</td>
<td>-0.968* (0.730)</td>
<td>0.215 (1.461)</td>
</tr>
<tr>
<td></td>
<td>400</td>
<td>18</td>
<td>80.6</td>
<td>26.51</td>
<td>87.5</td>
<td>0.0</td>
<td>100.0</td>
<td>-1.829* (1.155)</td>
<td>4.053† (2.309)</td>
</tr>
<tr>
<td></td>
<td>500</td>
<td>36</td>
<td>79.2</td>
<td>30.18</td>
<td>100.0</td>
<td>0.0</td>
<td>100.0</td>
<td>-1.370* (0.817)</td>
<td>0.951 (2.633)</td>
</tr>
<tr>
<td></td>
<td>501</td>
<td>39</td>
<td>72.4</td>
<td>27.98</td>
<td>75.0</td>
<td>0.0</td>
<td>100.0</td>
<td>-1.095* (0.784)</td>
<td>0.723 (1.569)</td>
</tr>
<tr>
<td><strong>Acid-Base</strong></td>
<td>200</td>
<td>36</td>
<td>69.4</td>
<td>36.84</td>
<td>83.4</td>
<td>0.0</td>
<td>100.0</td>
<td>-0.845* (0.817)</td>
<td>-0.689 (1.633)</td>
</tr>
<tr>
<td></td>
<td>201</td>
<td>27</td>
<td>56.5</td>
<td>31.46</td>
<td>50.0</td>
<td>0.0</td>
<td>100.0</td>
<td>0.094 (0.943)</td>
<td>-1.340 (1.886)</td>
</tr>
<tr>
<td></td>
<td>300</td>
<td>45</td>
<td>79.4</td>
<td>19.43</td>
<td>75.0</td>
<td>25.0</td>
<td>100.0</td>
<td>-0.630 (0.730)</td>
<td>-0.092 (1.461)</td>
</tr>
<tr>
<td></td>
<td>400</td>
<td>18</td>
<td>69.4</td>
<td>31.57</td>
<td>75.0</td>
<td>0.0</td>
<td>100.0</td>
<td>-1.108 (1.155)</td>
<td>0.802 (2.309)</td>
</tr>
<tr>
<td></td>
<td>500</td>
<td>36</td>
<td>81.3</td>
<td>20.16</td>
<td>75.0</td>
<td>25.0</td>
<td>100.0</td>
<td>-0.844* (0.817)</td>
<td>0.173 (1.633)</td>
</tr>
<tr>
<td></td>
<td>501</td>
<td>39</td>
<td>73.7</td>
<td>22.90</td>
<td>75.0</td>
<td>25.0</td>
<td>100.0</td>
<td>-0.111 (0.784)</td>
<td>-1.377 (1.569)</td>
</tr>
</tbody>
</table>

*negatively skewed distribution  
†leptokurtic distribution classroom  
GI = guided inquiry classroom  
TL = traditional lecture classroom
Many of the sections have negatively skewed distributions. This is to be expected because many of the students had higher percentages on the post-test content questions than lower percentages, skewing the data. Only section 400 had a leptokurtic distribution for the post-test percentages for the chemical equations content question percentages.

In Table 4.12 there is a summary of the descriptive statistics for the total post-test content question percentages for all of the topics based on the class section the students were enrolled in. The total percentages are based on the different teaching styles (guided inquiry and traditional lecture) the students were subjected to for the different topics. Each class section had a different representation of topics covered for each teaching style. Section 200 had guided inquiry teaching for the chemical equations topic and traditional lecture for bonding and acid-base chemistry. Section 201 had guided inquiry teaching for bonding and acid-base chemistry and traditional lecture for chemical equations. Section 300 was subjected to guided inquiry teaching for all three topics. Section 400 had guided inquiry teaching for chemical equations and acid-base chemistry and traditional lecture for bonding. Section 500 had guided inquiry teaching for bonding and chemical equations and traditional lecture for acid-base chemistry. Section 501 had guided inquiry teaching for acid-base chemistry and traditional lecture for bonding and chemical equations.
Table 4.12

*Post-Test Percentage Statistics by Teaching Style for Students in the Main Study by Class Section*

<table>
<thead>
<tr>
<th>Teaching Style</th>
<th>Sec</th>
<th>n</th>
<th>Mean</th>
<th>SD</th>
<th>Med</th>
<th>Min</th>
<th>Max</th>
<th>Skew (±ses)</th>
<th>Kurt (±sek)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Guided Inquiry</td>
<td>200</td>
<td>36</td>
<td>75.9</td>
<td>31.49</td>
<td>100.0</td>
<td>0.0</td>
<td>100.0</td>
<td>-1.034* (0.817)</td>
<td>-0.065 (1.633)</td>
</tr>
<tr>
<td></td>
<td>201</td>
<td>27</td>
<td>54.2</td>
<td>24.76</td>
<td>62.5</td>
<td>0.0</td>
<td>100.0</td>
<td>-0.246 (0.943)</td>
<td>-0.426 (1.886)</td>
</tr>
<tr>
<td></td>
<td>300</td>
<td>45</td>
<td>76.3</td>
<td>15.18</td>
<td>83.3</td>
<td>33.3</td>
<td>100.0</td>
<td>-0.546 (0.730)</td>
<td>0.272 (1.461)</td>
</tr>
<tr>
<td></td>
<td>400</td>
<td>18</td>
<td>75.0</td>
<td>27.45</td>
<td>81.3</td>
<td>0.0</td>
<td>100.0</td>
<td>-1.537* (1.155)</td>
<td>2.346† (2.309)</td>
</tr>
<tr>
<td></td>
<td>500</td>
<td>39</td>
<td>63.1</td>
<td>26.89</td>
<td>62.5</td>
<td>12.5</td>
<td>100.0</td>
<td>-0.337 (0.784)</td>
<td>-0.965 (1.569)</td>
</tr>
<tr>
<td></td>
<td>501</td>
<td>42</td>
<td>72.6</td>
<td>23.30</td>
<td>75.0</td>
<td>25.0</td>
<td>100.0</td>
<td>-0.183 (0.756)</td>
<td>-1.143 (1.512)</td>
</tr>
<tr>
<td>Traditional Lecture</td>
<td>200</td>
<td>36</td>
<td>65.0</td>
<td>33.59</td>
<td>60.0</td>
<td>0.0</td>
<td>100.0</td>
<td>-0.610 (0.817)</td>
<td>-0.806 (1.633)</td>
</tr>
<tr>
<td></td>
<td>201</td>
<td>34</td>
<td>63.2</td>
<td>35.48</td>
<td>75.0</td>
<td>0.0</td>
<td>100.0</td>
<td>-0.638 (0.840)</td>
<td>-0.843 (1.680)</td>
</tr>
<tr>
<td></td>
<td>300</td>
<td>0</td>
<td>69.4</td>
<td>27.88</td>
<td>62.5</td>
<td>25.0</td>
<td>100.0</td>
<td>-0.083 (1.155)</td>
<td>-1.538 (2.309)</td>
</tr>
<tr>
<td></td>
<td>400</td>
<td>18</td>
<td>69.4</td>
<td>20.34</td>
<td>75.0</td>
<td>24.0</td>
<td>100.0</td>
<td>-0.754 (0.795)</td>
<td>-0.016 (1.589)</td>
</tr>
<tr>
<td></td>
<td>500</td>
<td>38</td>
<td>80.2</td>
<td>20.25</td>
<td>62.5</td>
<td>25.0</td>
<td>100.0</td>
<td>-0.303 (0.775)</td>
<td>-0.601 (1.549)</td>
</tr>
<tr>
<td></td>
<td>501</td>
<td>40</td>
<td>65.0</td>
<td>20.25</td>
<td>62.5</td>
<td>25.0</td>
<td>100.0</td>
<td>-0.303 (0.775)</td>
<td>-0.601 (1.549)</td>
</tr>
</tbody>
</table>

*negatively skewed distribution
†leptokurtic distribution

Only sections 200 and 400 have negatively skewed distributions for the post-test content questions total percentage when taught via the guided inquiry method, showing that many of the students received high percentages on the post-tests.

Section 400 also has a leptokurtic distribution when taught via the guided inquiry
method. All of the sections have normal distributions when taught via traditional lecture.

Normalized gain scores were also calculated for the students. Table 4.13 shows the descriptive statistics for the gain scores of the students based on the topic and by the total gain score on all of the topics based on the style of teaching. The standard error of skewness (ses) and standard error of kurtosis (sek) are ±0.346 and ±0.693 respectively for the variables with a subject number (n) of 200 and ±0.380 and ±0.760 respectively for the variable with a subject number (n) of 166.

Table 4.13

<table>
<thead>
<tr>
<th>Variable</th>
<th>n</th>
<th>Mean</th>
<th>SD</th>
<th>Med</th>
<th>Min</th>
<th>Max</th>
<th>Skew</th>
<th>Kurt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bonding</td>
<td>200</td>
<td>0.56</td>
<td>0.315</td>
<td>0.50</td>
<td>-0.33</td>
<td>1.00</td>
<td>-0.340</td>
<td>-0.468</td>
</tr>
<tr>
<td>Chemical Equations</td>
<td>200</td>
<td>0.74</td>
<td>0.309</td>
<td>0.75</td>
<td>-0.33</td>
<td>1.00</td>
<td>-1.081*</td>
<td>0.418</td>
</tr>
<tr>
<td>Acid-Base Chemistry</td>
<td>200</td>
<td>0.71</td>
<td>0.286</td>
<td>0.75</td>
<td>0.00</td>
<td>1.00</td>
<td>-0.773*</td>
<td>-0.192</td>
</tr>
<tr>
<td>Guided Inquiry</td>
<td>200</td>
<td>0.69</td>
<td>0.264</td>
<td>0.75</td>
<td>0.00</td>
<td>1.00</td>
<td>-0.616*</td>
<td>-0.299</td>
</tr>
<tr>
<td>Traditional Lecture</td>
<td>166</td>
<td>0.67</td>
<td>0.295</td>
<td>0.75</td>
<td>-0.33</td>
<td>1.00</td>
<td>-0.761*</td>
<td>0.192</td>
</tr>
</tbody>
</table>

*negatively skewed distribution

All of the topics and teaching styles except bonding have negatively skewed distributions, meaning most of the students have an increase in their percentage from the pre-survey content questions. All of the topics and teaching styles have normal distributions in terms of kurtosis.

Table 4.14 shows the descriptive statistics for the gain scores of the students based on the topic covered. The data are broken down based on the students’ class section.
Table 4.14

*Gain Score Statistics for Students in the Main Study by Class Section*

<table>
<thead>
<tr>
<th>Topic</th>
<th>Sec</th>
<th>n</th>
<th>Mean</th>
<th>SD</th>
<th>Med</th>
<th>Min</th>
<th>Max</th>
<th>Skew (±ses)</th>
<th>Kurt (±sek)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bonding</td>
<td>200</td>
<td>36</td>
<td>0.57</td>
<td>0.407</td>
<td>0.50</td>
<td>-0.33</td>
<td>1.00</td>
<td>-0.417 (.817)</td>
<td>-0.946 (1.633)</td>
</tr>
<tr>
<td></td>
<td>201</td>
<td>27</td>
<td>0.50</td>
<td>0.304</td>
<td>0.50</td>
<td>0.00</td>
<td>1.00</td>
<td>0.017 (0.943)</td>
<td>-0.936 (1.886)</td>
</tr>
<tr>
<td></td>
<td>300</td>
<td>45</td>
<td>0.62</td>
<td>0.269</td>
<td>0.67</td>
<td>0.00</td>
<td>1.00</td>
<td>-0.874 (0.730)</td>
<td>0.571 (1.461)</td>
</tr>
<tr>
<td></td>
<td>400</td>
<td>18</td>
<td>0.67</td>
<td>0.276</td>
<td>0.50</td>
<td>0.25</td>
<td>1.00</td>
<td>0.094 (1.155)</td>
<td>-1.460 (2.309)</td>
</tr>
<tr>
<td></td>
<td>500</td>
<td>36</td>
<td>0.51</td>
<td>0.331</td>
<td>0.50</td>
<td>-0.33</td>
<td>1.00</td>
<td>-0.253 (0.817)</td>
<td>-0.159 (1.633)</td>
</tr>
<tr>
<td></td>
<td>501</td>
<td>39</td>
<td>0.52</td>
<td>0.264</td>
<td>0.50</td>
<td>0.00</td>
<td>1.00</td>
<td>-0.037 (0.784)</td>
<td>-0.777 (1.569)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Chemical Equations</th>
<th>200</th>
<th>36</th>
<th>0.73</th>
<th>0.322</th>
<th>1.00</th>
<th>0.00</th>
<th>1.00</th>
<th>-0.816 (0.817)</th>
<th>-0.572 (1.633)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>201</td>
<td>27</td>
<td>0.58</td>
<td>0.373</td>
<td>0.67</td>
<td>-0.33</td>
<td>1.00</td>
<td>0.701 (0.943)</td>
<td>-0.177 (1.886)</td>
</tr>
<tr>
<td></td>
<td>300</td>
<td>45</td>
<td>0.79</td>
<td>0.266</td>
<td>1.00</td>
<td>0.00</td>
<td>1.00</td>
<td>-1.411* (0.730)</td>
<td>1.802† (1.461)</td>
</tr>
<tr>
<td></td>
<td>400</td>
<td>17</td>
<td>0.80</td>
<td>0.287</td>
<td>1.00</td>
<td>0.00</td>
<td>1.00</td>
<td>-1.690* (1.188)</td>
<td>2.727† (2.376)</td>
</tr>
<tr>
<td></td>
<td>500</td>
<td>36</td>
<td>0.78</td>
<td>0.306</td>
<td>1.00</td>
<td>0.00</td>
<td>1.00</td>
<td>-1.273* (0.817)</td>
<td>0.638 (2.633)</td>
</tr>
<tr>
<td></td>
<td>501</td>
<td>39</td>
<td>0.71</td>
<td>0.282</td>
<td>0.75</td>
<td>0.00</td>
<td>1.00</td>
<td>-0.962* (0.784)</td>
<td>0.432 (1.569)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Acid-Base Chemistry</th>
<th>200</th>
<th>36</th>
<th>0.69</th>
<th>0.368</th>
<th>0.83</th>
<th>0.00</th>
<th>1.00</th>
<th>-0.845* (0.817)</th>
<th>-0.689 (1.633)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>201</td>
<td>27</td>
<td>0.56</td>
<td>0.312</td>
<td>0.50</td>
<td>0.00</td>
<td>1.00</td>
<td>0.146 (0.943)</td>
<td>-1.261 (1.886)</td>
</tr>
<tr>
<td></td>
<td>300</td>
<td>45</td>
<td>0.78</td>
<td>0.206</td>
<td>0.75</td>
<td>0.25</td>
<td>1.00</td>
<td>-0.534 (0.730)</td>
<td>-0.367 (1.461)</td>
</tr>
<tr>
<td></td>
<td>400</td>
<td>17</td>
<td>0.66</td>
<td>0.323</td>
<td>0.75</td>
<td>0.25</td>
<td>1.00</td>
<td>-0.902 (1.188)</td>
<td>0.199 (2.376)</td>
</tr>
<tr>
<td></td>
<td>500</td>
<td>36</td>
<td>0.80</td>
<td>0.215</td>
<td>0.75</td>
<td>0.25</td>
<td>1.00</td>
<td>-0.768 (0.817)</td>
<td>-0.145 (1.633)</td>
</tr>
<tr>
<td></td>
<td>501</td>
<td>39</td>
<td>0.71</td>
<td>0.265</td>
<td>0.75</td>
<td>0.00</td>
<td>1.00</td>
<td>-0.496 (0.784)</td>
<td>-0.389 (1.569)</td>
</tr>
</tbody>
</table>

*negatively skewed distribution  †leptokurtic distribution  
GI = guided inquiry classroom  
TL = traditional lecture classroom
A few of the sections have negatively skewed gain score distributions, meaning many of the gain scores fell at the higher end of the distribution. Sections 300 and 400 had leptokurtic distributions for the gain scores for the chemical equation topic, meaning many students had one value for their gain scores and the distribution was very peaked.

The gain scores were also calculated for the total gain scores on all of the topics combined based on the teaching style used for each topic (guided inquiry or traditional lecture). Table 4.15 shows the descriptive statistics for these gain scores. Again, section 300 was not subjected to the traditional lecture style of teaching for any of the three topics covered during the research study.
Table 4.15

*Gain Scores Statistics by Teaching Style for Students in the Main Study by Class Section*

<table>
<thead>
<tr>
<th>Topic</th>
<th>Sec</th>
<th>n</th>
<th>Mean</th>
<th>SD</th>
<th>Med</th>
<th>Min</th>
<th>Max</th>
<th>Skew (±ses)</th>
<th>Kurt (±sek)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Guided Inquiry</td>
<td>200</td>
<td>36</td>
<td>0.75</td>
<td>0.318</td>
<td>1.00</td>
<td>0.00</td>
<td>1.00</td>
<td>-0.959* (0.817)</td>
<td>-0.256 (1.633)</td>
</tr>
<tr>
<td></td>
<td>201</td>
<td>27</td>
<td>0.52</td>
<td>0.250</td>
<td>0.57</td>
<td>0.00</td>
<td>1.00</td>
<td>-0.152 (0.943)</td>
<td>-0.481 (1.886)</td>
</tr>
<tr>
<td></td>
<td>300</td>
<td>45</td>
<td>0.74</td>
<td>0.166</td>
<td>0.78</td>
<td>0.27</td>
<td>1.00</td>
<td>-0.550 (0.730)</td>
<td>0.259 (1.461)</td>
</tr>
<tr>
<td></td>
<td>400</td>
<td>18</td>
<td>0.72</td>
<td>0.284</td>
<td>0.75</td>
<td>0.00</td>
<td>1.00</td>
<td>-1.146 (1.155)</td>
<td>1.037 (2.309)</td>
</tr>
<tr>
<td></td>
<td>500</td>
<td>39</td>
<td>0.61</td>
<td>0.273</td>
<td>0.625</td>
<td>0.13</td>
<td>1.00</td>
<td>-0.345 (0.784)</td>
<td>-0.869 (1.569)</td>
</tr>
<tr>
<td></td>
<td>501</td>
<td>42</td>
<td>0.70</td>
<td>0.266</td>
<td>0.75</td>
<td>0.00</td>
<td>1.00</td>
<td>-0.483 (0.756)</td>
<td>-0.435 (1.512)</td>
</tr>
<tr>
<td>Traditional Lecture</td>
<td>200</td>
<td>36</td>
<td>0.64</td>
<td>0.344</td>
<td>0.60</td>
<td>-0.14</td>
<td>1.00</td>
<td>-0.686 (0.817)</td>
<td>-0.555 (1.633)</td>
</tr>
<tr>
<td></td>
<td>201</td>
<td>34</td>
<td>0.61</td>
<td>0.376</td>
<td>0.75</td>
<td>-0.33</td>
<td>1.00</td>
<td>-0.765 (0.840)</td>
<td>-0.259 (1.680)</td>
</tr>
<tr>
<td></td>
<td>300</td>
<td>0</td>
<td>0.69</td>
<td>0.278</td>
<td>0.58</td>
<td>0.25</td>
<td>1.00</td>
<td>-0.027 (1.155)</td>
<td>-1.534 (2.309)</td>
</tr>
<tr>
<td></td>
<td>400</td>
<td>18</td>
<td>0.79</td>
<td>0.215</td>
<td>0.75</td>
<td>0.24</td>
<td>1.00</td>
<td>-0.684 (0.795)</td>
<td>-0.278 (1.589)</td>
</tr>
<tr>
<td></td>
<td>500</td>
<td>38</td>
<td>0.63</td>
<td>0.210</td>
<td>0.63</td>
<td>0.24</td>
<td>1.00</td>
<td>-0.188 (0.775)</td>
<td>-0.768 (1.549)</td>
</tr>
<tr>
<td></td>
<td>501</td>
<td>40</td>
<td>0.63</td>
<td>0.210</td>
<td>0.63</td>
<td>0.24</td>
<td>1.00</td>
<td>-0.188 (0.775)</td>
<td>-0.768 (1.549)</td>
</tr>
</tbody>
</table>

*negatively skewed distribution

Only section 200 has a negatively skewed distribution for the gain scores when the teaching method was guided inquiry, meaning more of the students had higher gain scores. All of the other sections have normal distributions regardless of the style of teaching used for the topics in terms of skewness and kurtosis.

The frequencies and percentages of the final grades can be found in Table 4.16 for all of the students involved in the study. They are broken down by the class section and the total for all of the sections. Final grades were assigned by the
instructor for the course and included all of the work the students did during the semester and not just the work done for the research study.

Table 4.16

*Frequencies of Final Grades for Students in Main Study by Class Section and Total*

<table>
<thead>
<tr>
<th>Grade</th>
<th>Frequency by Class Section (%)</th>
<th>Total Frequency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>200</td>
<td>201</td>
</tr>
<tr>
<td>A</td>
<td>12(33)</td>
<td>7(18)</td>
</tr>
<tr>
<td>A-</td>
<td>7(19)</td>
<td>8(21)</td>
</tr>
<tr>
<td>B+</td>
<td>3(8)</td>
<td>4(11)</td>
</tr>
<tr>
<td>B</td>
<td>3(8)</td>
<td>3(8)</td>
</tr>
<tr>
<td>B-</td>
<td>3(8)</td>
<td>3(8)</td>
</tr>
<tr>
<td>C+</td>
<td>4(11)</td>
<td>5(13)</td>
</tr>
<tr>
<td>C</td>
<td>2(6)</td>
<td>4(11)</td>
</tr>
<tr>
<td>C-</td>
<td>1(3)</td>
<td>1(3)</td>
</tr>
<tr>
<td>D+</td>
<td>0(0)</td>
<td>0(0)</td>
</tr>
<tr>
<td>D</td>
<td>0(0)</td>
<td>1(3)</td>
</tr>
<tr>
<td>D-</td>
<td>0(0)</td>
<td>0(0)</td>
</tr>
<tr>
<td>F</td>
<td>1(3)</td>
<td>0(0)</td>
</tr>
<tr>
<td>WD</td>
<td>0(0)</td>
<td>2(5)</td>
</tr>
<tr>
<td>n</td>
<td>36</td>
<td>38</td>
</tr>
</tbody>
</table>

Inferential Statistics

Pilot Study Phase One

**Research Hypothesis One**: There is a significant difference, for the reduction-oxidation topic, between students’ post-test percentages and teaching style in a non-science majors’ one semester chemistry course, such that students who participate in the guided inquiry activities will have significantly higher post-test percentages.
than the students in the traditional lecture classroom. This hypothesis was shown to be true with 95 percent confidence ($t_{83} = 2.861, p = 0.003$) that students taught via guided inquiry had statistically significant higher percentages on post-tests for the reduction-oxidation topic than the traditional lecture students. A summary of these statistics can be seen in Table 4.17.

Table 4.17

Research Hypothesis One: Independent t-test Statistics for Phase One Pilot Study Data

<table>
<thead>
<tr>
<th></th>
<th>Mean Score</th>
<th>t</th>
<th>df</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Guided Inquiry Percent vs. Total Traditional Lecture Percent</td>
<td>55.0 vs. 45.5</td>
<td>2.861</td>
<td>83</td>
<td>0.003*</td>
</tr>
</tbody>
</table>

n = 85
*statistically significant at 0.05 level

Research Hypothesis Two: There is a significant difference, for the reduction-oxidation topic, for student test percentages in a non-science majors’ one-semester chemistry course taught via guided inquiry, such that a statistically significant difference exists between males and females, between traditional students and non-traditional students, among students of different races, among students with differing years in school, among students of different majors, and among students with varying cumulative GPA groups. For this hypothesis, one of the variables was found to have statistically significant differences between reduction-oxidation post-test percentages when taught via guided inquiry. The variable to show this difference with a 95 percent confidence was student major ($F_{7,35} = 4.213, p = 0.002$). A summary of the independent t-test statistics for gender and age group variables can be seen in Table 4.18. Table 4.19 contains the summary
for the ANOVA statistics for the variables race, year in school, major, and cumulative GPA groups.

Table 4.18

*Research Hypothesis Two: Independent t-test Statistics for Overall Guided Inquiry Data by Categorical Variable*

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean Score</th>
<th>t</th>
<th>df</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>Females vs. Males Percent</td>
<td>56.2 vs.</td>
<td>0.479</td>
<td>41</td>
<td>0.634</td>
</tr>
<tr>
<td>Traditional vs. Non-Traditional Student Percent</td>
<td>56.2 vs.</td>
<td>0.880</td>
<td>41</td>
<td>0.384</td>
</tr>
</tbody>
</table>

n = 43

Table 4.19

*Research Hypothesis Two: ANOVA Statistics for Overall Guided Inquiry Data by Categorical Variable*

<table>
<thead>
<tr>
<th>Variable</th>
<th>n</th>
<th>F</th>
<th>df</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>Race Percent</td>
<td>41</td>
<td>0.731</td>
<td>3,37</td>
<td>0.540</td>
</tr>
<tr>
<td>Year in School Percent</td>
<td>43</td>
<td>1.649</td>
<td>3,39</td>
<td>0.194</td>
</tr>
<tr>
<td>Major Percent</td>
<td>43</td>
<td>4.213</td>
<td>7,35</td>
<td>0.002*</td>
</tr>
<tr>
<td>GPA Group Percent</td>
<td>43</td>
<td>2.931</td>
<td>2,40</td>
<td>0.065</td>
</tr>
</tbody>
</table>

*statistically significant at 0.05 level

A post hoc analysis could not be done on the post-test percentages for the reduction-oxidation topic because one or more of the groups contained only one subject. Therefore, it cannot be determined which majors have statistically significant differences.
Pilot Study Phase Two

Research Hypothesis One: There is a significant difference, overall and based on topic, between students’ post-test percentages and teaching style in a non-science majors’ one semester chemistry course, such that students who participate in the guided inquiry activities will have significantly higher post-test percentages than the students in the traditional lecture classroom. The first part of this hypothesis, for overall percentage differences, was rejected and the null hypothesis (that there is no difference in overall post-test percentages based on teaching style) was shown to be true with 95 percent confidence ($t_{23} = -2.584, p = 0.009$). The research hypothesis is rejected because the researcher predicted that the guided inquiry students would have higher post-test percentages, but it was found in the study that the traditional lecture students actually had higher post-test percentages. Therefore, the null hypothesis stating there is no difference between the two groups has to be accepted. A summary of these statistics can be seen in Table 4.20.

Table 4.20

Research Hypothesis One: Dependent t-test Statistics for Overall Pilot Study Phase

Two Data

<table>
<thead>
<tr>
<th></th>
<th>Mean Score</th>
<th>t</th>
<th>df</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Guided Inquiry Percent vs. Total Traditional Lecture Percent</td>
<td>57.7 vs. 68.5</td>
<td>-2.584</td>
<td>23</td>
<td>0.009*</td>
</tr>
</tbody>
</table>

n = 24

For the second part of hypothesis one, the difference in percentages based on topic, it was found that this hypothesis can again be rejected for one of the topics.
For the bonding topic there was no statistically significant difference between the post-test percentages for the students taught via guided inquiry and the students taught via traditional lecture ($t_{24} = -0.637, p = 0.530$). For the acid-base chemistry topic, there was a statistically significant difference between the post-test percentages with the guided inquiry students scoring significantly higher than the traditional lecture students ($t_{22} = 3.943, p = 0.001$). Table 4.21 contains a summary of these results.

Table 4.21

Research Hypothesis One: Independent t-test Statistics per Topic for Pilot Study Phase

Two Data

<table>
<thead>
<tr>
<th></th>
<th>Mean Score</th>
<th>n</th>
<th>t</th>
<th>df</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bonding</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Traditional Lecture Percent vs. Guided Inquiry Percent</td>
<td>64.8 vs. 59.3</td>
<td>26</td>
<td>-0.637</td>
<td>24</td>
<td>0.530</td>
</tr>
<tr>
<td>Acid-Base Chemistry</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Traditional Lecture Percent vs. Guided Inquiry Percent</td>
<td>50.5 vs. 79.2</td>
<td>24</td>
<td>3.943</td>
<td>22</td>
<td>0.001*</td>
</tr>
</tbody>
</table>

*statistically significant at 0.05 level

Research Hypothesis Two: There is a significant difference, overall and based on topic, for students' post-test percentages in a non-science majors' one semester chemistry course taught via guided inquiry, such that a statistically significant difference exists between males and females, between traditional students and non-traditional students, among students of different races, among students with differing years in school, among students of different majors, and among students with varying cumulative GPA groups. For the first part of this hypothesis about the overall percentages, none of the variables was found to have
statistically significant differences between post-test percentages when taught via
guided inquiry. So the null hypothesis (that there is no significant difference
between guided inquiry students’ post-test percentages and gender, age group, race,
year in school, major, and cumulative GPA group) was shown to be true at a 95
percent confidence.

A summary of the independent $t$-test statistics for the gender and age group
variables can be seen in Table 4.22. Table 4.23 contains the summary for the
ANOVA statistics for the variables race, year in school, major, and cumulative GPA
groups.

Table 4.22

Research Hypothesis Two: Independent $t$-test Statistics for Overall Guided Inquiry

Data by Categorical Variable for Pilot Study Phase Two

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean Score</th>
<th>t</th>
<th>df</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>Females vs. Males Percent</td>
<td>55.5 vs.</td>
<td>-0.745</td>
<td>24</td>
<td>0.464</td>
</tr>
<tr>
<td>Males Percent</td>
<td>61.9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Traditional vs. Non-Traditional Student Percent</td>
<td>57.8 vs.</td>
<td>0.056</td>
<td>24</td>
<td>0.956</td>
</tr>
<tr>
<td>Non-Traditional Student Percent</td>
<td>57.1</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

n = 26

Table 4.23

Research Hypothesis Two: ANOVA Statistics for Overall Guided Inquiry Data by

Categorical Variable for Pilot Study Phase Two

<table>
<thead>
<tr>
<th>Variable</th>
<th>n</th>
<th>F</th>
<th>df</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>Race Percent</td>
<td>24</td>
<td>3.368</td>
<td>1.22</td>
<td>0.080</td>
</tr>
<tr>
<td>Year in School Percent</td>
<td>26</td>
<td>0.822</td>
<td>3.22</td>
<td>0.496</td>
</tr>
<tr>
<td>Major Percent</td>
<td>26</td>
<td>1.776</td>
<td>5.20</td>
<td>0.164</td>
</tr>
<tr>
<td>GPA Group Percent</td>
<td>26</td>
<td>1.367</td>
<td>2.23</td>
<td>0.275</td>
</tr>
</tbody>
</table>

*statistically significant at 0.05 level
To look at the second part of hypothesis two, the analysis was broken down based on the content topic covered and the statistical differences in post-test percentages was analyzed when taught via guided inquiry based on the categorical variables. For the bonding topic, there were no statistically significant differences found between post-test percentages when taught via guided inquiry for any of the variables. Therefore, the researcher’s hypothesis is rejected and the null hypothesis is accepted for the bonding topic at a 95 percent confidence level. A summary of the independent t-tests conducted on gender and age group can be seen in Table 4.24. A summary of the ANOVAs conducted on race, year in school, major, and cumulative GPA group can be seen in Table 4.25.

Table 4.24

*Research Hypothesis Two: Independent t-test Statistics for Bonding Guided Inquiry*

*Data by Categorical Variable for Pilot Study Phase Two*

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean Score</th>
<th>t</th>
<th>df</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>Females vs. Males Percent</td>
<td>61.4 vs. 76.2</td>
<td>-1.091</td>
<td>11</td>
<td>0.299</td>
</tr>
<tr>
<td>Traditional vs. Non-Traditional Student Percent</td>
<td>63.6 vs. 71.4</td>
<td>-0.473</td>
<td>11</td>
<td>0.645</td>
</tr>
</tbody>
</table>

n = 13
Table 4.25

Research Hypothesis Two: ANOVA Statistics for Bonding Guided Inquiry Data by Categorical Variable for Pilot Study Phase Two

<table>
<thead>
<tr>
<th>Variable</th>
<th>n</th>
<th>F</th>
<th>df</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>Race Percent</td>
<td>13</td>
<td>0.139</td>
<td>1, 11</td>
<td>0.717</td>
</tr>
<tr>
<td>Year in School Percent</td>
<td>13</td>
<td>0.171</td>
<td>3, 9</td>
<td>0.913</td>
</tr>
<tr>
<td>Major Percent</td>
<td>13</td>
<td>2.322</td>
<td>3, 9</td>
<td>0.144</td>
</tr>
<tr>
<td>GPA Group Percent</td>
<td>13</td>
<td>2.322</td>
<td>1, 11</td>
<td>0.156</td>
</tr>
</tbody>
</table>

*statistically significant at 0.05 level

For the acid-base chemistry topic, there were no statistically significant differences found between post-test percentages when taught via guided inquiry for any of the variables. Therefore, the research hypothesis is rejected and the null hypothesis is accepted for the acid-base chemistry topic at a 95 percent confidence level. A summary of the independent t-tests conducted on gender and age group can be seen in Table 4.26. A summary of the ANOVAs conducted on race, year in school, major, and cumulative GPA group can be seen in Table 4.27.

Table 4.26

Research Hypothesis Two: Independent t-test Statistics for Acid-Base Chemistry Guided Inquiry Data by Categorical Variable for Pilot Study Phase Two

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean Score</th>
<th>t</th>
<th>df</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>Females vs. Males Percent</td>
<td>46.9 vs.</td>
<td>-0.725</td>
<td>11</td>
<td>0.483</td>
</tr>
<tr>
<td>Males Percent</td>
<td>54.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Traditional vs. Non-Traditional</td>
<td>51.9 vs.</td>
<td>0.606</td>
<td>11</td>
<td>0.557</td>
</tr>
<tr>
<td>Student Percent</td>
<td>42.9</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

n = 13
Table 4.27

Research Hypothesis Two: ANOVA Statistics for Acid-Base Chemistry Guided Inquiry

Data by Categorical Variable for Pilot Study Phase Two

<table>
<thead>
<tr>
<th>Variable</th>
<th>n</th>
<th>F</th>
<th>df</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>Race Percent</td>
<td>11</td>
<td>3.529</td>
<td>1, 9</td>
<td>0.093</td>
</tr>
<tr>
<td>Year in School Percent</td>
<td>13</td>
<td>0.444</td>
<td>2, 10</td>
<td>0.654</td>
</tr>
<tr>
<td>Major Percent</td>
<td>13</td>
<td>0.522</td>
<td>5, 7</td>
<td>0.754</td>
</tr>
<tr>
<td>GPA Group Percent</td>
<td>13</td>
<td>0.168</td>
<td>2, 10</td>
<td>0.848</td>
</tr>
</tbody>
</table>

*statistically significant at 0.05 level

Main Study

Since sections were combined and compared, equivalency between the sections needed to be established. According to Nurrenbern and Robinson (1994), one way to establish equivalency between groups when random assignment cannot be done is to look at similarities in relevant measures. A chi-square ($\chi^2$) analysis was conducted by class on the categorical demographic variables and the final course grade to look at differences between the sections. It was found that there were significant differences between the class sections on the cumulative GPA groups the students were in when they enrolled in the course, the age groups of the students, and the final grade breakdown of the students in the course. These statistical results can be seen in Table 4.28.
An analysis of variance (ANOVA) was conducted by class on the pre-survey content question percentages and student cumulative GPA. Table 4.29 shows the results of these analyses. None of the classes was found to be statistically significantly different on the pre-survey content question percentages. The classes were found to be statistically significantly different on the cumulative GPA values, just like the cumulative GPA groups. A post hoc analysis was done to determine what classes were statistically significantly different; these results can be seen in Table 4.30.

**Table 4.28**

χ² Results for Class Comparisons

<table>
<thead>
<tr>
<th>Variable</th>
<th>χ²</th>
<th>df</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>2.104</td>
<td>5</td>
<td>0.835</td>
</tr>
<tr>
<td>Race</td>
<td>27.170</td>
<td>20</td>
<td>0.131</td>
</tr>
<tr>
<td>Year in School</td>
<td>24.123</td>
<td>15</td>
<td>0.063</td>
</tr>
<tr>
<td>Major</td>
<td>33.919</td>
<td>35</td>
<td>0.520</td>
</tr>
<tr>
<td>GPA Group</td>
<td>32.433</td>
<td>20</td>
<td>0.039*</td>
</tr>
<tr>
<td>Age Group</td>
<td>17.115</td>
<td>5</td>
<td>0.004*</td>
</tr>
<tr>
<td>Final Course Grade</td>
<td>94.350</td>
<td>50</td>
<td>0.000*</td>
</tr>
</tbody>
</table>

n = 224
*statistically significant at 0.05 level

**Table 4.29**

ANOVA Results for Class Comparisons

<table>
<thead>
<tr>
<th>Variable</th>
<th>F</th>
<th>df</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bonding  Pre-survey %</td>
<td>1.042</td>
<td>5, 218</td>
<td>0.394</td>
</tr>
<tr>
<td>Chemical Equations Pre-survey %</td>
<td>0.795</td>
<td>5, 218</td>
<td>0.555</td>
</tr>
<tr>
<td>Acid-Base Chemistry Pre-survey %</td>
<td>0.999</td>
<td>5, 218</td>
<td>0.419</td>
</tr>
<tr>
<td>Cumulative GPA</td>
<td>4.493</td>
<td>5, 218</td>
<td>0.001*</td>
</tr>
</tbody>
</table>

n = 224
*statistically significant at 0.05 level
Table 4.30

Games-Howell Post Hoc Values for Cumulative GPA by Class Section

<table>
<thead>
<tr>
<th>Variables Between</th>
<th>Mean Difference</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>200 vs. 201</td>
<td>-0.039</td>
<td>1.000</td>
</tr>
<tr>
<td>200 vs. 300</td>
<td>-0.780</td>
<td>0.035*</td>
</tr>
<tr>
<td>200 vs. 400</td>
<td>-0.706</td>
<td>0.145</td>
</tr>
<tr>
<td>200 vs. 500</td>
<td>0.118</td>
<td>0.999</td>
</tr>
<tr>
<td>200 vs. 501</td>
<td>-0.479</td>
<td>0.502</td>
</tr>
<tr>
<td>201 vs. 300</td>
<td>-0.741</td>
<td>0.020*</td>
</tr>
<tr>
<td>201 vs. 400</td>
<td>-0.666</td>
<td>0.125</td>
</tr>
<tr>
<td>201 vs. 500</td>
<td>0.157</td>
<td>0.995</td>
</tr>
<tr>
<td>201 vs. 501</td>
<td>-0.439</td>
<td>0.494</td>
</tr>
<tr>
<td>300 vs. 400</td>
<td>0.074</td>
<td>0.998</td>
</tr>
<tr>
<td>300 vs. 500</td>
<td>0.898</td>
<td>0.004*</td>
</tr>
<tr>
<td>300 vs. 501</td>
<td>0.301</td>
<td>0.410</td>
</tr>
<tr>
<td>400 vs. 500</td>
<td>0.824</td>
<td>0.038*</td>
</tr>
<tr>
<td>400 vs. 501</td>
<td>0.227</td>
<td>0.881</td>
</tr>
</tbody>
</table>

*statistically significant at 0.05 level

There is a statistically significant difference in cumulative GPA for four of the sections. There is a statistically significant difference between sections 200 and 300, sections 201 and 300, and sections 300 and 500, with 300 having a higher cumulative GPA in all of the comparisons. Sections 400 and 500 are also significantly different with 400 having a higher cumulative GPA than 500. All of the rest of the pair-wise comparisons have non-significant differences between the cumulative GPAs of the students enrolled.

Nurrenbern and Robinson (1994) state that some of the relevant measures to show equivalency between groups are recent achievement scores, pre-tests, gender, age and class standing. Oliver-Hoyo, Allen, Hunt, Hutson and Pitts (2004) showed equivalency between classes by also comparing academic major as well as the
number of prior chemistry classes at the college level. Gutwill-Wise (2001) only used pre-test results to show that classes were equivalent.

The students in the six sections observed during the study had non-statistically significant differences in the demographic data of gender, race, year in school and major. The pre-survey percentages for the three different topics also had non-statistically significant differences between the sections under study. The lack of significant differences allowed the researcher to conclude that cross-class comparisons could be made, along with joining the groups together to make some of the comparisons for the study.

There was a statistically significant difference between the ages of students in the six sections. This shows that not all of the classes were entering with similar age groupings, but this was to be expected when considering that day classes and evening classes are offered for the course. The statistically significant difference in the cumulative grade point averages for the six sections shows that the students in each section are coming in with different levels of achievement. From the post hoc analysis, only four of the sections had statistically significant differences, whereas a majority of the sections were similar. However, the non-statistically significant differences in the pre-survey content questions showed that these students all had similar familiarity with the chemistry topics under study. The final grades for the students in the class were also statistically significantly different between the sections; this was thought to be an instructor bias on the distributing of the grades.
and would not have an ultimate effect on the class comparisons done by the researcher.

**Research Hypothesis One:** There is a significant difference, overall and based on topic, between students’ post-test percentages and teaching style in a non-science majors’ one semester chemistry course, such that students who participate in the guided inquiry activities will have significantly higher post-test percentages than the students in the traditional lecture classroom. The first part of this hypothesis, for overall percentage differences on all the topics combined, was rejected and the null hypothesis (that there is no difference in overall post-test percentages based on teaching style) was shown to be true with 95 percent confidence ($t_{155} = 0.388$, $p = 0.350$). Gain scores were also used to determine if there was a statistically significant difference between guided inquiry and traditional lecture teaching styles when the pre-test knowledge is controlled for. Again the null hypothesis is accepted; there is no statistically significant difference in gain scores between the different teaching styles ($t_{155} = 0.167$, $p = 0.434$). A summary of these statistics can be seen in Table 4.31. For this analysis, data from section 300 could not be used because that class was subjected only to the guided inquiry style of teaching for all three topics.
Table 4.31

*Research Hypothesis One: Dependent t-test Statistics for Overall Main Study Data*

<table>
<thead>
<tr>
<th>Compared to</th>
<th>Mean Score</th>
<th>t</th>
<th>df</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Guided Inquiry Percent vs.</td>
<td>69.3 vs.</td>
<td>0.388</td>
<td>155</td>
<td>0.350</td>
</tr>
<tr>
<td>Total Traditional Lecture Percent</td>
<td>68.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Guided Inquiry Gain Score vs.</td>
<td>0.672 vs.</td>
<td>0.167</td>
<td>155</td>
<td>0.434</td>
</tr>
<tr>
<td>Total Traditional Lecture Gain Score</td>
<td>0.668</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*n = 156*

For the second part of hypothesis one, the difference in percentages based on topic, it was found that this hypothesis can again be rejected for two of the topics. For the bonding and acid-base chemistry topics there was no statistically significant difference between the post-test percentages for the students taught via guided inquiry and the students taught via traditional lecture ($t_{210} = 0.716$, $p = 0.238$ and $t_{208} = 0.972$, $p = 0.166$, respectively). For the chemical equations topic, there was a statistically significant difference between the post-test percentages, with the guided inquiry students scoring significantly higher than the traditional lecture students ($t_{210} = -2.437$, $p = 0.008$). Similar results were found when gain scores were used, to control for the pre-test knowledge. Table 4.32 contains a summary of these results. Effect sizes are included in the table to show the practicality of the statistical test. The chemical equations topic had a small effect size ($\eta^2 > 0.01$), meaning there is a small effect for the style of teaching on the post-test percentage or gain score for the student. None of the other topics showed any effect on teaching style based on the effect size calculated.
Table 4.32

*Research Hypothesis One: Independent t-test Statistics per Topic for Main Study Data*

<table>
<thead>
<tr>
<th></th>
<th>Mean Score</th>
<th>n</th>
<th>t</th>
<th>df</th>
<th>Sig</th>
<th>$\eta^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bonding</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Traditional Lecture Percent vs. Guided Inquiry Percent Chemical Equations</td>
<td>60.1 vs. 57.2</td>
<td>212</td>
<td>0.716</td>
<td>210</td>
<td>0.238</td>
<td>0.002</td>
</tr>
<tr>
<td>Chemical Equations</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Traditional Lecture Percent vs. Guided Inquiry Percent Acid-Base Chemistry</td>
<td>68.2 vs. 78.6</td>
<td>212</td>
<td>-2.437</td>
<td>210</td>
<td>0.008*</td>
<td>0.028</td>
</tr>
<tr>
<td>Acid-Base Chemistry</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Traditional Lecture Percent vs. Guided Inquiry Percent Bonding</td>
<td>75.0 vs. 71.1</td>
<td>210</td>
<td>0.972</td>
<td>208</td>
<td>0.166</td>
<td>0.005</td>
</tr>
<tr>
<td>Bonding</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Traditional Lecture Gain Score vs. Guided Inquiry Gain Score Chemical Equations</td>
<td>0.575 vs. 0.540</td>
<td>212</td>
<td>-0.804</td>
<td>210</td>
<td>0.211</td>
<td>0.003</td>
</tr>
<tr>
<td>Chemical Equations</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Traditional Lecture Gain Score vs. Guided Inquiry Gain Score Acid-Base Chemistry</td>
<td>0.668 vs. 0.769</td>
<td>211</td>
<td>-2.243</td>
<td>209</td>
<td>0.013*</td>
<td>0.024</td>
</tr>
<tr>
<td>Acid-Base Chemistry</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Traditional Lecture Gain Score vs. Guided Inquiry Gain Score</td>
<td>0.743 vs. 0.696</td>
<td>210</td>
<td>1.168</td>
<td>201</td>
<td>0.122</td>
<td>0.007</td>
</tr>
</tbody>
</table>

*statistically significant at 0.05 level

Research Hypothesis Two: There is a significant difference, overall and based on topic, for student post-test percentages in a non-science majors’ one semester chemistry course taught via guided inquiry, such that a statistically significant difference exists between males and females, between traditional students and non-traditional students, among students of different races, among students with differing years in school, among students of different majors, and among students with varying cumulative GPA groups. For the first part of this hypothesis about the overall percentages, three of the variables were found to have statistically significant differences between post-test percentages when taught via
guided inquiry. The three variables to show this difference with 95 percent confidence were race, year in school and cumulative GPA group ($F_{4,200} = 5.772, p < 0.000; F_{3,203} = 3.197, p = 0.024; F_{4,202} = 9.184, p < 0.000$, respectively). When the same statistics were computed using gain scores, only two of the categorical variables had a statistically significant difference in gain scores. The two variables to show a significant difference between groups were race and cumulative GPA group ($F_{4,200} = 5.492, p < 0.000$ and $F_{4,202} = 9.313, p < 0.000$, respectively).

A summary of the independent $t$-test statistics for the gender and age group variables can be seen in Table 4.33. Table 4.34 contains the summary for the ANOVA statistics for the variables race, year in school, major, and cumulative GPA groups. Both tables also include effect sizes for each of the variables to look at the practicality of the statistics. The variables of race and GPA group both had medium effect sizes ($\eta^2 \geq 0.09$), meaning that these variables had somewhat of an effect on the post-test percentages or the gain scores for the students. The year in school and student major variables had small effect sizes ($\eta^2 \geq 0.01$).
Table 4.33

Research Hypothesis Two: Independent t-test Statistics for Overall Guided Inquiry

Main Study Data by Categorical Variable

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean Score</th>
<th>t</th>
<th>df</th>
<th>Sig</th>
<th>η²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Females vs. Males Percent</td>
<td>70.1 vs. 69.9</td>
<td>0.058</td>
<td>205</td>
<td>0.953</td>
<td>0.000</td>
</tr>
<tr>
<td>Traditional vs. Non-Traditional Student Percent</td>
<td>70.2 vs. 69.1</td>
<td>0.225</td>
<td>205</td>
<td>0.822</td>
<td>0.000</td>
</tr>
<tr>
<td>Female vs. Males Gain Score</td>
<td>0.688 vs. 0.668</td>
<td>0.511</td>
<td>205</td>
<td>0.610</td>
<td>0.000</td>
</tr>
<tr>
<td>Traditional vs. Non-Traditional Student Gain Score</td>
<td>0.681 vs. 0.678</td>
<td>0.063</td>
<td>205</td>
<td>0.950</td>
<td>0.000</td>
</tr>
</tbody>
</table>

n = 207

Table 4.34

Research Hypothesis Two: ANOVA Statistics for Overall Guided Inquiry Main Study

Data by Categorical Variable

<table>
<thead>
<tr>
<th>Variable</th>
<th>n</th>
<th>F</th>
<th>df</th>
<th>Sig</th>
<th>η²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Race Percent</td>
<td>205</td>
<td>5.772</td>
<td>4,200</td>
<td>0.000*</td>
<td>0.103</td>
</tr>
<tr>
<td>Year in School Percent</td>
<td>207</td>
<td>3.197</td>
<td>3,203</td>
<td>0.024*</td>
<td>0.045</td>
</tr>
<tr>
<td>Major Percent</td>
<td>207</td>
<td>1.061</td>
<td>7,199</td>
<td>0.390</td>
<td>0.036</td>
</tr>
<tr>
<td>GPA Group Percent</td>
<td>207</td>
<td>9.184</td>
<td>4,202</td>
<td>0.000*</td>
<td>0.154</td>
</tr>
<tr>
<td>Race Gain Score</td>
<td>205</td>
<td>5.492</td>
<td>4,200</td>
<td>0.000*</td>
<td>0.099</td>
</tr>
<tr>
<td>Year in School Gain Score</td>
<td>207</td>
<td>2.171</td>
<td>3,203</td>
<td>0.093</td>
<td>0.031</td>
</tr>
<tr>
<td>Major Gain Score</td>
<td>207</td>
<td>1.102</td>
<td>7,199</td>
<td>0.363</td>
<td>0.037</td>
</tr>
<tr>
<td>GPA Group Gain Score</td>
<td>207</td>
<td>9.313</td>
<td>4,202</td>
<td>0.000*</td>
<td>0.156</td>
</tr>
</tbody>
</table>

*statistically significant at 0.05 level

Post hoc analyses were conducted for the variables that had a statistically significant difference between post-test percentages. A Games-Howell test was conducted for the race variable because equal variance between the groups could not be assumed. A Tukey’s HSD test was conducted for the year in school and cumulative GPA group variables because equal variance between the groups could
be assumed. Post hoc analyses were also done for the variables that had statistically significant differences between gain scores. A Tukey's HSD test was conducted for both the race and cumulative GPA group variables because equal variance between the groups could be assumed in each case. Tables 4.35 through 4.39 contain the statistics for these post hoc analyses.

Table 4.35

Games-Howell Post Hoc Values for Post-Test Guided Inquiry Percentages by Race

<table>
<thead>
<tr>
<th>Variables Between</th>
<th>Mean Difference</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caucasian vs. African American</td>
<td>24.325</td>
<td>0.196</td>
</tr>
<tr>
<td>Caucasian vs. Latino/Hispanic</td>
<td>39.322</td>
<td>0.668</td>
</tr>
<tr>
<td>Caucasian vs. Asian</td>
<td>3.9054</td>
<td>1.000</td>
</tr>
<tr>
<td>Caucasian vs. Other</td>
<td>26.227</td>
<td>0.412</td>
</tr>
<tr>
<td>African American vs. Latino/Hispanic</td>
<td>14.997</td>
<td>0.979</td>
</tr>
<tr>
<td>African American vs. Asian</td>
<td>-20.420</td>
<td>0.953</td>
</tr>
<tr>
<td>African American vs. Other</td>
<td>1.901</td>
<td>1.000</td>
</tr>
<tr>
<td>Latino/Hispanic vs. Asian</td>
<td>-35.417</td>
<td>0.896</td>
</tr>
<tr>
<td>Latino/Hispanic vs. Other</td>
<td>-13.095</td>
<td>0.990</td>
</tr>
<tr>
<td>Asian vs. Other</td>
<td>22.321</td>
<td>0.957</td>
</tr>
</tbody>
</table>

*statistically significant at 0.05 level

Through the post hoc analysis, it can be seen that there were no statistically significant differences found between the individual groups. A type I error could have occurred in this analysis. This result could also be due to the pair-wise comparisons of the post hoc being more stringent than the original ANOVA and interaction effects are not considered in the pair-wise analysis and they are in the ANOVA, or due to the unequal group sizes.
### Table 4.36

**Tukey’s HSD Post Hoc Values for Post-Test Guided Inquiry Percentages by Year in School**

<table>
<thead>
<tr>
<th>Variables Between</th>
<th>Mean Difference</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freshman vs. Sophomore</td>
<td>8.474</td>
<td>0.216</td>
</tr>
<tr>
<td>Freshman vs. Junior</td>
<td>14.456</td>
<td>0.044*</td>
</tr>
<tr>
<td>Freshman vs. Senior/Higher</td>
<td>-0.073</td>
<td>1.000</td>
</tr>
<tr>
<td>Sophomore vs. Junior</td>
<td>5.983</td>
<td>0.638</td>
</tr>
<tr>
<td>Sophomore vs. Senior/Higher</td>
<td>-8.547</td>
<td>0.371</td>
</tr>
<tr>
<td>Junior vs. Senior/Higher</td>
<td>-14.530</td>
<td>0.094</td>
</tr>
</tbody>
</table>

*statistically significant at 0.05 level

It was found that freshmen level students had statistically significantly higher percentages on post-tests when taught via guided inquiry than junior level students. All other pair-wise comparisons showed non-significant differences.

### Table 4.37

**Tukey’s HSD Post Hoc Values for Post-Test Guided Inquiry Percentages by Cumulative GPA Group**

<table>
<thead>
<tr>
<th>Variables Between</th>
<th>Mean Difference</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.35-4.0 vs. 2.65-3.34</td>
<td>7.929</td>
<td>0.299</td>
</tr>
<tr>
<td>3.35-4.0 vs. 1.65-2.64</td>
<td>25.108</td>
<td>0.000*</td>
</tr>
<tr>
<td>3.35-4.0 vs. 0-1.64</td>
<td>55.748</td>
<td>0.011*</td>
</tr>
<tr>
<td>3.35-4.0 vs. Entering Freshmen/Transfer Student</td>
<td>3.352</td>
<td>0.972</td>
</tr>
<tr>
<td>2.65-3.34 vs. 1.65-2.64</td>
<td>17.180</td>
<td>0.003*</td>
</tr>
<tr>
<td>2.65-3.34 vs. 0-1.64</td>
<td>47.820</td>
<td>0.044*</td>
</tr>
<tr>
<td>2.65-3.34 vs. Entering Freshmen/Transfer Student</td>
<td>-4.577</td>
<td>0.910</td>
</tr>
<tr>
<td>1.65-2.64 vs. 1-1.64</td>
<td>30.640</td>
<td>0.392</td>
</tr>
<tr>
<td>1.65-2.64 vs. Entering Freshmen/Transfer Student</td>
<td>-21.756</td>
<td>0.003*</td>
</tr>
<tr>
<td>0-1.64 vs. Entering Freshmen/Transfer Student</td>
<td>-52.396</td>
<td>0.025*</td>
</tr>
</tbody>
</table>

*statistically significant at 0.05 level

It was found that the high cumulative GPA group of 3.35-4.00 had statistically significantly higher percentages on post-tests when taught via guided inquiry than
the two lower cumulative GPA groups of 1.65-2.64 and 0.00-1.64. The second level of cumulative GPA groups, 2.65-3.34, and entering freshman/transfer students also had statistically significantly higher percentages on post-tests than the two lower cumulative GPA groups (1.65-2.64 and 0.00-1.64).

Table 4.38

*Tukey's HSD Post Hoc Values for Guided Inquiry Gain Scores by Race*

<table>
<thead>
<tr>
<th>Variables Between</th>
<th>Mean Difference</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caucasian vs. African American</td>
<td>0.2450</td>
<td>0.030*</td>
</tr>
<tr>
<td>Caucasian vs. Latino/Hispanic</td>
<td>0.3735</td>
<td>0.095</td>
</tr>
<tr>
<td>Caucasian vs. Asian</td>
<td>0.0193</td>
<td>1.000</td>
</tr>
<tr>
<td>Caucasian vs. Other</td>
<td>0.2885</td>
<td>0.032*</td>
</tr>
<tr>
<td>African American vs. Latino/Hispanic</td>
<td>0.1285</td>
<td>0.941</td>
</tr>
<tr>
<td>African American vs. Asian</td>
<td>-0.2256</td>
<td>0.788</td>
</tr>
<tr>
<td>African American vs. Other</td>
<td>0.0435</td>
<td>0.997</td>
</tr>
<tr>
<td>Latino/Hispanic vs. Asian</td>
<td>-0.3542</td>
<td>0.556</td>
</tr>
<tr>
<td>Latino/Hispanic vs. Other</td>
<td>-0.0850</td>
<td>0.989</td>
</tr>
<tr>
<td>Asian vs. Other</td>
<td>0.2691</td>
<td>0.687</td>
</tr>
</tbody>
</table>

*statistically significant at 0.05 level

It was found that Caucasian students had statistically significantly higher gain scores when taught via guided inquiry than both the African American students and the race classification of other students. All other pair-wise comparisons showed non-significant differences.
Table 4.39

Tukey’s HSD Post Hoc Values for Guided Inquiry Gain Scores by Cumulative GPA Group

<table>
<thead>
<tr>
<th>Variables Between</th>
<th>Mean Difference</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.35-4.0 vs. 2.65-3.34</td>
<td>0.7983</td>
<td>0.333</td>
</tr>
<tr>
<td>3.35-4.0 vs. 1.65-2.64</td>
<td>0.2684</td>
<td>0.000*</td>
</tr>
<tr>
<td>3.35-4.0 vs. 0-1.64</td>
<td>0.5407</td>
<td>0.023*</td>
</tr>
<tr>
<td>3.35-4.0 vs. Entering Freshmen/Transfer Student</td>
<td>0.0327</td>
<td>0.978</td>
</tr>
<tr>
<td>2.65-3.34 vs. 1.65-2.64</td>
<td>0.1886</td>
<td>0.001*</td>
</tr>
<tr>
<td>2.65-3.34 vs. 0-1.64</td>
<td>0.4609</td>
<td>0.076</td>
</tr>
<tr>
<td>2.65-3.34 vs. Entering Freshmen/Transfer Student</td>
<td>-0.0471</td>
<td>0.913</td>
</tr>
<tr>
<td>1.65-2.64 vs. 0-1.64</td>
<td>0.2723</td>
<td>0.555</td>
</tr>
<tr>
<td>1.65-2.64 vs. Entering Freshmen/Transfer Student</td>
<td>-0.2357</td>
<td>0.001*</td>
</tr>
<tr>
<td>0-1.64 vs. Entering Freshmen/Transfer Student</td>
<td>-0.5080</td>
<td>0.045*</td>
</tr>
</tbody>
</table>

*statistically significant at 0.05 level

It was found that the high cumulative GPA group of 3.35-4.00 had statistically significantly higher gain scores when taught via guided inquiry than the two lower cumulative GPA groups of 1.65-2.64 and 0.00-1.64. The second level of cumulative GPA groups, 2.65-3.34, also had statistically significantly higher gain scores than the cumulative GPA group of 1.64-2.64. Entering freshman/transfer students also had significantly higher gain scores than the two lower cumulative GPA groups (1.65-2.64 and 0.00-1.64).

To look at the second part of Hypothesis Two, the analysis was broken down based on the content topic covered. The statistical differences in post-test percentages when taught via guided inquiry were analyzed based on the categorical variables. For the bonding topic, there were statistically significant differences found between post-test percentages when taught via guided inquiry for race, year in school, and cumulative GPA group ($F_{4,112} = 5.051, p = 0.001; F_{3,114} = 2.786, p = 0.044; F_{4,113} = 2.554, p = 0.043$, respectively). The other variables did not have
statistically significant differences in post-test percentages. When the same analysis was done on gain scores, only the race variable had a statistically significant difference ($F_{4,112} = 4.301, p = 0.003$).

A summary of the independent $t$-tests conducted on gender and age group can be seen in Table 4.40. A summary of the ANOVAs conducted on race, year in school, major, and cumulative GPA group can be seen in Table 4.41. Effect sizes were also included in the tables to show how much effect the independent variables had on the dependent variable. The variables of race and student major have medium effect sizes ($\eta^2 \geq 0.09$) on the post-test percentages for the bonding topic, while the variables of year in school and cumulative GPA group have small effect sizes ($\eta^2 \geq 0.01$). For the gain scores, only the race has a medium effect size, while year in school, student major and cumulative GPA group have small effects.

Table 4.40

*Research Hypothesis Two: Independent $t$-test Statistics for Bonding Guided Inquiry*

*Main Study Data by Categorical Variable*

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean Score</th>
<th>t</th>
<th>df</th>
<th>Sig</th>
<th>$\eta^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Females vs. Males Percent</td>
<td>58.0 vs. 56.0</td>
<td>0.377</td>
<td>116</td>
<td>0.707</td>
<td>0.001</td>
</tr>
<tr>
<td>Traditional vs. Non-Traditional Student Percent</td>
<td>56.9 vs. 58.8</td>
<td>-0.269</td>
<td>116</td>
<td>0.789</td>
<td>0.001</td>
</tr>
<tr>
<td>Females vs. Males Gain Scores</td>
<td>0.545 vs. 0.533</td>
<td>0.218</td>
<td>116</td>
<td>0.828</td>
<td>0.000</td>
</tr>
<tr>
<td>Traditional vs. Non-Traditional Student Gain Score</td>
<td>0.540 vs. 0.542</td>
<td>-0.023</td>
<td>116</td>
<td>0.982</td>
<td>0.000</td>
</tr>
</tbody>
</table>

n = 118
Table 4.41

*Research Hypothesis Two: ANOVA Statistics for Bonding Guided Inquiry Main Study*

*Data by Categorical Variable*

<table>
<thead>
<tr>
<th>Variable</th>
<th>n</th>
<th>F</th>
<th>df</th>
<th>Sig</th>
<th>( \eta^2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Race Percent</td>
<td>117</td>
<td>5.051</td>
<td>4, 112</td>
<td>0.001*</td>
<td>0.153</td>
</tr>
<tr>
<td>Year in School Percent</td>
<td>118</td>
<td>2.786</td>
<td>3, 114</td>
<td>0.044*</td>
<td>0.068</td>
</tr>
<tr>
<td>Major Percent</td>
<td>118</td>
<td>1.603</td>
<td>7, 110</td>
<td>0.142</td>
<td>0.093</td>
</tr>
<tr>
<td>GPA Group Percent</td>
<td>118</td>
<td>2.554</td>
<td>4, 113</td>
<td>0.043*</td>
<td>0.083</td>
</tr>
<tr>
<td>Race Gain Score</td>
<td>117</td>
<td>4.307</td>
<td>4, 112</td>
<td>0.003*</td>
<td>0.133</td>
</tr>
<tr>
<td>Year in School Gain Score</td>
<td>118</td>
<td>1.485</td>
<td>3, 114</td>
<td>0.223</td>
<td>0.038</td>
</tr>
<tr>
<td>Major Gain Score</td>
<td>118</td>
<td>1.267</td>
<td>7, 110</td>
<td>0.273</td>
<td>0.075</td>
</tr>
<tr>
<td>GPA Group Gain Score</td>
<td>118</td>
<td>2.061</td>
<td>4, 113</td>
<td>0.091</td>
<td>0.068</td>
</tr>
</tbody>
</table>

*statistically significant at 0.05 level

Post hoc analyses were conducted for the variables that had statistically significant differences between bonding post-test percentages. Post hoc analyses could not be completed for race and cumulative GPA group because each variable contained a category with only one subject. Therefore, it is impossible to determine between which categories the significant difference lies. A Tukey's HSD test was conducted for the year in school variable and a summary of the results can be seen in Table 4.42. A post hoc analysis could not be conducted for the gain score differences by race. Again one of the categories had only one subject, so it cannot be determined between which categories the significant difference in gain scores lies.
Tables 4.42

*Tukey’s HSD Post Hoc Values for Bonding Post-Test Guided Inquiry Percentages by Year in School*

<table>
<thead>
<tr>
<th>Variables Between</th>
<th>Mean Difference</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freshman vs. Sophomore</td>
<td>2.3148</td>
<td>0.984</td>
</tr>
<tr>
<td>Freshman vs. Junior</td>
<td>19.9916</td>
<td>0.061</td>
</tr>
<tr>
<td>Freshman vs. Senior/Higher</td>
<td>0.3704</td>
<td>1.000</td>
</tr>
<tr>
<td>Sophomore vs. Junior</td>
<td>17.6768</td>
<td>0.059</td>
</tr>
<tr>
<td>Sophomore vs. Senior/Higher</td>
<td>-1.9444</td>
<td>0.995</td>
</tr>
<tr>
<td>Junior vs. Senior/Higher</td>
<td>-19.6212</td>
<td>0.150</td>
</tr>
</tbody>
</table>

*statistically significant at 0.05 level

Although none of the categories was found to have statistically significant differences at the 0.05 level when the post hoc analysis was completed, the freshmen and sophomore level students did have much higher bonding post-test percentages than the junior level students.

For the chemical equations topic, there were significant differences found among the post-test percentages when taught via guided inquiry for race, and cumulative GPA group ($F_{4,132} = 4.555, p = 0.002; F_{4,133} = 3.818, p = 0.001,$ respectively). The other variables did not have statistically significant differences in post-test percentages. Similar results were found when the analysis was done on gain scores for chemical equations ($F_{4,131} = 5.235, p = 0.006; F_{4,132} = 4.510, p = 0.002,$ respectively).

A summary of the independent $t$-tests conducted on gender and age group can be seen in Table 4.43. A summary of the ANOVAs conducted on race, year in school, major, and cumulative GPA group can be seen in Table 4.44. Effect sizes are included in the table to show the practicality that each variable had on the post-test
percentages or gain scores. The variables of race and cumulative GPA had medium
effects on the post-test percentages and gain scores for the chemical equations topic,
while the year in school and student major variables had small effects.

Table 4.43

Research Hypothesis Two: Independent t-test Statistics for Chemical Equations Guided
Inquiry Main Study Data by Categorical Variable

<table>
<thead>
<tr>
<th>Variable</th>
<th>n</th>
<th>Mean Score</th>
<th>t</th>
<th>df</th>
<th>Sig</th>
<th>η^2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Females vs. Males Percent</td>
<td>138</td>
<td>76.6 vs. 81.7</td>
<td>-1.029</td>
<td>136</td>
<td>0.305</td>
<td>0.008</td>
</tr>
<tr>
<td>Traditional vs. Non-Traditional Percent</td>
<td>138</td>
<td>77.6 vs. 84.1</td>
<td>-0.984</td>
<td>136</td>
<td>0.327</td>
<td>0.007</td>
</tr>
<tr>
<td>Females vs. Males Gain Scores</td>
<td>137</td>
<td>0.755 vs. 0.792</td>
<td>-0.702</td>
<td>135</td>
<td>0.484</td>
<td>0.004</td>
</tr>
<tr>
<td>Traditional vs. Non-Traditional Gain Score</td>
<td>137</td>
<td>0.758 vs. 0.828</td>
<td>-0.985</td>
<td>135</td>
<td>0.326</td>
<td>0.007</td>
</tr>
</tbody>
</table>

Table 4.44

Research Hypothesis Two: ANOVA Statistics for Chemical Equations Guided Inquiry

Main Study Data by Categorical Variable

<table>
<thead>
<tr>
<th>Variable</th>
<th>n</th>
<th>F</th>
<th>df</th>
<th>Sig</th>
<th>η^2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Race Percent</td>
<td>137</td>
<td>4.555</td>
<td>4, 132</td>
<td>0.002*</td>
<td>0.121</td>
</tr>
<tr>
<td>Year in School Percent</td>
<td>138</td>
<td>1.729</td>
<td>3, 134</td>
<td>0.164</td>
<td>0.037</td>
</tr>
<tr>
<td>Major Percent</td>
<td>138</td>
<td>0.463</td>
<td>7, 130</td>
<td>0.860</td>
<td>0.024</td>
</tr>
<tr>
<td>GPA Group Percent</td>
<td>138</td>
<td>5.235</td>
<td>4, 133</td>
<td>0.001*</td>
<td>0.136</td>
</tr>
<tr>
<td>Race Gain Score</td>
<td>136</td>
<td>3.818</td>
<td>4, 131</td>
<td>0.006*</td>
<td>0.104</td>
</tr>
<tr>
<td>Year in School Gain Score</td>
<td>137</td>
<td>1.127</td>
<td>3, 133</td>
<td>0.341</td>
<td>0.025</td>
</tr>
<tr>
<td>Major Gain Score</td>
<td>137</td>
<td>0.441</td>
<td>7, 129</td>
<td>0.874</td>
<td>0.023</td>
</tr>
<tr>
<td>GPA Group Gain Score</td>
<td>137</td>
<td>4.510</td>
<td>4, 132</td>
<td>0.002*</td>
<td>0.120</td>
</tr>
</tbody>
</table>

*statistically significant at 0.05 level
Post hoc analysis could not be completed for post-test percentages or gain scores on the chemical equations topic for race and cumulative GPA group because each variable contained a category with only one subject. Therefore, it is impossible to determine between which categories the significant difference lies.

For the acid-base chemistry topic, there were statistically significant differences found between post-test percentages when taught via guided inquiry for race, year in school, and cumulative GPA group ($F_{4,130} = 2.463, p = 0.048; F_{3,132} = 3.064, p = 0.030; F_{4,131} = 3.635, p = 0.008$, respectively). The other variables did not have significant differences in post-test percentages. When the same analysis was done on gain scores, only the cumulative GPA group variable had a statistically significant difference ($F_{4,131} = 3.887, p = 0.005$).

A summary of the independent $t$-tests conducted on gender and age group can be seen in Table 4.45. A summary of the ANOVAs conducted on race, year in school, major, and cumulative GPA group can be seen in Table 4.46. Effect sizes are also included. The only variable to show a medium effect ($\eta^2 \geq 0.09$) was cumulative GPA on the post-test percentages and gain scores for the acid-base chemistry topic. The other variables of race, year in school, and student major showed a small effect ($\eta^2 \geq 0.01$). For the acid-base chemistry post-test percentages, the age group variable also showed a small effect.
Table 4.45

Research Hypothesis Two: Independent t-test Statistics for Acid-Base Chemistry

Guided Inquiry Main Study Data by Categorical Variable

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean Score</th>
<th>t</th>
<th>df</th>
<th>Sig</th>
<th>η²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Females vs. Males Percent</td>
<td>71.8 vs.</td>
<td>0.338</td>
<td>134</td>
<td>0.736</td>
<td>0.001</td>
</tr>
<tr>
<td>Traditional vs. Non-Traditional</td>
<td>72.8 vs.</td>
<td>1.281</td>
<td>134</td>
<td>0.203</td>
<td>0.012</td>
</tr>
<tr>
<td>Student Percent</td>
<td>66.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Females vs. Males Gain Scores</td>
<td>0.707 vs.</td>
<td>0.583</td>
<td>134</td>
<td>0.561</td>
<td>0.003</td>
</tr>
<tr>
<td>Traditional vs. Non-Traditional</td>
<td>0.708 vs.</td>
<td>0.952</td>
<td>134</td>
<td>0.343</td>
<td>0.007</td>
</tr>
<tr>
<td>Student Gain Score</td>
<td>0.657</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

n = 136

Table 4.46

Research Hypothesis Two: ANOVA Statistics for Acid-Base Chemistry Guided Inquiry

Main Study Data by Categorical Variable

<table>
<thead>
<tr>
<th>Variable</th>
<th>n</th>
<th>F</th>
<th>df</th>
<th>Sig</th>
<th>η²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Race Percent</td>
<td>135</td>
<td>2.463</td>
<td>4, 130</td>
<td>0.048*</td>
<td>0.070</td>
</tr>
<tr>
<td>Year in School Percent</td>
<td>136</td>
<td>3.064</td>
<td>3, 132</td>
<td>0.030*</td>
<td>0.065</td>
</tr>
<tr>
<td>Major Percent</td>
<td>136</td>
<td>1.230</td>
<td>7, 128</td>
<td>0.291</td>
<td>0.063</td>
</tr>
<tr>
<td>GPA Group Percent</td>
<td>136</td>
<td>3.635</td>
<td>4, 131</td>
<td>0.008*</td>
<td>0.100</td>
</tr>
<tr>
<td>Race Gain Score</td>
<td>135</td>
<td>2.360</td>
<td>4, 130</td>
<td>0.057</td>
<td>0.068</td>
</tr>
<tr>
<td>Year in School Gain Score</td>
<td>136</td>
<td>2.598</td>
<td>3, 132</td>
<td>0.055</td>
<td>0.056</td>
</tr>
<tr>
<td>Major Gain Score</td>
<td>136</td>
<td>1.199</td>
<td>7, 128</td>
<td>0.308</td>
<td>0.062</td>
</tr>
<tr>
<td>GPA Group Gain Score</td>
<td>136</td>
<td>3.887</td>
<td>4, 131</td>
<td>0.005*</td>
<td>0.106</td>
</tr>
</tbody>
</table>

*statistically significant at 0.05 level

Post hoc analyses were conducted for the variables that had a significant difference between acid-base chemistry post-test percentages. Post hoc analysis could not be completed for race and cumulative GPA group because each variable contained a category with only one subject. Therefore, it is impossible to determine between which categories the significant difference lies. A Tukey’s HSD test was
conducted for the year in school variable and a summary of the results can be seen in Table 4.47. A post hoc analysis could not be conducted for the gain score differences by cumulative GPA group. Again, one of the categories had only one subject, so it cannot be determined between which categories the significant difference in gain scores lies.

Tables 4.47

Tukey's HSD Post Hoc Values for Acid-Base Post-Test Guided Inquiry Percentages by Year in School

<table>
<thead>
<tr>
<th>Variables Between</th>
<th>Mean Difference</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freshman vs. Sophomore</td>
<td>9.3715</td>
<td>0.356</td>
</tr>
<tr>
<td>Freshman vs. Junior</td>
<td>14.7081</td>
<td>0.181</td>
</tr>
<tr>
<td>Freshman vs. Senior/Higher</td>
<td>-4.1563</td>
<td>0.928</td>
</tr>
<tr>
<td>Sophomore vs. Junior</td>
<td>5.3366</td>
<td>0.845</td>
</tr>
<tr>
<td>Sophomore vs. Senior/Higher</td>
<td>-13.5279</td>
<td>0.118</td>
</tr>
<tr>
<td>Junior vs. Senior/Higher</td>
<td>-18.8645</td>
<td>0.062</td>
</tr>
</tbody>
</table>

*statistically significant at 0.05 level

Although none of the categories was found to have statistically significant differences at the 0.05 level when the post hoc analysis was completed, the senior/higher level students did have much higher bonding post-test percentages than the junior level students.
Interview Analysis

Descriptive Statistics

Twenty students participated in the interview portion of the main research study. See Table 3.6 for a breakdown of the number of students interviewed for each course section. During the interview, students were asked twelve content questions, four from each topic (bonding, chemical equations, and acid-base chemistry). These twelve questions were the same as the questions found on the pre-surveys and post-tests. Each question was followed by a series of questions asking the student why they gave the answer they did or asking them to explain terms that went along with the question. See Appendix H for the interview protocol.

For the bonding topic, the questions asked in the interview were:

1. What charge does the calcium ion have?
2. Describe the formation of an ionic bond in terms of the electrons.
3. What type of bond is present in a substance that has the following properties:
electrons shared between two non-metals, can be a solid, liquid or gas at room temperature, has a low melting or boiling point, and is usually soft?
4. How do you determine if a covalent bond is polar or nonpolar?

For the chemical equations topic the questions asked were:

5. State the type of chemical equation for the following reaction.
\[ \text{Mg} + \text{Ca}_3(\text{PO}_4)_2 \rightarrow \text{Mg}_3(\text{PO}_4)_2 + \text{Ca} \]
6. List the reactants in the following reaction.

\[ \text{Mg} + \text{Ca}_3(\text{PO}_4)_2 \rightarrow \text{Mg}_3(\text{PO}_4)_2 + \text{Ca} \]

7. What does the triangle mean above the arrow in the following equation?

\[ 2\text{CH}_3\text{OH}(l) + 3\text{O}_2(g) \xrightarrow{\Delta} 2\text{CO}_2 + 4\text{H}_2\text{O}(l) \]

8. Balance the following chemical equation.

\[ \underline{\quad} \text{Al} + \underline{\quad} \text{H}_2\text{SO}_4 \rightarrow \underline{\quad} \text{Al}_2(\text{SO}_4)_3 + \underline{\quad} \text{H}_2 \]

For the acid-base chemistry the questions asked were:

9. What is the pH range for acids?

10. In the following reaction label the base and the conjugate acid.

\[ \text{H}_3\text{PO}_4(aq) + \text{H}_2\text{O} \rightarrow \text{H}_2\text{PO}_4^-(aq) + \text{H}_3\text{O}^+(aq) \]

11. What is the pH of a solution that contains \(3.2 \times 10^{-7}\) M hydronium ions?

12. How many moles of sodium hydroxide (NaOH) would be needed to neutralize 2.0 moles of hydrochloric acid (HCl)?

Table 4.48 contains a breakdown for the frequency and percentage of students who answered each question correctly or incorrectly. Questions two, four, and ten had more students answer the question incorrectly and question eleven only had half of the students answering the question correctly. For these questions, the most common wrong answer and the percentage of students who gave that answer are listed in the table. The rest of the questions had a majority of the students answering the questions correctly.
Table 4.48

*Interview Content Question Frequencies for Correct and Wrong Answers*

<table>
<thead>
<tr>
<th>Question</th>
<th>Correct/Wrong Answer (Most Common Wrong Answer and Percent)</th>
<th>Frequency</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Correct – plus two charge</td>
<td>17</td>
<td>85.0</td>
</tr>
<tr>
<td></td>
<td>Wrong</td>
<td>3</td>
<td>15.0</td>
</tr>
<tr>
<td>2</td>
<td>Correct – electrons transfer between atoms and positive and negative charges attract (Don’t know with 35%)</td>
<td>5</td>
<td>25.0</td>
</tr>
<tr>
<td></td>
<td>Wrong</td>
<td>15</td>
<td>75.0</td>
</tr>
<tr>
<td>3</td>
<td>Correct – covalent bond</td>
<td>15</td>
<td>75.0</td>
</tr>
<tr>
<td></td>
<td>Wrong</td>
<td>5</td>
<td>25.0</td>
</tr>
<tr>
<td>4</td>
<td>Correct – the atoms do not share the electrons equally (Don’t know with 40%)</td>
<td>3</td>
<td>15.0</td>
</tr>
<tr>
<td></td>
<td>Wrong</td>
<td>17</td>
<td>85.0</td>
</tr>
<tr>
<td>5</td>
<td>Correct – single displacement</td>
<td>15</td>
<td>75.0</td>
</tr>
<tr>
<td></td>
<td>Wrong</td>
<td>5</td>
<td>25.0</td>
</tr>
<tr>
<td>6</td>
<td>Correct – Mg and Ca₃(PO₄)₂</td>
<td>15</td>
<td>75.0</td>
</tr>
<tr>
<td></td>
<td>Wrong</td>
<td>5</td>
<td>25.0</td>
</tr>
<tr>
<td>7</td>
<td>Correct – add heat or heat is used to cause reaction</td>
<td>17</td>
<td>85.0</td>
</tr>
<tr>
<td></td>
<td>Wrong</td>
<td>3</td>
<td>15.0</td>
</tr>
<tr>
<td>8</td>
<td>Correct – 2Al + 3H₂SO₄ → Al₂(SO₄)₃ + 3H₂</td>
<td>16</td>
<td>80.0</td>
</tr>
<tr>
<td></td>
<td>Wrong</td>
<td>4</td>
<td>20.0</td>
</tr>
<tr>
<td>9</td>
<td>Correct – 0 to 7 or any variation</td>
<td>17</td>
<td>85.0</td>
</tr>
<tr>
<td></td>
<td>Wrong</td>
<td>3</td>
<td>15.0</td>
</tr>
<tr>
<td>10</td>
<td>Correct – base is H₂O and conjugate acid is H₃O⁺ (acid &amp; base wrong, but conjugates with 15%)</td>
<td>9</td>
<td>45.0</td>
</tr>
<tr>
<td></td>
<td>Wrong</td>
<td>11</td>
<td>55.0</td>
</tr>
<tr>
<td>11</td>
<td>Correct – 6.49 (Any value other than ±6.49 with 30%)</td>
<td>10</td>
<td>50.0</td>
</tr>
<tr>
<td></td>
<td>Wrong</td>
<td>10</td>
<td>50.0</td>
</tr>
<tr>
<td>12</td>
<td>Correct – 2 moles NaOH</td>
<td>13</td>
<td>65.0</td>
</tr>
<tr>
<td></td>
<td>Wrong</td>
<td>7</td>
<td>35.0</td>
</tr>
</tbody>
</table>

n = 20

Table 4.49 contains the breakdown of the frequency of students who answered the bonding topic questions correctly or not by the type of teaching they received for the topic (guided inquiry or traditional lecture). Questions one and four appear to have similar percentages on correct and incorrect answers regardless of the teaching style. Questions two and three appear to have more students answering the questions correctly when taught via the traditional lecture method.
Table 4.49

Interview Content Question Frequencies for Correct and Wrong Answers for the Bonding Topic Questions Based on the Style of Teaching

<table>
<thead>
<tr>
<th>Question</th>
<th>Correct/Wrong Answer</th>
<th>Guided Inquiry</th>
<th>Traditional Lecture</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Correct – plus two charge</td>
<td>10 90.0</td>
<td>7 77.8</td>
</tr>
<tr>
<td></td>
<td>Wrong</td>
<td>1 9.1</td>
<td>2 22.2</td>
</tr>
<tr>
<td>2</td>
<td>Correct – electrons transfer between atoms and positive and negative charges attract</td>
<td>2 18.2</td>
<td>3 33.3</td>
</tr>
<tr>
<td></td>
<td>Wrong</td>
<td>9 81.8</td>
<td>6 66.7</td>
</tr>
<tr>
<td>3</td>
<td>Correct – covalent bond</td>
<td>7 63.6</td>
<td>8 88.9</td>
</tr>
<tr>
<td></td>
<td>Wrong</td>
<td>4 36.4</td>
<td>1 11.1</td>
</tr>
<tr>
<td>4</td>
<td>Correct – the atoms do not share the electrons equally</td>
<td>2 18.2</td>
<td>1 11.1</td>
</tr>
<tr>
<td></td>
<td>Wrong</td>
<td>9 81.8</td>
<td>8 88.9</td>
</tr>
</tbody>
</table>

n = 20

For questions two and three a breakdown of the codes for the wrong answers given along with the type of teaching are in Table 4.50. This shows that for question two, even though some students who were taught via the guided inquiry method could not give the correct answer, they did realize there was a change in the elements that made them attracted to each other. Most of the students who did not answer the question correctly and were taught via the traditional lecture method stated they did not know the answer and did not even attempt to answer the question. For question number three, many of the students who were taught via guided inquiry and answered the questions incorrectly gave an answer other than the correct answer of covalent bond.
**Table 4.50**

*Interview Content Question Frequencies for Wrong Answers for the Bonding Topic*

*Questions Two and Three Based on the Style of Teaching*

<table>
<thead>
<tr>
<th>Question</th>
<th>Wrong Answer Code</th>
<th>Guided Inquiry</th>
<th>Traditional Lecture</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>n</td>
<td>%</td>
</tr>
<tr>
<td>2  Electrons shared between atoms</td>
<td></td>
<td>2</td>
<td>18.2</td>
</tr>
<tr>
<td>Ions bonding</td>
<td></td>
<td>1</td>
<td>9.1</td>
</tr>
<tr>
<td>Change in element (charge, attracted to each other, polar/nonpolar)</td>
<td></td>
<td>2</td>
<td>18.2</td>
</tr>
<tr>
<td>Don’t know</td>
<td></td>
<td>4</td>
<td>36.4</td>
</tr>
<tr>
<td>3  Any other answer but covalent</td>
<td></td>
<td>3</td>
<td>27.3</td>
</tr>
<tr>
<td>Don’t know</td>
<td></td>
<td>1</td>
<td>9.1</td>
</tr>
</tbody>
</table>

Table 4.51 contains the breakdown of the frequency of students who answered the chemical equations topic questions correctly or not by the type of teaching they received for the topic (guided inquiry or traditional lecture). A comparison between the two types of teaching for the chemical equations topic cannot be completed with any certainty due to the small sample size of students who were taught this topic via traditional lecture.
Table 4.51

*Interview Content Question Frequencies for Correct and Wrong Answers for the Chemical Equations Topic Questions Based on the Style of Teaching*

<table>
<thead>
<tr>
<th>Question</th>
<th>Correct/Wrong Answer</th>
<th>Guided Inquiry</th>
<th>Traditional Lecture</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>n</td>
<td>%</td>
</tr>
<tr>
<td>5</td>
<td>Correct – single displacement</td>
<td>14</td>
<td>77.8</td>
</tr>
<tr>
<td></td>
<td>Wrong</td>
<td>4</td>
<td>22.2</td>
</tr>
<tr>
<td>6</td>
<td>Correct – Mg and Ca₃(PO₄)₂</td>
<td>14</td>
<td>77.8</td>
</tr>
<tr>
<td></td>
<td>Wrong</td>
<td>4</td>
<td>22.2</td>
</tr>
<tr>
<td>7</td>
<td>Correct – add heat or heat used to cause reaction</td>
<td>16</td>
<td>88.9</td>
</tr>
<tr>
<td></td>
<td>Wrong</td>
<td>2</td>
<td>11.1</td>
</tr>
<tr>
<td>8</td>
<td>Correct – 2Al + 3H₂SO₄ → Al₂(SO₄)₃ + 3H₂</td>
<td>14</td>
<td>77.8</td>
</tr>
<tr>
<td></td>
<td>Wrong</td>
<td>4</td>
<td>22.2</td>
</tr>
</tbody>
</table>

n = 20

Table 4.52 contains the breakdown of the frequency of students who answered the acid-base chemistry topic questions correctly or not by the type of teaching they received for the topic (guided inquiry or traditional lecture).

Questions nine, eleven and twelve appear to have similar percentages on correct and incorrect answers regardless of the teaching style. Question ten appears to have more students answering the questions correctly when taught via the traditional lecture method.
Table 4.52

*Interview Content Question Frequencies for Correct and Wrong Answers for the Acid-Base Chemistry Topic Questions Based on the Style of Teaching*

<table>
<thead>
<tr>
<th>Question</th>
<th>Correct/Wrong Answer</th>
<th>Guided Inquiry</th>
<th>Traditional Lecture</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>Correct – 0 to 7 or any variation</td>
<td>11 91.7</td>
<td>6 75.0</td>
</tr>
<tr>
<td></td>
<td>Wrong</td>
<td>1 8.3</td>
<td>2 25.0</td>
</tr>
<tr>
<td>10</td>
<td>Correct – base is H₂O and conjugate acid is H₃O⁺</td>
<td>4 33.3</td>
<td>5 62.5</td>
</tr>
<tr>
<td></td>
<td>Wrong</td>
<td>8 66.7</td>
<td>3 37.5</td>
</tr>
<tr>
<td>11</td>
<td>Correct – 6.49</td>
<td>6 50.0</td>
<td>4 50.0</td>
</tr>
<tr>
<td></td>
<td>Wrong</td>
<td>6 50.0</td>
<td>4 50.0</td>
</tr>
<tr>
<td>12</td>
<td>Correct – 2 moles NaOH</td>
<td>7 58.3</td>
<td>6 75.0</td>
</tr>
<tr>
<td></td>
<td>Wrong</td>
<td>5 41.7</td>
<td>2 25.0</td>
</tr>
</tbody>
</table>

For question ten a breakdown of the codes for the wrong answers given along with the type of teaching are in Table 4.53. This shows that, even though some students who were taught via the guided inquiry method could not give the correct answer, they were able to recognize conjugate acid-base pairs more than the traditional lectures students. All of the guided inquiry students also felt confident enough with the material to attempt an answer to the question, while one of the traditional lecture students did not even attempt an answer.
Table 4.53

*Interview Content Question Frequencies for Wrong Answers for the Acid-Base Chemistry Topic Question Ten Based on the Style of Teaching*

<table>
<thead>
<tr>
<th>Question</th>
<th>Wrong Answer Code</th>
<th>Guided Inquiry</th>
<th>Traditional Lecture</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>n</td>
<td>%</td>
</tr>
<tr>
<td>10</td>
<td>Base correct (H₂O) but conjugate acid wrong</td>
<td>2</td>
<td>16.7</td>
</tr>
<tr>
<td></td>
<td>Conjugate acid correct (H₃O⁺) but base wrong</td>
<td>1</td>
<td>8.3</td>
</tr>
<tr>
<td></td>
<td>Both base and conjugate acid wrong and not conjugates of each other</td>
<td>2</td>
<td>16.7</td>
</tr>
<tr>
<td></td>
<td>Both base and conjugate acid wrong but conjugates of each other</td>
<td>3</td>
<td>25.0</td>
</tr>
<tr>
<td></td>
<td>Don’t know</td>
<td>0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

n = 11

Questions two and four had more students answering incorrectly regardless of the style of teaching, while question ten had more students answering the question wrong when they were taught via guided inquiry and question eleven had half of the students answering wrong regardless of the style of teaching. To look more at these questions and the student understanding of the concepts behind the questions, students were asked what specific terms relating to the questions meant to them.

For question two, students were also asked the meaning of the term ion, since they were asked to describe an ionic bond in terms of the electrons. A breakdown of the frequency of students coded answers for the definition of an ion can be seen in Table 4.54, it is broken down by they got the original question right or wrong. Most students who answered the question were able to say that ions
were elements with a positive or negative charge regardless of whether they could answer correctly how an ionic bond was formed.

Table 4.54

_Interview Content Question Two Supplemental Question Responses_

<table>
<thead>
<tr>
<th>Answer Code</th>
<th>All Students who Answered</th>
<th>Answered Q2 Correctly</th>
<th>Answered Q2 Incorrectly</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elements that have a positive or negative charge</td>
<td>8 (57.1)</td>
<td>2 (40.0)</td>
<td>6 (66.7)</td>
</tr>
<tr>
<td>It is a bond</td>
<td>2 (14.3)</td>
<td>1 (20.0)</td>
<td>1 (11.1)</td>
</tr>
<tr>
<td>It is in a solution</td>
<td>1 (7.1)</td>
<td>1 (20.0)</td>
<td>0 (0.0)</td>
</tr>
<tr>
<td>Only one charge for ion (either positive or negative)</td>
<td>1 (7.1)</td>
<td>1 (20.0)</td>
<td>0 (0.0)</td>
</tr>
<tr>
<td>Don't know</td>
<td>2 (14.3)</td>
<td>0 (0.0)</td>
<td>2 (22.2)</td>
</tr>
<tr>
<td><strong>n</strong></td>
<td><strong>13</strong>*</td>
<td><strong>4</strong>*</td>
<td><strong>9</strong></td>
</tr>
</tbody>
</table>

* one student gave two answers

Table 4.55 shows the same breakdown as above, but is based on the type of teaching the student was subjected to for the bonding topic. Regardless of teaching style, most students said that an ion is an element with either a positive or a negative charge. When taught via guided inquiry, two of the students were not confident enough in their understanding to give an answer for the meaning of the term ion, while all of the students who were taught via traditional lecture attempted an answer to the question.
Table 4.55

*Interview Content Question Two Supplemental Question Responses Based on Teaching Style*

<table>
<thead>
<tr>
<th>Answer Code</th>
<th>Guided Inquiry</th>
<th>Traditional Lecture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elements that have a positive or negative charge</td>
<td>3 (50.0)</td>
<td>5 (62.5)</td>
</tr>
<tr>
<td>It is a bond</td>
<td>1 (16.7)</td>
<td>1 (12.5)</td>
</tr>
<tr>
<td>It is in a solution</td>
<td>0 (0.0)</td>
<td>1 (12.5)</td>
</tr>
<tr>
<td>Only one charge for ion (either positive or negative)</td>
<td>0 (0.0)</td>
<td>1 (12.5)</td>
</tr>
<tr>
<td>Don’t know</td>
<td>2 (33.3)</td>
<td>0 (0.0)</td>
</tr>
<tr>
<td>n</td>
<td>6</td>
<td>7*</td>
</tr>
</tbody>
</table>

* one student gave two answers

For question four, if students did not answer the questions correctly, students were also asked the meaning of the term polar, since they were asked to describe how to determine if a covalent bond is polar or nonpolar. A breakdown of the frequency of students’ coded answers is in Table 4.56. Many students were not able to give a definition of the term polar. Other students either stated that it had to do with the shape of the molecule or its solubility in water. Some students talked about negatives and positives but not with respect to their being on opposite sides of a molecule or bond.
Table 4.56

Interview Content Question Four Supplemental Question Responses for Students who Answered Question Four Incorrectly

<table>
<thead>
<tr>
<th>Answer Code</th>
<th>Frequency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dealing with shape of molecule</td>
<td>3 (20.0)</td>
</tr>
<tr>
<td>Solubility in water</td>
<td>3 (20.0)</td>
</tr>
<tr>
<td>Polar is negative &amp; nonpolar is positive</td>
<td>3 (20.0)</td>
</tr>
<tr>
<td>Positive and negatives add up</td>
<td>1 (6.7)</td>
</tr>
<tr>
<td>Things come together in polar</td>
<td>1 (6.7)</td>
</tr>
<tr>
<td>Don’t know</td>
<td>4 (26.6)</td>
</tr>
<tr>
<td>n</td>
<td>14*</td>
</tr>
</tbody>
</table>

* one student gave two answers

Table 4.57 shows the same breakdown as above for question four, but is based on the type of teaching the student was subjected to for the bonding topic.

Many of the students taught via guided inquiry talked about polar having to do with the solubility of something in water, while none of the traditional lecture students mentioned this. Over half of the students who were taught via traditional lecture were not confident enough in their own understanding of the term to give a definition, while all of the guided inquiry students attempted to give an answer.
Table 4.57

*Interview Content Question Four Supplemental Question Responses for Students who Answered Question Four Incorrectly Based on Teaching Style*

<table>
<thead>
<tr>
<th>Answer Code</th>
<th>Frequency (%)</th>
<th>Guided Inquiry</th>
<th>Traditional Lecture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dealing with shape of molecule</td>
<td>1 (12.5)</td>
<td>2 (28.6)</td>
<td></td>
</tr>
<tr>
<td>Solubility in water</td>
<td>3 (37.5)</td>
<td>0 (0.0)</td>
<td></td>
</tr>
<tr>
<td>Polar is negative &amp; nonpolar is positive</td>
<td>2 (25.0)</td>
<td>1 (14.3)</td>
<td></td>
</tr>
<tr>
<td>Positive and negatives add up</td>
<td>1 (12.5)</td>
<td>0 (0.0)</td>
<td></td>
</tr>
<tr>
<td>Things come together in polar</td>
<td>1 (12.5)</td>
<td>0 (0.0)</td>
<td></td>
</tr>
<tr>
<td>Don’t know</td>
<td>0 (0.0)</td>
<td>4 (57.1)</td>
<td></td>
</tr>
<tr>
<td>n</td>
<td>7*</td>
<td>7</td>
<td></td>
</tr>
</tbody>
</table>

* one student gave two answers

For question ten, students were asked to explain their reason for the base and conjugate acid choices that they made. Table 4.58 shows the breakdown for the frequency of coded answers the students gave based on whether or not they answered questions 10 correctly. Most students could say that a base accepts a proton (H⁺) and that is how they determined their answer; many could also say that if the molecule were an acid on one side it had to be a base on the other. Many of the students who got the original question correct could make those same statements. Two of the students who got the answer correct could define phosphoric acid (H₃PO₄) as the acid and work the rest of the problem from there. Many of the students who got the original question wrong stated that acids and bases either gain or lose electrons. Two of the student could correctly state that bases accept protons, but were unable to correctly identify the base and conjugate acid in the reaction.
Table 4.58

*Interview Content Question Ten Supplemental Question Responses*

<table>
<thead>
<tr>
<th>Answer Code</th>
<th>All Students who Answered</th>
<th>Answered Q10 Correctly</th>
<th>Answered Q10 Incorrectly</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base accepts H⁺, in reverse reaction it gives it up H₂O is a base, guess on conjugate</td>
<td>7 (29.2)</td>
<td>5 (45.5)</td>
<td>2 (15.4)</td>
</tr>
<tr>
<td>Gain or lose electrons (either acid or base)</td>
<td>4 (16.7)</td>
<td>1 (9.1)</td>
<td>3 (23.1)</td>
</tr>
<tr>
<td>If it is an acid on one side it is a base on the other</td>
<td>5 (20.8)</td>
<td>0 (0.0)</td>
<td>5 (38.5)</td>
</tr>
<tr>
<td>Acids lose H⁺ &amp; H₂PO₄ is the acid, so H₂O is the base</td>
<td>2 (8.3)</td>
<td>2 (18.2)</td>
<td>0 (0.0)</td>
</tr>
</tbody>
</table>

| n                                 | 18*                        | 9*                      | 10*                      |

* more than one student gave two answers

Table 4.59 shows the same breakdown as above for question ten, but is based on the type of teaching the student was subjected to for the acid-base chemistry topic. Over thirty percent of the students interviewed who were taught via guided inquiry were able to correctly state that a base accepts a proton (H⁺). Twenty-five percent of the students interviewed who were taught via guided inquiry also stated wrongly that acids and bases had to do with the loss or gain of electrons. For the students interviewed who were taught via traditional lecture, 25.0 percent of them stated correctly that bases accept protons, but 12.5 percent also stated that acids and bases deal with the gain or loss of electrons.
Table 4.59

Interpret Content Question Ten Supplemental Question Responses Based on Teaching Style

<table>
<thead>
<tr>
<th>Answer Code</th>
<th>Guided Inquiry</th>
<th>Traditional Lecture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base accepts H(^+), in reverse reaction it gives it up</td>
<td>5 (31.3)</td>
<td>2 (25.0)</td>
</tr>
<tr>
<td>H(_2)O is a base, guess on conjugate</td>
<td>2 (12.5)</td>
<td>2 (25.0)</td>
</tr>
<tr>
<td>Gain or lose electrons (either acid or base)</td>
<td>4 (25.0)</td>
<td>1 (12.5)</td>
</tr>
<tr>
<td>If it is an acid on one side it is a base on the other</td>
<td>4 (25.0)</td>
<td>2 (25.0)</td>
</tr>
<tr>
<td>Acids lose H(^+) &amp; H(_2)PO(_4) is the acid, so H(_2)O is the base</td>
<td>1 (6.3)</td>
<td>1 (12.5)</td>
</tr>
<tr>
<td>n</td>
<td>12*</td>
<td>6*</td>
</tr>
</tbody>
</table>

* one student gave two answers

For question eleven, students were also asked to state the equation they used to find the answer. A breakdown of the frequency of students coded answers for the equation used to answer question eleven based on if they got the original questions right or wrong can be seen in Table 4.60. As expected, all of the students who answered the question correctly used the correct equation, while over half of the students who answered the question wrong were able to determine the correct formula.

Table 4.60

Interpret Content Question Eleven Supplemental Question Responses

<table>
<thead>
<tr>
<th>Answer Code</th>
<th>All Students who Answered</th>
<th>Answered Q2 Correctly</th>
<th>Answered Q2 Incorrectly</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correct (-pH = -\log[H_3O^+])</td>
<td>15 (78.9)</td>
<td>10 (100.0)</td>
<td>5 (55.6)</td>
</tr>
<tr>
<td>([H_3O^+] = 10^{-pH})</td>
<td>1 (5.3)</td>
<td>0 (0.0)</td>
<td>1 (11.1)</td>
</tr>
<tr>
<td>Convert scientific notation</td>
<td>3 (15.8)</td>
<td>0 (0.0)</td>
<td>3 (33.3)</td>
</tr>
<tr>
<td>n</td>
<td>19</td>
<td>10</td>
<td>9</td>
</tr>
</tbody>
</table>
Table 4.61 shows the same breakdown as above for supplemental question eleven, but is based on the type of teaching the student was subjected to for the acid-base chemistry topic. Regardless of teaching style, most students were able to state the correct equation needed to answer the question.

Table 4.61

*Interview Content Question Eleven Supplemental Question Responses Based on Teaching Style*

<table>
<thead>
<tr>
<th>Answer Code</th>
<th>Frequency (%)</th>
<th>Guided Inquiry</th>
<th>Traditional Lecture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correct – pH = (-\log[H_3O^+])</td>
<td></td>
<td>9 (75.0)</td>
<td>6 (85.7)</td>
</tr>
<tr>
<td>([H_3O^+] = 10^{-pH})</td>
<td></td>
<td>1 (8.3)</td>
<td>0 (0.0)</td>
</tr>
<tr>
<td>Convert scientific notation</td>
<td></td>
<td>2 (16.7)</td>
<td>1 (14.3)</td>
</tr>
<tr>
<td><strong>n</strong></td>
<td></td>
<td>12</td>
<td>7</td>
</tr>
</tbody>
</table>

Attitudinal Analysis

*Research Hypothesis Three:* Students’ opinions about the guided inquiry activities used in a non-science majors’ one semester chemistry course will be mainly positive and students will find the activities helpful compared to the traditional style of teaching. To determine the accuracy of this hypothesis, the attitudinal portions of the twenty interviews were coded; the codes were put into a partially-ordered matrix to look for any trends or relationships among the interviews. The original matrix for the interviews consisted of the twenty interviews in rows and the column variables were: previous chemistry, thoughts on
group work/group interactions, comments on helpful items, comments on non-helpful items, timing of the activities, lab and lecture connections, changes the student would make, and type of teaching preferred. The matrix was then ordered based on the students’ previous chemistry experiences.

Many of the students liked working in groups on the activities. The students’ comments related to each group member being good at different things, so they could help each other in different areas. Some direct quotes from some of the interviews include:

Student 204: The group interaction helped... for me as someone who had never seen any of this before, some of the other students did, so it was good to at least... they had some idea of what they were looking at. Um... even though beforehand I thought the description, or the explanation of what we were doing was good. It definitely helped to have just a little bit of a reflection for someone to say, that is completely not right you are going the wrong way with that. So the group interaction definitely helped.

Student 327: I loved my group... If one of us didn’t understand it, most of the time none of us understood it, so we would kind of talk through it... sometimes one of us would understand it and we would try to explain it to uh... the other people in our group.

Student 513: It was kind of nice doing it in groups because when you explain it to people it makes that much more sense to you, or you realize how much it doesn’t make sense by trying to explain it to other people.

The few students who did not like working in groups made comments about having members of their group slow them down on completing the activity or having members who did not help with the work. Some direct quotes from some of the students include:
Student 410: I do all the work and they (the group members) just copy my answers... And when I didn't get the answers it was frustrating because I didn't have anyone to say “Oh no, remember you do this instead.”

Student 535: I knew how to do it (meaning the information in the packets), but the rest of my lab group didn’t. So I felt like I needed to explain it all to them and I don’t like explaining it all to them when I am in class.

Student 583: But with any group you are going to get loafers and you are going got get ones that are like “What did you say?” and they just copy your answer... I don’t like to just give answers, which is why I didn’t prefer groups. I tried to explain it to them, but they just don’t even want to know.

Over half of the students interviewed thought the information in the guided inquiry activities was clearly presented and laid out in an understandable fashion. Some of the students found the guided inquiry activities very useful when studying for exams and would often go back and redo portions of it. Many of the students enjoyed doing the “hands on” aspect of the guided inquiry activities compared to just listening to a lecture. Some direct quotes from some of the students interviewed include:

Student 234: The notes with the questions flowed good... flowed well. So it wasn’t here’s a bunch of notes now apply it, it was here’s a concept lets work through it. Okay let's build on that concept as it goes. It was nice. Yeah, I like this, it actually made sense. This wasn’t... we weren’t lectured on it... it wasn’t here is how we do this take notes on what and you don’t get any of it actually.

Student 324: I think it helped a lot (referring to the guided inquiry activity). Having it all laid out like this and then working in a group.

Student 403: I do like how you... the information and then the questions based on that so you can go back and look at it. I liked doing that, that was helpful to me. Um... I used this to study from so... what I would do is, for the test then I would go back and I would answer the questions again on my own. So... I like having the packets.
On the other hand, some of the students thought that the questions in the guided inquiry activities were too difficult to understand with the information presented. Many of these same students also felt that there was not enough instructor help in the classroom to make completing the activities and understanding the material realistic. Some direct quotes included:

Student 327: The questions that they ask they didn’t explain it enough... they didn’t explain enough to let us actually answer it. I don’t think it was explained exactly what you had to do.

Student 403: You know I was confused. I tend to... with these things I tend to get confused really easily with this stuff. It seems like a lot of information to me.

Student 535: Because there is only three people walking around to help us, so it is harder to like... to sit there and explain it to them (meaning the lab group) when I am just trying to finish it.

A few of the students also made comments on the classroom set-up and environment, the students either talked about them being helpful or not helpful. Some of the students interviewed stated that having an instructor or multiple people walking around the classroom to guide and answer questions was very helpful, while other students commented that the classroom was too chaotic and noisy to concentrate while working on the activity, and that the lab was also very disorganized and chaotic, distracting them from learning. Some direct student quotes include:

Student 513: Because we do them in class which is nice and then... so it is our notes and we do the work ourselves and then we have people, like classmates and teachers, to bounce off of and ask questions to understand.

Student 518: And then it was more of a teaching/learning atmosphere. We did... It was hands on. You did it and then if you had questions you could ask
your group members or you could ask the teachers that were walking around.

Student 204: The labs to me seem... They seem to a little... they just seem too chaotic. They seem like they could be a little bit more uh... controlled and thought out about how the lab was... uh... you know take course. I don’t feel like they are very organized.

Student 346: The whole group dynamic, the breaking into small groups was pure bedlam in the class. And I have a lot of trouble with a lot of exterior input of noise. First of all with hearing and secondly with being able to think.

The students who were interviewed had mixed opinions on whether or not there was enough time to complete the guided inquiry activities in the time allotted for the lecture portion of the class. Many students thought there was enough time and one even stated that there was too much time, while other students were not able to complete the guided inquiry packet in the time allotted. Some of the students who were not able to complete the activity in the classroom were able to go home and complete the activity outside of class. When students were asked if they were able to finish the activity in the time allotted, many stated yes. A direct quote from Student 318, who was not able to finish the activity, is:

We didn’t get any farther than that (referring to the second page of the pH and neutralization activity). The rest of these (referring to the rest of the questions in the activity) I think I did... Yeah I did these when I got back to my room.

Most of the students were able to see a connection between the guided inquiry activity which they completed during the lecture portion of the class and the laboratory that they completed in the lab. Some of the students who saw the connections were able to make strong connections between the lecture and the
laboratory and to verbally demonstrate how the two were connected during the interview. Some quotes from some students to show this include:

Student 346: It was a good application of what was in the lesson (referring to the bonding laboratory). You know... put down on paper what... what you observed and that kind of reinforces what you learned in the lab, plus in the classroom. I did refer back to my notes when... you know that I took during the learning part of it... to help to put the lab book together.

Student 415: I think the activity we did in class (referring to the chemical equations laboratory) we were actually performing what we went over in class (referring to the chemical equations guided inquiry activity). I think that was good. Um... good to see that we actually wrote it down at first and later on we actually did it with the um... elements and stuff like that. I thought that part was good. Because they went pretty much hand-in-hand I thought.

Student 518: [Referring to the bonding guided inquiry activity and lab] It was really good to have what we learned in class for this lab. Just because it showed... you actually got to see the results from what you learned and that also helped me a lot on the test. I could reflect back on what we did in lab and then remember what we did in class.

Student 315: I think they all went along pretty well (referring to the laboratories that went along with the guided inquiry activities). I mean... Yeah... I think they all went along pretty well with the classroom information.

Student 513: I like it (referring to the guided inquiry activities) better than the slides honestly. 'Cause it is more... what we will actually have to know and... content to understand so that you know what you are doing in lab.

The three students interviewed who did not see connections, had differing views on which topics they saw a connection with, and one did not see any connections for any of the topics. Student 327 did not see connections between the two portions of the class and stated the following:

It's just sometimes I didn't understand how it would relate to what we were learning in class. It would feel like it was another lab, that we would kin of just follow. I didn't understand. Some of them I understood. Um... I could feel a similarity, but them some I like just didn't have any idea. So like... I
don’t know if someone could tell us like this is like... this is what we were learning in class and this is what we are doing in lab, this is how they are the same kind of thing.

Many of the students had similar suggestions about changes to make the guided inquiry activities more useful. The students suggested seeing more examples worked out in the activities and with the examples have some step-by-step instructions to go with them. Several of the students also wanted to see the follow-up that was given on the activities to be given the same day as completing the activities instead of the following day. Some of the students also wanted to see a complete review of the activity instead of just an overview. Along with that, a few of the students wanted to be told explicitly how the lecture or activity correlated with the lab, and what the “take home” message was for the content. Some illustrative quotes regarding this summary include:

Student 332: If I could have just seen... examples and then step-by-step through examples on paper in front of me I thing that would have helped.

Student 583: I do wish we would have gone over the packet that day in class instead of the next day because I tend to forget things if I don’t know they are the right answer or not.

Student 318: I think it would have been nice if we had time in class to review the whole packet. Cause I remember having to go back to my room and finish it myself and I don’t think... I obviously didn't remember it as well. Cause it would have been nice to have like 10 or 15 minutes at the end of class to review through every problem.

Among the twenty students interviewed, there were very different opinions on the preferred type of teaching in their chemistry course. The teaching styles favored by the students could be broken down into three different categories, guided inquiry activities, 50/50 activity/lecture, and straight lecture. The students
that wanted to see a 50/50 mixture of activity and lecture wanted to see both styles of teaching done in the same class period. The students often stated they wanted to see a ten to fifteen minute lecture some time during the activity to help clarify the information.

From the general comments, no relationships or trends could be seen in the large partially-ordered matrix. This large matrix was then broken down into smaller chunks based on the different variables. By breaking the large attitudinal matrix down into small chunks some trends and relationships appeared among the groups of students.

From the breakdowns based on previous chemistry course, three out of four students who had no prior chemistry class said they would prefer to see guided inquiry activities done in other science courses. All four of these students found working in a group helpful; they were able to get their questions answered by members of their groups when they had problems. Only one of these students felt that the group was not needed and the student could have completed the activity alone. The students who had a high school chemistry course before taking the college course under study, had mixed reactions on all of the variables. The students who had either taken Advanced Placement Chemistry or a college chemistry course prior to taking the course under study preferred to see a mix of the guided inquiry activities and lecture. These students also found the group work helpful and saw connections between all of the activities and the labs.
When the matrix was broken down by the type of teaching preferred, additional trends were seen. All but one of the students who stated a preference for the guided inquiry activities had positive group experiences and found their group to be a helpful part of working on the activities. The student who did not have a positive group experience found the group frustrating because the student had to explain much material to the rest of the group instead of just completing the activity. These four students were all able to complete the activities in the allotted time, although a few of the students reported feeling slightly rushed. These students also made positive comments about the activities, including that the information was presented in a way where they had to do the work (similar to an exam) and that doing the activity helped in understanding the material.

These students also stated that they were able to see the connections between the guided inquiry activities done in the lecture portion of the class and the laboratories. Some of the negative comments were that there was a lot of information to take in during one class period so sometimes things got confusing, and that it was hard to understand what was expected the first time they worked on the activities. Overall, these students had positive experiences with the guided inquiry activities. The simplified matrix can be seen in Table 4.62. The matrix contains the researcher’s paraphrases from the interviews; the identifiers for the interview quotes have been stripped.
Table 4.62

*Partially-Ordered Attitudinal Interview Matrix for Students who Prefer the Guided Inquiry Activities*

<table>
<thead>
<tr>
<th>ID</th>
<th>Prior Chem</th>
<th>Group Thoughts</th>
<th>Found Helpful</th>
<th>Not Found Helpful</th>
<th>Timing</th>
</tr>
</thead>
<tbody>
<tr>
<td>204</td>
<td>No</td>
<td>Helped because others knew the material</td>
<td>Info was clearly presented Group members had seen info before</td>
<td>Labs did not seem to correlate Lab too chaotic and unorganized</td>
<td>Seemed to be enough time</td>
</tr>
<tr>
<td>415</td>
<td>No</td>
<td>Group worked well, had different strengths</td>
<td>Actually doing/working/writing Examples Info given in activity Instructor helping Follow-ups</td>
<td>Hard to understand what doing at first Took a while to grasp some of the info</td>
<td>Finished most of the time Timing not an issue</td>
</tr>
<tr>
<td>518</td>
<td>No</td>
<td>3 group members understood &amp; worked faster, but helped when asked</td>
<td>Packets explained well Teaching/learning atmosphere People to help Useful for studying Follow-ups Doing the activity</td>
<td>Not everyone incorporated into group to do the work</td>
<td>Felt rushed with equations activity</td>
</tr>
<tr>
<td>403</td>
<td>HS</td>
<td>Worked well together Helped each other</td>
<td>Questions &amp; info all in one place to refer back to Hands on/doing</td>
<td>Things got confusing fast with a lot of info Calculator work</td>
<td>Felt rushed Always able to finish</td>
</tr>
<tr>
<td>535</td>
<td>HS</td>
<td>Had to explain everything &amp; did not like</td>
<td>Follow-ups Reading the packet Engaged in activity</td>
<td>Only 3 people around to help Working in lab groups</td>
<td>NA</td>
</tr>
<tr>
<td>513</td>
<td>HS+</td>
<td>Groups helped by explaining or by having to explain</td>
<td>Doing the work Set up like test Working in group and discussing info Follow-ups Instructor to help</td>
<td>Had to figure it out yourself</td>
<td>Finished all packets</td>
</tr>
</tbody>
</table>

n = 6
Several of the students who would prefer to see the traditional lecture style in a science class had negative interactions with their groups. Some felt “left behind” by the other members of their group or had group members who did not do anything to help, leaving the other to feel like they were working on their own. These students often found the information in the activities confusing and they felt that the questions in the activity were too difficult to answer. Many of these students also felt that they did not have enough time to complete the activity or if they did complete the activity they often felt rushed and they did not have enough time to absorb and understand the information. On the positive side, many of these students used the activities when studying for the tests given in class and felt that the information was presented clearly and was well organized. It appears that many of the students who prefer the traditional lecture had very negative experiences when working with the guided inquiry activities. The simplified matrix can be seen in Table 4.63. The matrix contains the researcher’s paraphrases from the interviews; the identifiers for the interview quotes have been stripped.
Table 4.63

*Partially-Ordered Attitudinal Interview Matrix for Students who Prefer the Traditional Lecture*

<table>
<thead>
<tr>
<th>ID</th>
<th>Prior Chem</th>
<th>Group Thoughts</th>
<th>Found Helpful</th>
<th>Not Found Helpful</th>
<th>Timing</th>
</tr>
</thead>
<tbody>
<tr>
<td>217</td>
<td>No</td>
<td>Worked well together, but didn’t need</td>
<td>Laid out/organized well</td>
<td>NA</td>
<td>Equation Lab was too long</td>
</tr>
<tr>
<td>538</td>
<td>HS-</td>
<td>Worked in pairs instead of group of four</td>
<td>Able to study from packets</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>327</td>
<td>HS</td>
<td>Group worked well together &amp; able to talk through things</td>
<td>Laid out well (AB Prop activity)</td>
<td>Hard to understand activities Questions difficult with info given Teaching yourself</td>
<td>NA</td>
</tr>
<tr>
<td>346</td>
<td>HS</td>
<td>Left behind by others in group Rather do alone</td>
<td>Well organized All material needed in the activity</td>
<td>Too confusing Too much noise working in group to concentrate</td>
<td>Need more time to let information sink in</td>
</tr>
<tr>
<td>332</td>
<td>HS</td>
<td>Got help from someone outside of group</td>
<td>Follow-ups</td>
<td>Need to see &amp; have explained, not just written on paper</td>
<td>Equations activity took a long time to understand</td>
</tr>
<tr>
<td>410</td>
<td>HS</td>
<td>Group with two others that did not work or help</td>
<td>Instructor answering/asking questions Info to refer back to Writing notes Follow-ups</td>
<td>Not having people to bounce ideas off of with hard questions</td>
<td>Took a long time to complete without help</td>
</tr>
<tr>
<td>201</td>
<td>HS+</td>
<td>Helped partner that didn’t understand</td>
<td>NA</td>
<td>NA</td>
<td>Got done quickly in Equations activity</td>
</tr>
</tbody>
</table>

n = 7
The students who preferred a 50/50 mix of the guided inquiry activities and the traditional lecture also had a mixture of thoughts on the activities. There were no strong trends in this group's responses. The simplified matrix can be seen in Table 4.64. The matrix contains the researcher's paraphrases from the interviews; the identifiers for the interview quotes have been stripped.
Table 4.64

*Partially-Ordered Attitudinal Interview Matrix for Students who Prefer a 50/50 Mix of Activity and Lecture*

<table>
<thead>
<tr>
<th>ID</th>
<th>Prior Chem</th>
<th>Group Thoughts</th>
<th>Found Helpful</th>
<th>Not Found Helpful</th>
<th>Timing</th>
</tr>
</thead>
<tbody>
<tr>
<td>318</td>
<td>HS-</td>
<td>Non-traditional student in group made harder</td>
<td>Talking to other groups</td>
<td>Back-tracked a lot to help group member</td>
<td>Not finish any activity</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Learn things on own helped remember more</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Applying info</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>315</td>
<td>HS</td>
<td>3 / 4 helpful because all good at different things</td>
<td>Talking to other groups to get info</td>
<td>Felt rushed &amp; not enough time to finish in class</td>
<td>Not finish any activity</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Help each other</td>
<td>Trying it &amp; then get answers</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Had to do a lot of explaining to 4th member</td>
<td>Challenging questions</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>583</td>
<td>HS</td>
<td>Not like groups, would rather have partners</td>
<td>Info to answer questions &amp; study from</td>
<td>Not going over answers right away</td>
<td>Finished very early</td>
</tr>
<tr>
<td></td>
<td></td>
<td>People in groups copy</td>
<td>People around to help</td>
<td>Not hearing it explained before doing</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>416</td>
<td>AP</td>
<td>Worked well together</td>
<td>Instructor around help</td>
<td>Some info given too complicated</td>
<td>No problem with time</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Did a lot of explaining, other group members not have prior chem</td>
<td>Working through the material</td>
<td>Not enough to make some connections</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Follow-ups</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>324</td>
<td>PC</td>
<td>1 member good at math, rest lagged behind</td>
<td>Layout of activity</td>
<td>Not enough info to answer questions</td>
<td>Not finish the Neutralization activity</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Disadvantage if not had 1 member</td>
<td>Group</td>
<td>Chem hard to visualize on paper</td>
<td>Finished others</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

n = 5
CHAPTER V

CONCLUSIONS

This study was designed to answer the three research questions presented in Chapter I. This study utilized the methods discussed in Chapter III to analyze the data as presented in Chapter IV. The three research questions are:

1. Is there a significant difference, overall and based on topic, between student test percentages based on the style of teaching in a non-science major’s chemistry course?

2. Is there a significant difference, overall and based on topic, in test percentages for students in a non-science major’s chemistry course taught via guided inquiry based on students’ gender, age, race, year in school, major, or cumulative GPA?

3. What are non-science major students’ opinions about guided inquiry lessons in chemistry?

This chapter contains a summary of the findings presented in Chapter IV, discussion of the implications of the study for teaching and learning chemistry, and directions for the future.
Differences Based on Teaching Style

In summary, students in the guided inquiry classroom had overall higher percentages on post-tests, and overall higher gain scores, but this difference was not statistically significant. It was shown that the guided inquiry style of teaching did not help or hinder the teaching of chemistry to non-science majors. When the individual topics (bonding, chemical equations, and acid-base chemistry) are considered, some differences are seen. For the bonding and acid-base topics, students in the traditional classroom had higher post-test percentages and gain scores than the guided inquiry students, although these results were again not statistically significant. This shows that on these two topics, using the guided inquiry method of teaching did not help or hinder the learning of the chemistry topics. For the chemical equations topic, students in the guided inquiry classroom had statistically significant higher post-test percentages and gain scores than the traditional classroom students. This shows that teaching the topic of chemical equations via guided inquiry may help students understand the topic more fully. A summary of the post-test percentage results can be seen in Figure 5.1.
Figure 5.1. Post-test percentages, overall and for each topic, based on the style of teaching. The chemical equations topic has a statistically significant difference (*) at an alpha of 0.05.

When students were asked to answer the post-test questions during an interview, the students who were subjected to the guided inquiry style of teaching had frequencies of correct responses to the questions similar to those of the students who were taught via the traditional lecture method. The one question that had a lower correct frequency for students taught via the guided inquiry method was the acid-base topic, specifically the identification of the base and its conjugate acid in a reaction. For this question, more students were able to pick conjugate acid-base pairs when taught via guided inquiry; although, they were not always the correct conjugate acid-base pair for which the question asked them to state. These frequencies of correct answers show that the guided inquiry method of teaching did
not help or hinder the students in learning the chemistry topics presented during this research.

Guided Inquiry Differences Based on Demographic Data

Regarding differences in demographic data, there were no statistically significant differences between post-test percentages or gain scores overall or based on the topic covered (bonding, chemical equations, and acid-base chemistry) among groups based on gender, age (traditional student or non-traditional student), or major. This shows that the guided inquiry method of teaching does not favor one gender, age group or major over another. This result demonstrates that guided inquiry does not hinder or discriminate against the teaching of chemistry to males and females, all age groups of students, and all majors.

The demographic variable of race did show statistically significant differences for the overall post-test percentages for all three topics; it was also statistically significantly different for the overall gain scores and for the bonding and chemical equations topics gain scores. These statistically significant results are not considered to be practically significant since the effect sizes were found to be low for race. This statistical result could also be due to the large difference between the different races of students who took the course, with a majority of the students being Caucasian. This is also seen with the post hoc analysis on the difference
among races showing no statistically significant results among the races overall and the gain scores only showing significant results in favor of the Caucasian students.

The students’ year in school also showed some statistically significant results for the overall post-test percentages and the bonding and the acid-base topics. However, there were not any statistically significant results for gain scores with respect to year in school. For the overall post-test percentages, freshmen had statistically significantly higher post-test percentages than juniors in the course. When the post hoc analyses were conducted on the bonding and acid-base topics, there were no statistically significant results for different years in school. One reason that freshmen might have better results when working with the guided inquiry method is that this method is more familiar to them as a style of teaching. This is because there has been a recent push at the high school level to include more of the guided inquiry methods in the classroom and most freshmen have just recently finished high school.

The students’ cumulative grade point average (GPA) group also showed statistically significant differences between the different groups for the overall post-test percentages and all three of the topics; it also showed statistically significant differences for gain scores overall and for the chemical equations and the acid-base chemistry topics. When the post hoc analysis was conducted for the overall data, the two higher cumulative GPA groups (3.35 to 4.00 and 2.65 to 3.34) had statistically significant higher post-test percentages than the two lower levels (2.64 to 1.63 and 0.00 to 1.64). This shows that the higher-achieving students tend to
learn more from the guided inquiry activities than the lower-achieving students.

The entering freshmen (with no GPA yet) also had higher percentages than the two lower cumulative GPA levels. This shows that entering freshmen also tend to learn more when taught via guided inquiry than the lower-achieving students. The gain scores also showed similar results. No post hoc analyses could be conducted for the individual topics because of the small group sizes for the different cumulative GPA levels. There were very few low-achieving students in the course, which could alter the practicality of these results. With the small effect sizes that were calculated for the cumulative GPA group, this variable has only a small effect on how well students learn from guided inquiry activities. These results could also be due to high-achieving students doing well no matter what the style of teaching, guided inquiry activities or traditional lecture. These results also show that the guided inquiry style of teaching may not be the best method for the low-achieving students, or possibly the low-achieving students may simply not tend to do as well no matter what style of teaching is used.

Students’ Opinions on Guided Inquiry Teaching

In general, students had either positive or negative opinions about the guided inquiry style of teaching; very few students were “on-the-fence” about guided inquiry. The students who liked the group they worked in, or just liked working in a group, tended to like the guided inquiry method. Almost all of the
students interviewed felt like the information in the guided inquiry activities was clearly presented. At times, the amount of information presented was overwhelming or hard to understand.

The suggestions some of the students made during the interviews about the activities included wanting to see more examples given in the activities and the laboratories, and also having some of those examples written out in a step-by-step fashion or with step-by-step guidelines. Many students also wanted the follow-up on the same day as the activity or wanted some “take home message” presented before they left for the day.

About a third of the students interviewed stated that they preferred the guided inquiry method of teaching, a little over a third preferred traditional lecture, and a little under a third wanted to see a mix of the two methods presented in the same day. Many of the students who preferred the lecture wanted to see more of an interactive lecture and not just PowerPoint notes that they printed and brought to class.

Implications

Teaching a non-science majors’ chemistry course via a more active style such as guided inquiry, may help students understand material more when the topic is one that requires practice on the students’ part. Writing and balancing chemical equations is an example of a topic that requires students to practice in order to be
able to apply it to other situations. Similar topics might include mole calculations, unit conversions, and stoichiometry.

If guided inquiry is implemented in a non-science majors’ chemistry course, the student groups should be specifically assigned and not just randomly assigned or based on student preferences. Since group interactions have been shown to be an important aspect of how well the guided inquiry activities work in the classroom, care should be taken to assign the groups to achieve the best interaction between group members. This could be done by using randomly stratified groups based on students’ prior chemistry courses or answers to content questions that students answer the first day of the course.

Furthermore, when guided inquiry is used in the non-science majors’ chemistry classroom, time should be taken either throughout the class period to give mini-lectures to help students grasp the material or at the end of the period to summarize the material that the students should have learned. An instructor should be available to answer questions while the students are working on the activity, and if possible, a second or third person, such as a teaching assistant or peer tutor, should also be available to help answer students’ questions.

Students tend to have a hard time understanding what is expected and required of them when they complete their first guided inquiry activity. Therefore, the student behaviors and goals should also be outlined at the start of the first few activities so that students are aware of what is expected of them while completing
the activity. This style of teaching should also be used on more than one occasion, to help with the students’ confidence in learning via this method of teaching.

Limitations

This study was limited by the variety of instructors who taught the course each semester. There is always some instructor impact on grades and student attitudes about the course in general. This limitation was partly controlled for by the researcher’s involvement in the classroom on the days the research topics were taught; the researcher presented the material, not the instructor. This helped to ensure that the material covered for each topic was consistent and did not have instructor bias. The researcher was not in the classroom during the rest of the class days, so the material that the instructor covered on those days was not controlled for. Material from each of the research topics could have been reviewed on the days that the researcher was not in the classroom, and this would bias the class by having the material presented to them twice.

The testing environment for each semester and course was also different. Some of the post-test questions were included on the instructors’ exams for the course, while at other times the research post-test questions were given on a quiz for just that material. The researcher was also not present when the post-test questions were given to the students, so the researcher does not know what other material or help was given to the students during the answering of the questions.
The teaching assistant for the laboratory portion of the course was also different each semester and could play a role in the results of the study. This could have affected the information the students were given prior to completing the laboratories for the research study, as each teaching assistant gave a short pre-lab discussion and not the researcher. Each teaching assistant also interacted with the students to a different amount and answered questions differently. Although the researcher was also in the laboratory while the students completed the lab, they would often talk to the teaching assistant they were more familiar with and not the researcher.

Another limitation for the study was the number of students interviewed may not be representative of all of the students in the study since only twenty students were interviewed out of the 224 students who participated in the main study. The students who were interviewed consisted of a random sample of students from each semester, but the students volunteered to be interviewed and only represented a small sample of the actual study participants. The attitudes and opinions were not collected for all of the students who participated in the study.

Future Work

A wider variety of student interviews would add breadth to the study. Also, interviews could be conducted after each topic to get the students’ opinions on the guided inquiry activities and the laboratories right away, instead of waiting until the
end of the semester. The attitudes and opinions that students have about the guided inquiry activities could also be collected for each student enrolled in the study by having the students complete surveys after the activities. This would give the researcher a better idea of the individual students’ or groups’ attitudes toward the guided inquiry activities.

Another extension to the study would be to include more topics for the guided inquiry style of teaching, such as more algorithmic chemistry topics, such as the mole and gas law calculations, and more conceptual chemistry topics, such as atomic structure and organic functional groups. Study of these topics would inform instructors as to what types of topics are best suited for guided inquiry with non-science majors. Another change would be to incorporate mini-lectures into the guided inquiry activities used in the classroom. These mini-lectures might help students to feel more confident about the material they are learning and give all of the groups some equal guidance in the information being presented. This change could also help orient the students into a more active learning role versus the all or none that the full guided inquiry activities or traditional lecture give. Another approach that might be tested is to teach an entire course with the guided inquiry method of teaching rather than having specific topics covered via guided inquiry, and to compare that to a full class taught via the traditional lecture style of teaching. By conducting the study in this fashion, the students would be able to get used to the guided inquiry style of teaching versus only having it a few days out of the semester.
Although using this format would not control for any differences between the students in the class or the instructors for the course.
BIBLIOGRAPHY


APPENDIX A

NOTICES OF APPROVAL

NOTICE OF APPROVAL

Date: January 13, 2009
To: Adessa E. Butler
500 Jackson St.
Minneapolis, MN 55457

From: Sharon McMillen, IRB Administrator

Re: IRB Number 20090107 “Effectiveness of Inquiry Methods on Non-Science Major College Students’ Comprehension and Retention of Chemistry Concepts”

Thank you for submitting your IRB Application for Review of Research Involving Human Subjects for the referenced project. Your application was approved on January 13, 2009. Your protocol represents minimal risk to subjects and matches the following federal category for exemptions:

☐ Exemption 1 - Research conducted in established or commonly accepted educational settings, involving normal educational practices.

☐ Exemption 2 - Research involving the use of educational tests, survey procedures, interview procedures, or observation of public behavior.

☐ Exemption 3 - Research involving the use of educational tests, survey procedures, interview procedures, or observation of public behavior not exempt under category 2, but subjects are elected or appointed public officials or candidates for public office.

☐ Exemption 4 - Research involving the collection or study of existing data, documents, records, pathological specimens, or diagnostic specimens.

☐ Exemption 5 - Research and demonstration projects conducted by or subject to the approval of department or agency heads, and which are designed to study, evaluate, or otherwise examine public programs or benefits.

☐ Exemption 6 - Taste and food quality evaluation and consumer acceptance studies.

Annual continuation applications are not required for exempt projects. If you make changes to the study’s design or procedures that increase the risk to subjects or include activities that do not fall within the approved exemption category, please contact me to discuss whether or not a new application must be submitted. Any such changes or modifications must be reviewed and approved by the IRB prior to implementation.

Please retain this letter for your files. If the research is being conducted for a master’s thesis or doctoral dissertation, the student must file a copy of this letter with the thesis or dissertation.

☐ Approved consent form/s enclosed

Cc: William Donovan - Advisor
Cc: Stephanie Woods - IRB Chair

Office of Research Services and Sponsored Programs
Arlon, OH 44325-2102
330-972-7688 • 330-972-0281 Fax
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NOTICE OF APPROVAL

Date: August 11, 2009

To: Adessa E. Butler
    500 Jackson St.
    Minerva, Ohio 44657

From: Sharon McWhorter, IRB Administrator

Re: IRB Number 20090107-2 “Effectiveness of Guided Inquiry Methods on Non-Science Major College Students’ Comprehension of Chemistry Concepts”

Thank you for submitting your Request for Change to the referenced study. Your request was approved on August 11, 2009. The protocol represents minimal risk to subjects and matches the following federal category for exemption:

☐ Exemption 1 - Research conducted in established or commonly accepted educational settings, involving normal educational practices.

☒ Exemption 2 - Research involving the use of educational tests, survey procedures, interview procedures, or observation of public behavior.

☐ Exemption 3 - Research involving the use of educational tests, survey procedures, interview procedures, or observation of public behavior not exempt under category 2, but subjects are elected or appointed public officials or candidates for public office.

☐ Exemption 4 - Research involving the collection or study of existing data, documents, records, pathological specimens, or diagnostic specimens.

☐ Exemption 5 - Research and demonstration projects conducted by or subject to the approval of department or agency heads, and which are designed to study, evaluate, or otherwise examine public programs or benefits.

☐ Exemption 6 - Taste and food quality evaluation and consumer acceptance studies.

Annual continuation applications are not required for exempt projects. If you make changes to the study’s design or procedures that increase the risk to subjects or include activities that do not fall within the approved exemption category, please contact me to discuss whether or not a new application must be submitted. Any such changes or modifications must be reviewed and approved by the IRB prior to implementation.

Please retain this letter for your files. If the research is being conducted for a master’s thesis or doctoral dissertation, the student must file a copy of this letter with the thesis or dissertation.

☒ Approved consent form/s enclosed

Cc: William Donovan - Advisor
    Stephanie Woods - IRB Chair

Office of Research Services and Sponsored Programs
Aurora, OH 44325-2102
330-972-7966

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APPENDIX B

CONSENT FORMS

INFORMED CONSENT FORM FOR PARTICIPANTS
Chemistry for Everyone Instructor

Purpose of Research
You are invited to participate in a study being conducted by Ms. Adessa Butler (graduate assistant, Department of Chemistry) University of Akron, Akron, Ohio. The project focuses on the effectiveness of the inquiry method of delivering chemistry content in a general education chemistry college classroom. Two classes, one instructor and 96 students will be involved.

Procedure
During two topics (electrochemistry and acids/bases) being taught during the semester, one class will be exposed to the inquiry method of teaching (Process oriented guided inquiry learning, inquiry labs, and follow-up discussion) while the other class is exposed to the traditional style of teaching (lecture, "cookbook" labs, and no follow-up discussion). The method each class is exposed to will switch for each topic. At the start of the topic, students will be given a pre-test and later the topic will be tested for understanding on a post test. A final exam will also be given to students at the end of the semester to test the retention of the material covered. The instructor will give the researcher copies of student tests and labs so that the level of understanding for the material can be determined for each student.

Duration of Participation
The students in the class will be followed for the Spring 2009 semester. The length of time each of these topics will be covered in class will be one class period (one lecture and one lab); the follow-up for the inquiry method will be the first 15 minutes of the following class period.

Confidentiality
If you decide to participate, the student’s responses to the content questions will be paired before and after the topic curriculum for comparison. Only the researcher will have access to the student names, tests, and labs. Each student will be assigned a random number by the researcher, to code the data. Data will be retained in a locked office for four years and then destroyed.

Voluntary Nature of Participation
Your participation in this study is voluntary and you may withdraw at any time. Your participation is appreciated and will add to the validity of the study.

Risks and Benefits
There are no anticipated benefits or risks to you as a participant, aside from the opportunity to be exposed to other forms of teaching methods, reflect on your teaching of chemistry and for your students to gain a better understanding of some chemistry concepts.

Contacts
If you have any questions about the research project, you can reach Adessa Butler at (330) 972-6651 or adelass@uakron.edu. This project has been reviewed and approved by The University of Akron Institutional Review Board. If you have any questions about your rights as a research participant, you may call the IRB at (330) 972-7666 or 1-888-232-8790.

Thank you for your participation!
I consent to participate in this project:

Printed Name
Signature
Date

APPROVED
IRB 1/3/09

The University of Akron is an equal education and employment institution.
INFORMED CONSENT FORM FOR PARTICIPANTS

Chemistry for Everyone Student

Purpose of Research
You are invited to participate in a study being conducted by Ms. Adessa Butler (graduate assistant, Department of Chemistry) University of Akron, Akron, Ohio. The project focuses on the effectiveness of the inquiry method of delivering chemistry content in a general education chemistry college classroom. Two classes, one instructor and 96 students will be involved.

Procedure
During two topics (electrochemistry and acids/bases) being taught during the semester, one class will be exposed to the inquiry method of teaching (Process oriented guided inquiry learning, inquiry labs, and follow-up discussion) while the other class is exposed to the traditional style of teaching (lecture, "cookbook" labs, and no follow-up discussion). The method each class is exposed to will switch for each topic. At the start of the topic, a pre-test will be given and later the topic will be tested for understanding on a post test. A final exam will also be given at the end of the semester to test the retention of the material covered. The instructor will give the researcher copies of tests and labs so that the level of understanding for the material can be determined for each student.

Duration of Participation
The research will be conducted during the Spring 2009 semester. The length of time each of these topics will be covered in class will be one class period (one lecture and one lab), the follow-up for the inquiry method will be the first 15 minutes of the following class period.

Confidentiality
If you decide to participate, your responses to the content questions will be paired before and after the topic curriculum for comparison. Only the researcher will have access to the tests and labs. You will be assigned a random number to code the data. Data will be retained in a locked office for four years and then destroyed.

Voluntary Nature of Participation
Your participation in this study is voluntary and you may withdraw at any time. To withdraw please inform the instructor to not pass your tests and labs to the researcher. Your participation is appreciated and will add to the validity of the study.

Risks and Benefits
There are no anticipated benefits or risks to you as a participant, aside from gaining a better understanding of some chemistry concepts.

Contacts
If you have any questions about the research project, you can reach Adessa Butler at (330) 972-6651 or adessa@uakron.edu. This project has been reviewed and approved by The University of Akron Institutional Review Board. If you have any questions about your rights as a research participant, you may call the IRB at (330) 972-7666 or 1-888-232-8790.

Thank you for your participation!
I consent to participate in this project:

Printed Name

Signature

Date

Department of Chemistry
Buchtel College of Arts and Sciences
Akron, OH 44325-3601
330-972-7372 Office • 330-972-6085 Fax

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APPROVED
IRB 1/13/09

Date

The University of Akron
INFORMED CONSENT FORM FOR INTERVIEW PARTICIPANTS
Chemistry for Everyone Student

Purpose of Research
You are invited to participate in a study being conducted by Ms. Adessa Butler, graduate assistant, Department of Chemistry, University of Akron, Akron, Ohio. The project focuses on the effectiveness of guided inquiry methods of delivering chemistry content in a general education chemistry college classroom. A random sample from two Chemistry for Everyone classes will be involved in the interview protocol.

Procedure
You will be asked a series of questions about the chemistry topics that were part of the guided inquiry methods intervention. You will also be asked some attitudinal questions about the POGIL (Process Oriented Guided Inquiry Learning) activities and the inquiry labs you completed during the semester. The duration of the interview will be approximately one hour. Your interview will be tape recorded and transcribed. The purpose of the tape recording is to assure that what you say is represented accurately in the research process.

Confidentiality
If you decide to participate, your responses to the interview questions will be stored on the researcher’s computer and backed up on a memory stick. You will be assigned a random number to code the data; your name will not appear on any of the data. Transcribed data and audio recordings will be retained in a locked office for four years and then destroyed.

Voluntary Nature of Participation
Your participation in this study is voluntary and you may withdraw at any time. You can refuse to answer specific questions at any time. To withdraw please inform the researcher. The information you have given up to the time of your withdrawal will be retained for the study unless otherwise requested. Your participation is appreciated and will add to the validity of the study.

Risks and Benefits
There are no anticipated risks to you as a participant.

Contacts
If you have any questions about the research project, you can reach Adessa Butler at adessa@uakron.edu. This project has been reviewed and approved by The University of Akron Institutional Review Board. If you have any questions about your rights as a research participant, you may call the IRB at (330) 972-7666 or 1-800-233-5172.

Thank you for your participation!
I consent to participate in this project:

Printed Name __________________________ Signature __________________________ Date __________________________

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APPENDIX C

PILOT STUDY PRE-SURVEY FORMS

Spring 2009 Pre Survey

Name: 

Gender: M / F Age: 

Race: Caucasian African-American Latino/Hispanic Asian Other ________

Class Year: Freshman Sophomore Junior Senior

Major: Current GPA: 

Highest completed college math class: Grade in last math class: 

List any previous chemistry courses taken and the grade received (high school and/or college):

What is your reason for taking Chemistry for Everyone?

What do you hope to get out of this class?
Please answer the following chemistry questions. If you do not know the answer, leave it blank. These questions will not affect your class grade.

What is oxidation number of the pure element H₂?

Which element is more electronegative Nitrogen or Fluorine?

When electrons are transferred to an atom the charge on the atom changes to what sign, positive or negative?

In the following equation what is being oxidized?

\[ \text{Mg(s)} + 2 \text{ HCl(aq)} \rightarrow \text{MgCl}_2(aq) + \text{H}_2(g) \]

What is the pH range for acids?

In the following reaction what is the base?

\[ \text{H}_3\text{PO}_4(aq) + \text{H}_2\text{O} \rightarrow \text{H}_2\text{PO}_4^-(aq) + \text{H}_3\text{O}^+(aq) \]

What is the pH of a solution that contains 3.2×10⁻⁷M hydronium ions?

What is the pH of a neutral solution?
Summer 2009 Pre-Survey

Name:

Gender: M / F

Age:

Race: Caucasian   African-American   Latino/Hispanic   Asian   Other ________

Class Year: Freshman   Sophomore   Junior   Senior

Major:

Current GPA:

Highest completed college math class:   Grade in last math class:

List any previous chemistry courses taken and the grade received (high school and/or college):

What is your reason for taking Chemistry for Everyone?

What do you hope to get out of this class?

Please answer the following chemistry questions. If you do not know the answer, leave it blank. These questions will not affect your class grade.

1. How many valence electrons does sulfur have?

2. Draw the Lewis dot symbol of chlorine.

3. What charge does the calcium ion have?

4. What attraction holds ions together to form ionic compounds?
5. What type of bond is present in a substance that has the following properties: electrons shared between two non-metals, can be a solid, liquid or gas at room temperature, has a low melting or boiling point, and is usually soft?

6. How do you determine if a covalent bond is polar or nonpolar?

7. Draw the Lewis structure for HCN.

8. What is the pH range for acids?

9. In the following reaction label the base and the conjugate acid?

\[ \text{H}_3\text{PO}_4(aq) + \text{H}_2\text{O} \rightarrow \text{H}_2\text{PO}_4^-(aq) + \text{H}_3\text{O}^+(aq) \]

10. What is the pH of a solution that contains \(3.2 \times 10^{-7}\) M hydronium ions? (Show work)

11. What is the pH of a neutral solution?

12. What is the difference between a strong and a weak acid?

13. How many moles of sodium hydroxide (NaOH) would be needed to neutralize 2.0 moles of hydrochloric acid (HCl)?

14. What two products are formed when an acid and a base are mixed together?
APPENDIX D

PHASE ONE PILOT STUDY GUIDED INQUIRY ACTIVITY AND LAB

Reduction-Oxidation Guided Inquiry Activity

**Electron Transfer Reactions**

**Why?**
Electron transfer reactions are involved in the corrosion of metals, the combustion of fuels, the generation of electricity from batteries, and many biological processes. In these reactions, which also are called oxidation-reduction or redox reactions, electrons are transferred from one chemical species to another. By understanding the principles of redox reactions, scientists and engineers can prevent corrosion, design conditions for more efficient combustion, produce new kinds of batteries, and increase the lifespan of materials and biological systems.

**Learning Objectives**
- Distinguish electron transfer reactions from other kinds of reactions.
- Characterize electron transfer reactions in terms of changes in oxidation numbers and electron flow.

**Success Criteria**
- Assign oxidation numbers to atoms in a chemical compound.
- Identify the oxidizing agent and the reducing agent in a redox reaction.
- Identify the number of electrons transferred in a redox reaction.

**Electronegativity**
The ability of an atom to attract electrons in a molecule.

Electronegativity is a measure of the ability of an atom to attract electrons in a molecule. Electrons are pulled toward the atoms that have the larger electronegativities.

The oxidation number of an atom is the charge an atom would have if each of its bonding electrons were assigned to the more electronegative atom in each bond. The oxidation number helps you keep track of electron flow in redox reactions even though electrons may not be transferred completely. The oxidation number of an atom in a chemical compound is the basic tool used to identify and understand redox reactions.
When an atom is *oxidized*, it loses electrons, and its oxidation number increases. When an atom is *reduced*, it gains electrons, and its oxidation number decreases. So in forming CO, C has been oxidized, and O has been reduced, because oxygen has a higher electronegativity than carbon.

The atom being oxidized serves as a *reducing agent* because it is providing electrons to another atom. The atom being reduced serves as an oxidizing agent because it is removing electrons from another atom.

To summarize: Oxidation is the loss of electrons from a chemical species. Reduction is the gain of electrons by a chemical species. “Reduction” means that the oxidation number is reduced.

**Model 1: Guidelines for Assigning Oxidation Numbers**

The key to understanding oxidation numbers is to remember that the *oxidation number* is defined as the charge an atom would have if each of its bonding electrons were assigned to the more electronegative atom in each of its bonds. The rationale below is based on this idea.

<table>
<thead>
<tr>
<th>Compound</th>
<th>Oxidation Number</th>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>O₂</td>
<td>0</td>
<td>The oxidation number of an atom of a pure element is 0 because there is no electronegativity difference when all the atoms are the same.</td>
</tr>
<tr>
<td>Fe metal</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Na metal</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Na⁺</td>
<td>+1</td>
<td>Group IA metals lose one electron to form ionic compounds.</td>
</tr>
<tr>
<td>Mg²⁺</td>
<td>+2</td>
<td>Group IIA metals lose two electrons to form ionic compounds.</td>
</tr>
<tr>
<td>Cl⁻</td>
<td>−1</td>
<td>The oxidation number of a monatomic ion is its charge.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>For a polyatomic ion, the sum of the oxidation numbers of the atoms is equal to the charge on the ion.</td>
</tr>
<tr>
<td>H₂O, CH₄</td>
<td>H = +1</td>
<td>In compounds with more electronegative elements, the oxidation number of H is +1. When H is combined with metals having a smaller electronegativity, its oxidation number is −1.</td>
</tr>
<tr>
<td>LiH, NaH</td>
<td>H = −1</td>
<td></td>
</tr>
<tr>
<td>H₂O, NO₃⁻</td>
<td>O = −2</td>
<td>In compounds with other elements, the oxidation number of O is −2, except in peroxides, like hydrogen and sodium peroxide, in which their oxidation number is −1.</td>
</tr>
<tr>
<td>H₂O₂, Na₂O₂</td>
<td>O = −1</td>
<td></td>
</tr>
<tr>
<td>CCl₄, KCl</td>
<td>Cl = −1</td>
<td>Group VIIA elements (halogens) are assigned oxidation numbers of −1 in compounds with other elements, except when the halogen is combined with oxygen or other halides that have a larger electronegativity.</td>
</tr>
<tr>
<td>HClO₄</td>
<td>Cl = +7</td>
<td>Oxygen is the most electronegative element in this compound, so each oxygen is assigned both electrons in the bonds. This leaves H and Cl with no electrons, and oxidation numbers of +1 and +7 respectively.</td>
</tr>
<tr>
<td>ClF₅</td>
<td>Cl = +5</td>
<td>F is the most electronegative element in this compound, so each F is assigned both electrons in the bonds. This leaves Cl with 2 electrons and a +5 oxidation number.</td>
</tr>
</tbody>
</table>
**KEY QUESTIONS FOR MODEL 1**

1. What is the oxidation number of a pure element like H₂, O₂, N₂, Na, K, Ni, S₈, and Cu?

2. For the polyatomic ion SO₄²⁻, what is the sum of the oxidation numbers of sulfur and the 4 oxygen atoms?

3. In terms of relative electronegativities, why is the oxidation number of hydrogen +1 in compounds with C, N, O, and Cl, but −1 in compounds with metals like Li, Na, and Al?

4. In terms of relative electronegativities, why does Chlorine have a negative oxidation number in CCl₄, but a positive oxidation number in HClO?

**Got It!**

Explain why you agree or disagree with each of the following statements in terms of the number of electrons and how they are assigned to the atoms.

1. The most electronegative atom in a compound will have a negative oxidation number equal to the number of electrons needed to complete its valence octet.

2. The least electronegative atom in a compound will have a positive oxidation number.

3. The sum of all oxidation numbers must be equal to the charge on the species. For a neutral compound, the sum must be 0; for a cation like NH₄⁺, the sum must be +1; and for an anion like SO₄²⁻, the sum must be −2.
**EXERCISES FOR MODEL 1**

1. Using the guidelines in the model and the insight gained from your answers to the Key Questions and Got It! section, assign oxidation numbers to all atoms in the following compounds or ions.

- $\text{H}_2\text{O}$
- $\text{CO}_2$
- $\text{NaNO}_3$
- $\text{SO}_4^{2-}$
- $\text{H}_2\text{O}_2$
- $\text{CuCl}_2$
- $\text{P}_4$
- $\text{Cr}_2\text{O}_3$
- $\text{Na}_2\text{Cr}_2\text{O}_7$

**MODEL 2: Oxidation of Copper**

In the oxidation of copper metal, electrons are transferred from copper atoms to molecular oxygen to form copper oxide. The chemical reaction equation is

$$2\text{Cu} + \text{O}_2 \rightarrow 2\text{CuO}$$

Two electrons are transferred from each of two copper atoms to an oxygen molecule. The O-O bond breaks, and Cu-O bonds form. The oxidation number of each copper atom changes from 0 to +2 because 2 electrons were lost, and the oxidation number of each oxygen atom changes from 0 to −2 because 2 electrons were gained.

Oxygen is reduced because the oxidation number decreases, and copper is oxidized. Oxygen, therefore, is the oxidizing agent, and copper is the reducing agent.

You can recognize a redox reaction by determining whether or not oxidation numbers change.

**KEY QUESTIONS FOR MODEL 2**

5. In the oxidation of copper, how many electrons are transferred from one copper atom to one oxygen atom?
6. What are the oxidation numbers of the atoms in Cu metal, O₂, and CuO?

7. In the oxidation of copper, what is the chemical species that is oxidized, and what is the chemical species that is reduced?

8. In the oxidation of copper, what is the oxidizing agent, and what is the reducing agent?

9. If some chemical species contain an atom that has an increase in the oxidation number during a chemical reaction, does that species act as the oxidizing agent or the reducing agent?

10. How can you distinguish a redox reaction from other types of chemical reactions?

**Exercises for Model 2**

1. Assign oxidation numbers to all the atoms in the following reactions, identify the reactions that are redox reactions.
   a. \( 2H_2O^+(aq) + Mg(s) \rightarrow Mg^{2+}(aq) + H_2(g) + 2H_2O(aq) \)

   b. \( HCl(aq) + NaOH(aq) \rightarrow NaCl(aq) + H_2O(aq) \)

2. For the redox reactions in Exercise 1, identify the atoms that are oxidized and the atoms that are reduced.

3. For the redox reactions in Exercise 1, identify the oxidizing agent and the reducing agent.

4. For each of the redox reactions in Exercise 1, identify the number of electrons that are transferred from the reducing agent to the oxidizing agent.

5. The following net reaction occurs in an automobile battery when a car is started. Identify the species that are oxidized, reduced, the reducing agent, and the oxidizing agent. (Hint: \( SO_4^{2-} \) same ion on both sides equals)

\[ Pb(s) + 2 HSO_4^-(aq) + PbO_2(s) + 2 H_2O(l) \rightarrow 2 PbSO_4(s) + 4 H_2O(l) \]
The Electrochemical Cell
(How Does a Battery Work?)

Model: Schematic of a Galvanic Cell.

The beaker on the left contains 1 M Zn(NO₃)₂ and the beaker on the right contains 1 M Cu(NO₃)₂.

Information

It is possible to design a redox reaction such that the oxidation occurs at one location and the reduction occurs at another location. The device is called a galvanic or voltaic cell. The cathode (usually a metal bar or carbon rod) is the electrode where reduction takes place; the anode (usually a metal bar or carbon rod) is the electrode where oxidation takes place. The salt bridge allows ions to slowly migrate from one beaker to the other to maintain electrical neutrality in each half-cell. The voltmeter measures the voltage (or potential), V, between the two electrodes. If the temperature is 298 K, and the solutions are 1 M, then the beakers with the electrodes are each considered to be a standard half-cell.

When the switch is closed, the following is observed in the model:

- The mass of the Cu electrode increases and the concentration of Cu²⁺(aq) decreases.
- The mass of the Zn electrode decreases and the concentration of Zn²⁺(aq) increases.
- Electrons (e⁻) are observed to flow through the wire.
- The voltage measured with the voltmeter is 1.10 V.
The Electrochemical Cell

Critical Thinking Questions

1. What is the half-reaction occurring in the copper half-cell?

2. What is the half-reaction occurring in the zinc half-cell?

3. What is the overall (net) chemical reaction taking place in the galvanic cell? (Note: This reaction should not have any e\(^{-}\) in it.)

4. Label the anode and the cathode in the diagram.

5. In which direction (through the wire) are the electrons flowing?

6. Electrons flow from negative to positive. Which electrode, Zn or Cu, is the negative electrode?

7. For the cell in the model:
   a) What species is oxidized in the overall process?
   b) What species is reduced in the overall process?

8. Is there any way to stop the electron transfer process once the switch has been closed?

9. What use(s) could be made of the flow of electrons in the wire?

10. Give one advantage of a voltaic cell, as described in the model, compared to inserting a zinc bar into a Cu\(^{2+}\) solution.
Information

The chemical processes taking place in a galvanic cell may be viewed as a "tug-of-war" for electrons between the two half-cells. The "winner" is the one containing the stronger oxidizing agent—it is the one that gains the electrons and gets reduced. The voltage is a measure of the difference in electron-pulling strength.

"I'll take that electron." "No! Give it to me."

As a standard basis for comparing relative electron-pulling strength (also referred to as reduction potential), the Standard Hydrogen Electrode (SHE) is often used. This half-cell consists of a platinum electrode (Pt is chemically inert, but it is an excellent conductor of electricity) submerged in a 1 M solution of H⁺ ions (this designation is used rather than H₂O⁺, but the meaning is the same) at 298 K, and bathed by H₂ gas at 1 atm pressure.

Figure 1. The standard hydrogen electrode.

The standard reduction potential (reduction potential under standard conditions), $E^{\text{Red}}$ of the SHE is defined as zero volts.

$$2e^- + 2H^+(1 \text{ M}) \rightleftharpoons H_2(\text{g, 1 atm}) \quad E^{\text{Red}} = 0.00 \text{ V}$$

When a SHE is connected to the Cu/Cu^{2+} half-cell from the model, the Cu/Cu^{2+} half-cell exhibits a stronger pull on electrons than does the SHE half-cell. Thus, the following reaction takes place at the Cu electrode (cathode):
The Electrochemical Cell

$$\text{Cu}^{2+}(1 \text{ M}) + 2e^- \rightleftharpoons \text{Cu(s)}$$

Simultaneously, at the Pt electrode (anode), the following reaction takes place:

$$\text{H}_2(\text{g}; 1 \text{ atm}) \rightleftharpoons 2\text{H}^+(1 \text{ M}) + 2e^-$$

The experimental voltage, $E^*$, is 0.34 V.

Critical Thinking Questions

11. Which is the stronger oxidizing agent, Cu$^{2+}$(aq) or H$^+$(aq)?

12. In terms of volts, how much stronger is the stronger of the two oxidizing agents in CTQ 11?

13. What value (in volts) should be assigned as the standard reduction potential, $E^\circ_{\text{Red}}$, of the Cu/Cu$^{2+}$ half-cell?

Skill Development Questions

1. For the cell in the model, which is the stronger oxidizing agent—Zn$^{2+}$ or Cu$^{2+}$?

2. For the cell in the model, how much stronger (in terms of volts) is the stronger oxidizing agent?

3. Draw a galvanic cell consisting of a SHE and the copper electrode described above. Indicate a) the anode and the cathode, b) the direction of flow of the electrons in the wire, and c) which electrode is positive and which electrode is negative. Write down the half-reactions that are occurring at each electrode, and then write down the overall chemical process occurring in the cell.

Reduction-Oxidation Laboratory

Oxidation-Reduction Reactions and Voltaic Cells

Name: _____________________________________________
Lab Partners: _______________________________________

I. Interaction of metals and metal ions

1. Clean and rinse with distilled water, four small test tubes (12-95mm). Shake excess water out of the tubes. Clean wires of Zn, Cu, and Ag metal and Pb strips by gently sandpapering each.
2. Fill the tubes ⅓ full of Zn(NO₃)₂ solution. In one test tube, submerge the clean Zn wire for about 30 seconds. In a second test tube, submerge the clean Cu wire for about 30 seconds. In a third test tube, submerge the clean Ag wire for about 30 seconds. In the last tube, submerge the Pb strip for about 30 seconds. Record your observation in the following table.
3. Remove the strip/wires of metal using a pair of forceps. Clean the strip/wires again.
   Discard the liquid waste in the waste container. Clean each tube.
4. Repeat the above steps for Cu(NO₃)₂, AgNO₃, and Pb(NO₃)₂.

<table>
<thead>
<tr>
<th></th>
<th>Zn(s)</th>
<th>Cu(s)</th>
<th>Ag(s)</th>
<th>Pb(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zn²⁺</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cu²⁺</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ag⁺</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pb²⁺</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Questions:

1. Write the half reactions and total balanced chemical equations for each system tested. (If you observed no change in the system write NO REACTION.) Pick one of the reactions and explain why you chose the products.

2. What patterns are shown in these data? (Hint: compare the relative reactivity of the metals. Compare the relative reactivity of the metal ions. Identify any connections between these two.)

3. From the above question, rank the four metals in order of increasing reducing agents. (Remember, the stronger the reducing agent the greater its tendency to give up electrons)
II. Voltaic Cells

1. Clean, rinse and dry four small beakers (50mL). Label each beaker “Zn,” “Pb,” “Cu,” and “Ag.” Fill the beaker 1/2 full of Zn(NO₃)₂, Pb(NO₃)₂, Cu(NO₃)₂, and AgNO₃ solutions, respectively. Put a clean piece of Zn wire in the Zn(NO₃)₂ solution, a clean strip of Pb in the Pb(NO₃)₂ solution, a clean piece of Cu wire in the Cu(NO₃)₂ solution, and a clean piece of Ag wire in the AgNO₃ solution. Bend the end of the metal wire/strip over the edges of the beaker.

2. Assemble the Zn/Pb cell (Short hand notation is Zn/Zn²⁺ || Pb²⁺/Pb). Do this by connecting the two half-cells together with a salt bridge. The salt bridge is a piece of filter paper soaked in KNO₃. See figure.

3. Set the voltmeter to measure 0-2 volts. Clip one lead to the Zn wire and the other to the Pb strip. Leave them on long enough to take a reading. If the reading is negative, the positive and negative leads are hooked up backwards, switch the leads and take a new reading.

4. Work with another group to assemble all of the possible six cells from the four half-cells. Record the voltage for each cell. Use a new salt bridge for each cell.

5. Go through the procedure again to take a second voltage reading for each cell. Record these readings and compute an average for each cell.

**Voltaic Cell Figure**

Cell = 1/2 cell (1) + 1/2 cell (2)

<table>
<thead>
<tr>
<th>Voltage</th>
<th>First Voltage</th>
<th>Second Voltage</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Zn/Zn²⁺</td>
<td></td>
<td>Pb²⁺/Pb</td>
<td></td>
</tr>
<tr>
<td>2. Zn/Zn²⁺</td>
<td></td>
<td>Cu²⁺/Cu</td>
<td></td>
</tr>
<tr>
<td>3. Zn/Zn²⁺</td>
<td></td>
<td>Ag⁺/Ag</td>
<td></td>
</tr>
<tr>
<td>4. Ag/Ag²⁺</td>
<td></td>
<td>Pb²⁺/Pb</td>
<td></td>
</tr>
<tr>
<td>5. Ag/Ag²⁺</td>
<td></td>
<td>Cu²⁺/Cu</td>
<td></td>
</tr>
<tr>
<td>6. Cu/Cu²⁺</td>
<td></td>
<td>Pb²⁺/Pb</td>
<td></td>
</tr>
</tbody>
</table>
Questions:

1. Electricity is usually viewed as a flow of electrons. Explain why these experimental set-ups cause an electrical current to flow through the wires and voltmeter. (Hint: choose one combination of cells and suggest what reaction may be occurring in each half cell. How do the reactions of the two half cells combine to give a net flow of electrons? What might be the net reaction of the combined half cells? Draw a figure to help demonstrate and label all parts.)

2. What patterns exist in the voltage reading for the several combinations of half cells? How do these patterns compare to those found in part 1?

3. Based on the position in the periodic table, which would you expect to be a stronger reducing agent: zinc or lithium?

4. What advantage might there be to using lithium rather than zinc as the anode in a battery designed to run a power-hungry laptop computer?

III. See part C in the lab manual (page 51) on the Hydrogen Powered Model Car. Be able to draw a model of the energy and hydrogen cycles.

APPENDIX E

PHASE TWO PILOT STUDY GUIDED INQUIRY ACTIVITIES AND LABS

Bonding Guided Inquiry Activity

Types and Properties of Chemical Bonds

Why?
All substances are made up of atoms but each substance is different. One thing that makes them
different is their chemical bonds, or the forces that hold the atoms together. Diamonds and
graphite (lead found in your pencil) are both made of carbon, but both are very different and this
is due to the way the carbon atoms are bound together. In this activity, we will be looking at two
different types of bonding and how they are different.

Learning Objectives
- Identify types of bonds in a compound
- State properties of compounds based on their bonding type (from lab)

Success Criterion
- Form ionic compounds using the octet rule
- Distinguish between ionic and covalent compounds based on properties (from lab)
- State if a covalent bond is polar or nonpolar

Prerequisite Knowledge
- Structure of an atom

Information – Ions
Ions are charged atoms. They either lose or gain electrons to become more stable and less
reactive. In figure 1, there are two examples of atoms and their corresponding ions.

![Diagram of atoms and ions]

Figure 1 – Atoms and Ions
Key Questions

1. Show that both Atoms A and B are neutral (have no charge).

2. What is the difference between Atom A and Ion A? Between Atom B and Ion B?

3. What is the charge in Ion A? On Ion B?

Information – Valence and Core Electrons

In figure 1, the electrons on the outer most ring (outer most shell) are the *valence electrons*. These are the electrons that do the reacting in a reaction. The electrons on the inner rings (inner shells) are the *core electrons*. These do not change during a reaction.

Key Questions

4. What is the identity of Atom A? Of Atom B? (Hint: Based on the number of protons)

5. How many valence electrons does Atom A have? Atom B?

6. How many core electrons does Atom A have? Atom B?

7. How many valence electrons does a sodium atom have? How many core electrons?

8. How many valence electrons does a sulfur atom have? How many core electrons?

9. How many valence electrons are in Ion A? Ion B?
**Information – Octet Rule**

Based on figure 1, the total number of valence electrons in both ions is 8. Having this configuration makes the ions similar in electron structure to the noble gases, making them stable. All atoms will lose or gain electrons to have 8 electrons in their valence shell, this is called the *octet rule*. Atoms will also lose or gain electrons to have a charge closest to neutral or zero (lose or gain the smallest amount of electrons). Atom A, in the above diagram, had 2 valence electrons and it lost those 2 electrons to have a charge of 2+ and 8 electrons in its valence shell. It did not gain 6 electrons, to have a charge of 6−, and 8 in its valence shell.

**Key Questions**

10. A sodium atom has 1 valence electron. How many electrons will it lose or gain? What will be the charge of a sodium ion?

11. A sulfur atom has 6 valence electrons. How many electrons will it lose or gain? What will be the charge of a sulfur ion?

12. What will be the charge of a calcium ion?

13. What will be the charge of a bromine ion?

**Information – Ionic Bonds**

Positively charged ions are called *cations* and negatively charged ions are called *anions*. Cations and anions are attracted to each other due to the charges on the atoms (positive and negative charges attract). This is an *ionic bond*; electrons are transferred from one atom to another forming two charged ions which are attracted to each other.

These ions from a 3-D structure or *lattice structure*, containing the simplest whole number ratio of cations and anions. Figure 2 is a lattice structure of sodium chloride, each sphere represents an ion. The simplest whole number ration for NaCl is 1:1, hence the formula is written as NaCl. The dashed line in figure 2 shows that this is a 3-D structure.
Figure 2 – Lattice Structure of NaCl

Key Questions

14. In NaCl, what are the charges on each ion?

15. How does this explain the 1:1 ratio in the lattice structure?

16. Ionic compounds need a cation and an anion to form. Based on this, what two types of elements does an ionic compound contain? (Hint: think about metals, nonmetals and their location on the periodic table)

17. What is the smallest whole number ratio of magnesium ions to oxygen ions in the ionic compound magnesium oxide? (Hint: compare charges of the magnesium ion and the oxygen ion)

18. Write the formula for magnesium oxide using the smallest whole number ratio

19. What is the smallest whole number ratio of magnesium ions to chlorine ions in the ionic compound magnesium chloride?

20. Write the formula for magnesium chloride using the smallest whole number ratio.

21. What is the overall charge of any ionic compound?
**Information – Covalent Bonds**

Covalent bonds form when electrons are shared between atoms to form a molecule. This sharing occurs to satisfy the octet rule and make the atoms more stable. There are no charges involved but remembering how many electrons are needed to satisfy the octet rule will help you tell how many electrons the atom needs to share.

Chlorine has 7 valence electrons. Two chlorine atoms can share electrons so that both atoms have 8 valence electrons.

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

Each dot in the above reaction represents an electron. The line, in the above product, represents a pair of electrons (2 electrons) that is shared between the two atoms. This is a single covalent bond. The extra pairs of electrons around the chlorine atom that are not shared are called lone pairs or nonbonding pairs of electrons.

**Key Questions**

22. A sulfur atom has 6 valence electrons. How many electrons does the atom need to share to satisfy the octet rule?

23. How many chlorine atoms will sulfur need to combine with? (Hint: a chlorine atom only needs to share 1 electron)

24. Since there are no charges, no cations and anions, in covalent bonding, what types of elements are found in covalent molecules? (Hint: think about metals, nonmetals and their location on the periodic table)

25. Sharing 2 electrons (one pair) was called a single bond. What do you think we call a bond that shares 4 electrons (two pairs)?

26. What do you think we call a bond that shares 6 electrons (three pairs)?
Information – Multiple Bonds

When atoms share multiple pairs of electrons, they are said to have multiple bonds. Oxygen molecules (O₂) contain double bonds (sharing 2 pairs of electrons) and nitrogen molecules (N₂) contain triple bonds (sharing 3 pairs of electrons).

\[
\begin{align*}
\text{O}^\cdot + \text{O}^\cdot & \rightarrow \text{O}═\text{O}^\cdot \\
\text{N}^\cdot + \text{N}^\cdot & \rightarrow \text{N}═\text{N}^\cdot
\end{align*}
\]

O₂ – double bond

N₂ – triple bond

Information – Polar Covalent Bonds

A bond where the electrons are not shared equally between the two atoms is a polar covalent bond (the electrons are still shared). This occurs because each type of atom has a different attraction for an electron. This attraction is called electronegativity. The more electronegative an atom, the more it attracts an electron in a molecule. A bond that shares electrons equally between two atoms is a nonpolar covalent bond.

Key Questions

27. The most electronegative atom is fluorine in the top right hand corner of the periodic table; the least is cesium in the bottom left corner. Rubidium is more electronegative than cesium and potassium is more electronegative than both cesium and rubidium, oxygen is less electronegative than fluorine and nitrogen is less electronegative than both oxygen and fluorine. Based on this information, what do you think the trend is on the periodic table? (Hint: discuss trend down a group and across a period)

28. For each of the following compounds, state if the bonds are ionic, polar covalent or nonpolar covalent. (Hint: look at the atoms involved and think about where they are on the periodic table)

\[
\begin{align*}
\text{CaCl}_2 & \quad \text{PCl}_3 & \quad \text{H}_2 & \quad \text{KF}
\end{align*}
\]

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Properties of Bond Types

Name: ____________________________________________

Lab Partners: ____________________________________________

You have recently been informed about properties of ionic and covalent bonds; now let's explore some of the characteristics and physical properties of those types of bonds. If you do not remember the definitions of ionic, covalent and polarity go back and explore that information again.

Properties such as melting point, boiling point, solubility, electrical conductivity, and color can be used to distinguish between different bond types. You will be looking at a variety of solids and determining if they are ionic or covalent based on their properties.

Procedures:

You will be determining the type of bonds found in: Aspirin (acetylsalicylic acid), salt substitute (KCl), table sugar, rock salt, Epsom salt, naphthalene, and paraffin.

You will be looking at each compound’s appearance, volatility (odor), hardness, melting point, solubility in water, solubility in cyclohexane, and conductivity to determine the type of bonds. Record all of your data in the following table.

For the solubility tests, save any of the substances which are soluble in water or cyclohexane for the conductivity test.

Melting point:
1. Put a pea size amount of sample in the bottom of a test tube.
2. Heat each test tube. Do not heat the test tube for more than 1 minutes.
3. Since you can not accurately record a temperature, what other measurement could you use to compare the samples?

Conductivity: You will be using the LabQuest® handheld and Vernier® Conductivity Probe
1. For each compound that dissolved in either water or cyclohexane, make sure the test tube is 1/3 full. If not, add more of the solvent (water or cyclohexane).
2. Make sure the hand held is on and is set to 0-20000 on the probe.
3. Rinse probe with deionized water.
4. Put probe in test tube containing the first dissolved sample and record the reading on the screen.
5. Repeat steps 3 & 4 for each dissolved sample. Make sure you rinse the probe between each sample.

If you touch any of the chemicals make sure to wash your hands. Clean glassware before and after each test. Dispose of the cyclohexane in the organic waste container in the fume hood. DO NOT pour cyclohexane down the drain!
For the other properties listed come up with a way to test them with the materials provided.
Things to think about: does amount of material matter, does time matter, what do you need to control for?

Questions:

1. Using your knowledge of ionic and covalent bonds, classify each material as covalent or ionic.

2. Explain, in terms of types of bonds, the presence or absence of an odor for each substance.

3. Explain, in terms of types of bonds, the difference in melting points of the substances. What factors affect melting points? (What is happening when a substance is melting?)

4. Explain, in terms of types of bonds, the differences in solubility of the substances between water (which is polar) and cyclohexane (which is nonpolar).

5. Explain, in terms of types of bonds, the differences in conductivities of the substances.

Reference:
NEOCEx Teaching Key Chemistry Concepts, Summer 2009, The University of Akron
<table>
<thead>
<tr>
<th>Bond Type</th>
<th>Conductivity</th>
<th>Solubility in Water</th>
<th>Solubility in Point Melting</th>
<th>Hardness</th>
<th>Volatility</th>
<th>Appearance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Napthalene</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Epsom Salt</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Rock Salt</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Sugar</td>
<td></td>
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<tr>
<td>Table Salt</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Subsluice (KCl)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aspirin (acetylsaliicylic acid)</td>
<td></td>
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</tr>
</tbody>
</table>
All You Need to Understand Acids and Bases

Why?
Acids and bases are around you every day, from cleaning products to the foods you eat. Many health and environmental issues deal with acids and bases, such as blood acidity and acid rain. Many chemical reactions can be explained using acid-base terms. A pH value can help you determine how much acid or base is in a solution. The pH of pool water is checked to determine if it is safe to swim in.

Learning Objectives
- Identify characteristics of acids and bases
- Use the pH scale and interpret its meaning
- Identify and quantify the neutralization of an acid or a base

Success Criterion
- Recognized acids and bases from the molecular formula
- Write and label acid-base reactions
- Interconvert values between hydronium ions, hydroxide ions, pH and pOH
- Calculate concentrations to neutralized an acid or a base

Prerequisite Knowledge
- Chemical Equations
- Molarity

Information – Acids and Bases
An acid is defined as a chemical that donates a proton (H⁺) to another chemical. Some characteristics of acids include turning neutral litmus paper red, tasting sour, and reacting with metals such as zinc (Zn) and iron (Fe) to produce hydrogen gas (H₂). Remember do not taste chemicals in the lab!

A base is defined as a chemical that accepts a proton from another chemical. Some characteristics of bases include turning neutral litmus paper blue, tasting bitter, and feeling slippery on the skin. Remember do not touch chemicals in the lab without being instructed to do so!
Model 1: Acid-Base reactions

1. $\text{HCl(aq)} + \text{NH}_3(\text{aq}) \rightarrow \text{Cl}^-(\text{aq}) + \text{NH}_4^+(\text{aq})$
   
   Acid + Base

2. $\text{HNO}_3(\text{aq}) + \text{H}_2\text{O(l)} \rightarrow \text{H}_3\text{O}^+(\text{aq}) + \text{NO}_3^-(\text{aq})$

3. $\text{NH}_3(\text{aq}) + \text{H}_2\text{O(l)} \rightarrow \text{NH}_4^+(\text{aq}) + \text{OH}^-(\text{aq})$

4. $\text{H}_3\text{PO}_4(\text{aq}) + \text{H}_2\text{O(l)} \rightarrow \text{H}_3\text{PO}_4^-(\text{aq}) + \text{H}_2\text{O}^+(\text{aq})$
   
   $s = \text{solid}, \text{aq} = \text{aqueous}, \text{l} = \text{liquid}$

Key Questions

1. In Model 1, label each reactant as an acid or a base as demonstrated in the first reaction.

2. How did you determine which reactant was an acid and which reactant was a base?

3. Toilet bowl cleaner feels slippery to the touch and turns neutral litmus paper blue. Does this product contain an acid or a base?

4. In Model 1, are there any compounds that act as both an acid and a base? Explain how this can or cannot occur.

5. Would you call potassium hydroxide, KOH, an acid or a base? Why? (Hint: Potassium hydroxide ionizes in water to give $\text{K}^+(\text{aq})$ and $\text{OH}^-(\text{aq})$)

6. Write a balanced chemical equation for the acid-base reaction of $\text{NH}_3$ with $\text{H}_2\text{SO}_4$. Identify the acid and the base on the reactant side.

7. Give an example of an acid and a base that you have used in your daily life.
Information – Conjugate Acid-Base Pairs

A chemical that can act as both an acid and base is called amphoteric. Water is an amphoteric compound that can either donate a proton (acid) and form OH\textsuperscript{-} or accept a proton (base) and form H\textsubscript{3}O\textsuperscript{+}.

A pair of chemicals that differ only by a proton is called a conjugate acid-base pair. An example would be HCl and Cl\textsuperscript{-} from reaction 1 in Model 1. HCl was determined to be an acid because it donates a proton; if the reaction is reversed Cl\textsuperscript{-} can accept a proton so it is a base. Another example is NH\textsubscript{3} (base) and NH\textsubscript{4}\textsuperscript{+} (acid) from reaction 1 in Model 1.

When labeling reactions, the reactants are labeled as acids and bases and the products are labeled as conjugate acids and conjugate bases. Look for conjugate acid-base pairs to label the products correctly. Let's look at reaction 1 again:

\[
\text{HCl(aq)} + \text{NH}_3(\text{aq}) \rightarrow \text{Cl}^- (\text{aq}) + \text{NH}_4^+ (\text{aq})
\]

Acid Base

We can now label Cl\textsuperscript{-} as the conjugate base (it can accept a proton if the reaction was reversed) and NH\textsubscript{4}\textsuperscript{+} as the conjugate acid (it can donate a proton if the reaction was reversed).

\[
\text{HCl(aq)} + \text{NH}_3(\text{aq}) \rightarrow \text{Cl}^- (\text{aq}) + \text{NH}_4^+ (\text{aq})
\]

Acid Base Conjugate Acid

Conjugate Base

Key Questions

8. In Model 1, label each product as a conjugate acid or a conjugate base as demonstrated in the above example.

9. In Model 1, circle any amphoteric compounds.

10. Write the conjugate bases of HCN and H\textsubscript{2}SO\textsubscript{4}. Write the conjugate acids of F\textsuperscript{-} and HCO\textsubscript{3}\textsuperscript{-}.

Information – Strong and Weak Acids and Bases

Acids and bases are often identified as being strong or weak. A strong acid or base completely ionizes in water. An example would be HCl for an acid and NaOH for a base. In the solution of HCl, there is very little HCl and mainly H\textsubscript{3}O\textsuperscript{+} and Cl\textsuperscript{-}. Notice that in the reaction below, complete ionization is shown by the single arrow to show that only the products are found in the solution.

\[
\text{HCl(aq)} + \text{H}_2\text{O(l)} \rightarrow \text{H}_3\text{O}^+(\text{aq}) + \text{Cl}^-(\text{aq})
\]
A weak acid or base only partially ionizes in water. An example would be HCN for an acid and NH₃ for a base. In a solution of NH₃, there would be NH₃ and NH₄⁺ and OH⁻. Notice that in the reaction below, a partial ionization is shown by the two arrows to show that both the reactants and the products are found in the solution.

\[ \text{NH}_3(\text{aq}) + \text{H}_2\text{O}(l) \rightleftharpoons \text{NH}_4^+(\text{aq}) + \text{OH}^-(\text{aq}) \]

Some common strong acids are hydrochloric acid (HCl), sulfuric acid (H₂SO₄), and nitric acid (HNO₃). Some common strong bases are sodium hydroxide (NaOH), potassium hydroxide (KOH), and lithium hydroxide (LiOH).

**Key Question**

11. What is the difference between a strong acid and a weak acid?

12. List two common strong acids and two common strong bases.

**Information - pH**

The concentration of an acidic or basic solution is calculated by the concentration of the H⁺ and OH⁻ ions in the solution, respectively. Since hydrochloric acid is a strong acid, a one molar solution (1 M HCl) contains 1 mole of H⁺ ions per liter of solution. (Remember: molarity is calculated by moles of compound per liter of solution; \( M = \text{mol} / L \))

How acidic or basic a solution is, is represented by the pH scale. When calculating pH, the hydronium ion (H₃O⁺) concentration is used. To calculate pH the following formula is used: (Remember: \([\text{H}_3\text{O}^+]\) means the concentration of H₃O⁺, this would also be the same as H⁺ ions)

\[ \text{pH} = -\log[\text{H}_3\text{O}^+] \]

**Model 2 - pH Conversions**

<table>
<thead>
<tr>
<th>[H₃O⁺]</th>
<th>[H₃O⁺] in Scientific notation</th>
<th>pH formula</th>
<th>pH</th>
<th>Power formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00035</td>
<td>3.5×10⁻⁴</td>
<td>-log(3.5×10⁻⁴)</td>
<td>3.46</td>
<td>10⁻³.36</td>
</tr>
<tr>
<td>0.0024</td>
<td></td>
<td>-log(2.4×10⁻⁵)</td>
<td>5.10</td>
<td>10⁻⁵.24</td>
</tr>
</tbody>
</table>

**Key Questions**

12. Fill in the missing values in the Model 2 table.
13. According to Model 2, if you are given a hydronium ion concentration how do you calculate the pH?

14. According to Model 2, if you are given the pH how do you calculate the hydronium ion concentration?

15. The pH scale ranges from 0 – 14. What is the hydronium ion range that this scale covers?

16. Give a reason why you think the pH scale is used more than the concentration of hydronium ions when discussing the acidity or basicity of a solution?

17. What is the difference between a strong acid and a concentrated acidic solution?

**Information – Autoionization**

At 25°C, water undergoes autoionization by the following reaction

\[ \text{H}_2\text{O} + \text{H}_2\text{O} \rightarrow \text{H}_3\text{O}^+ + \text{OH}^- \]

The concentration of hydronium ions (H$_3$O$^+$) is 10$^{-7}$M and the concentration of hydroxide ions (OH$^-$) is 10$^{-7}$M. Since the two values are equal, pure water is said to be neutral. If the concentration of hydronium ions increases the solution becomes acidic, and if the hydroxide ion concentration increases the solution is said to be basic.

**Key Questions**

18. What is the pH of a neutral sample of pure water that has a hydronium ion concentration of 10$^{-7}$M?

19. If a solution has a pH of 4.50, is the hydronium ion concentration higher or lower than that of a neutral solution? Is this solution acidic or basic?
20. What would you expect the pH range of a basic solution to be?

**Information – p-scale**

A p-scale, like the pH scale, can be made for any quantity

\[ pX = - \log X \]

Another useful p-scale when discussing acids and bases is the \( p\text{OH} \) scale.

21. Give a formula to calculate the pOH of a solution.

22. What value would you need to be given to calculate the pOH of a solution?

**Model 3 – pH and pOH conversions**

<table>
<thead>
<tr>
<th>Solution</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>2.54</td>
<td>6.32</td>
<td>8.00</td>
<td>13.95</td>
</tr>
<tr>
<td>Calculated ([H_2O^+])</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>([\text{OH}^-])</td>
<td>3.47x10^{-12}</td>
<td>2.09x10^{-4}</td>
<td>1.00x10^{-6}</td>
<td>0.89</td>
</tr>
<tr>
<td>Calculated pOH</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(pH + pOH)</td>
<td>14.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>([H_2O^+] \times [\text{OH}^-])</td>
<td>1.00x10^{-14}</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

23. Using the relationships you know about concentration and p-values fill in the missing values in the Model 3 table.

24. Write a general statement and formula explaining the sum of pH and pOH values for solutions.

25. Write a general statement and formula explain the product of hydronium and hydroxide ion concentrations for solutions.

26. Lemon juice has a pH of 2.1. What are the hydronium ion concentration, the hydroxide ion concentration, and the pOH of the solution? Is lemon juice acidic, basic or neutral?

Acid-Base Chemistry Laboratory

Reactions of Acids and Bases

Name: 
Lab Partners: 

pH of Acids and Bases

You have recently been informed about characteristics of acids and bases; now let’s actually explore some of those characteristics. If you do not remember the definitions of acids, bases, and pH, go back and explore that information again.

To determine if something is an acid or a base we can use an indicator. An indicator is chemical that changes color based on the pH of the solution it is in. The indicator you will use in this lab is phenolphthalein.

Producers:

1. Clean and rinse a well plate with distilled water. Shake excess water out of the wells and dry.
2. Fill each well ¼ full with a different solution to be tested. Make sure you know what solution is in each well. The solutions to be tested are 0.1 M HCl, 0.1 M NaOH, Tap water, Vinegar and Ammonia.
3. Dip the tip of a stirring rod in the 0.1 M HCl. Touch the tip to a small piece of pH paper. Record the color of the paper and the corresponding pH value. Repeat for each solution making sure to clean the stirring rod between solutions.
4. Add one drop of phenolphthalein to the solution in each well. Record the color.

<table>
<thead>
<tr>
<th></th>
<th>0.1 M HCl</th>
<th>0.1 M NaOH</th>
<th>Tap Water</th>
<th>Vinegar</th>
<th>Ammonia</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Color with phenolphthalein</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Questions:

1. What are the pH ranges of acids, bases and neutral solutions?
2. What color is phenolphthalein in acids? in bases? in neutral solutions?

3. Can an indicator tell you the exact pH of a solution? Why or why not?

4. Calculate the pH from the $H_3O^+$ concentration of the 0.1 M HCl solution. Does this match the pH you recorded from the pH paper? Why or why not? (Hint: remember HCl is a strong acid)

Neutralization Reactions

When an acidic and a basic solution are mixed together they produce water and a salt. A salt is a general term for any ionic compound produced during this type of reaction not just table salt (NaCl).

$$\text{HNO}_3(\text{aq}) + \text{NaOH}(\text{aq}) \rightarrow \text{H}_2\text{O}(\text{l}) + \text{NaNO}_3(\text{aq})$$

The sodium nitrate (NaNO$_3$) is the salt in this acid-base reaction. This type of reaction is called a neutralization reaction.

If equal moles of $H^+$ ions (the acid) are combined with equal moles of $OH^-$ ions (the base) the final solution will be neutral.

In this lab, you will be using the technique of titration. A titration is the process of mixing two solutions until the reaction between them is complete. The point where the reaction is complete is called the end point. You will be mixing an acid and a base together until the final solution is neutral. To determine the end point of a titration, an indicator is used. You will again be using phenolphthalein as an indicator, make sure you know what color change you will be looking for to determine when you reach the end point!

You will also be using a buret in this experiment. A buret is a piece of glassware that accurately dispenses a liquid. The markings on the buret are accurate to tenths place and you can estimate to the hundredths place (0.01), so make sure you are using enough significant figures. Your TA will show you proper use of the buret, make sure you understand how to use the piece of glassware properly before you start.

Remember, molarity is used when talking about the concentration of a solution. The following is the formula for molarity (M):

$$M = \text{mol/L}$$
Both the acid and the base used in the experiment are strong; make sure you review what this term means.

Procedures:

1. Clean and rinse with distilled water a 250 mL Erlenmeyer flask and a 25 mL buret.
2. Add 20.0 mL of 0.1 M HCl to the Erlenmeyer flask.
3. Check and record the pH of the solution using pH paper.
4. Add 2-3 drops of phenolphthalein to the Erlenmeyer flask.
5. Fill the buret with 0.1 M NaOH. Remove any air bubbles from the tip by letting a few milliliters of liquid run out the tip into a waste beaker.
6. Record the initial volume in the buret.
7. Slowly add the NaOH to the HCl, using the buret, to neutralize the solution. See Figure 1 for the set-up.
8. Once you have reached the endpoint, check to make sure the solution is neutral using pH paper. If solution is still acidic continue adding NaOH. If your solution is highly basic, repeat the whole procedure.
9. Record the final volume of NaOH remaining in the buret.
10. Place 5 mL of the neutralized solution in a crucible.
11. Carefully boil off the liquid until the dish is dry. See Figure 2 for the set-up.
12. Repeat steps 2-8 again.

Figure 1

![Figure 1: Erlenmeyer flask and buret](image1)

Figure 2

![Figure 2: Crucible and crucible holder](image2)

<table>
<thead>
<tr>
<th></th>
<th>Trial 1</th>
<th>Trial 2</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume of HCl in flask</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moles of H$_3$O$^+$ (moles of HCl)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pH of HCl</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial volume of NaOH in buret</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Final volume of NaOH in buret</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volume of NaOH added to neutralize acid</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moles of OH$^-$ (moles of NaOH)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Difference in moles of H$_3$O$^+$ &amp; OH$^-$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pH of neutralized solution</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Questions:
7. Write the reaction for HCl and NaOH. Label the acid, base, conjugate acid, conjugate base, salt, and water. (Hint: some molecules will be labeled more than once)

8. What was the liquid you boiled away from the neutralized solution? What were the crystals that were left in the dish after the liquid had been boiled off?

9. Milk of magnesia is an antacid containing magnesium hydroxide, which is used to settle sour (acid) stomachs. Write an equation to show how the active ingredient (Mg(OH)$_2$) neutralizes excess hydrochloric acid (HCl). (Hint: make sure your equation is balanced)

10. If you have 4 moles of HCl how many moles of Mg(OH)$_2$ will you need to neutralize the acid?
APPENDIX F

MAIN STUDY PRE-SURVEY

Name:

Email:

Gender: M / F

Age:

Race: Caucasian African-American Latino/Hispanic Asian Other ________

Class Year: Freshman Sophomore Junior Senior

Major:

Current GPA:

Highest completed college math class: Grade in last math class:

List any previous chemistry courses taken and the grade received (high school and/or college):

What is your reason for taking Chemistry for Everyone?

Would you be willing to participate in an interview about this study this semester? Yes No
Please answer the following chemistry questions. If you do not know the answer, leave it blank. These questions will not affect your class grade.

1. What is the charge on a calcium ion?

2. Describe the formation of an ionic bond in terms of the electrons.

3. What type of bond is present in a substance that has the following properties: electrons shared between two non-metals, can be a solid, liquid or gas at room temperature, has a low melting or boiling point, and is usually soft?

4. How do you determine if a covalent bond is polar or nonpolar?

5. State the type of chemical equation for the reaction:
   \[ \text{Mg} + \text{Ca}_3(\text{PO}_4)_2 \rightarrow \text{Mg}_3(\text{PO}_4)_2 + \text{Ca} \]

6. For the chemical equation used in problem 5, list the reactants.

7. What does the triangle mean above the arrow in the following equation?
   \[ 2\text{CH}_3\text{OH}(l) + 3\text{O}_2(g) \xrightarrow{\Delta} 2\text{CO}_2 \uparrow + 4\text{H}_2\text{O}(l) \]

8. Balance the following chemical equation.
   \[ \_\_\_\text{Al} + \_\_\_\text{H}_2\text{SO}_4 \rightarrow \_\_\_\text{Al}_2(\text{SO}_4)_3 + \_\_\_\text{H}_2 \]

9. What is the pH range for acids?

10. In the following reaction label the base and the conjugate acid.
    \[ \text{H}_3\text{PO}_4(aq) + \text{H}_2\text{O} \rightarrow \text{H}_2\text{PO}_4(aq) + \text{H}_3\text{O}^+(aq) \]

11. What is the pH of a solution that contains \(3.2 \times 10^{-7}\)M hydronium ions? (Show work)

12. How many moles of sodium hydroxide (NaOH) would be needed to neutralize 2.0 moles of hydrochloric acid (HCl)?
Formulas:

\[ \text{pH} = -\log[H^+] \]
\[ \text{pOH} = -\log[OH^-] \]
\[ \text{pH} + \text{pOH} = 14.00 \]
APPENDIX G

MAIN STUDY GUIDED INQUIRY ACTIVITIES AND LABS

Bonding Guided Inquiry Activity

Types and Properties of Chemical Bonds

Why?

All substances are made up of atoms but each substance is different. One thing that makes them different is their chemical bonds, or the forces that hold the atoms together. Diamonds and graphite (lead found in your pencil) are both made of carbon, but both are very different and this is due to the way the carbon atoms are bound together. In this activity, we will be looking at two different types of bonding and how they are different.

Learning Objectives

- Identify types of bonds in a compound
- State properties of compounds based on their bonding type (from lab)

Success Criterion

- Form ionic compounds using the octet rule
- Distinguish between ionic and covalent compounds based on properties (from lab)
- State if a covalent bond is polar or nonpolar

Prerequisite Knowledge

- Structure of an atom

Information – Ions

Ions are charged atoms. They either lose or gain electrons to become more stable and less reactive. In figure 1, there are two examples of atoms and their corresponding ions.

Figure 1 – Atoms and Ions
Key Questions

1. Show that both Atoms A and B are neutral (have no charge).

2. What is the difference between Atom A and Ion A? Between Atom B and Ion B?

3. What is the charge in Ion A? On Ion B?

Information – Valence and Core Electrons

In figure 1, the electrons on the outer most ring (outer most shell) are the valence electrons. These are the electrons that do the reacting in a reaction. The electrons on the inner rings (inner shells) are the core electrons. These do not change during a reaction.

Key Questions

4. What is the identity of Atom A? Of Atom B? (Hint: Based on the number of protons)

5. How many valence electrons does Atom A have? Atom B?

6. How many core electrons does Atom A have? Atom B?

7. How many valence electrons does a sodium atom have? How many core electrons?

8. How many valence electrons does a sulfur atom have? How many core electrons?

9. How many valence electrons are in Ion A? Ion B?
Information – Octet Rule

Based on figure 1, the total number of valence electrons in both ions is 8. Having this configuration makes the ions similar in electron structure to the noble gases, making them stable. All atoms will lose or gain electrons to have 8 electrons in their valence shell, this is called the octet rule. Atoms will also lose or gain electrons to have a charge closest to neutral or zero (lose or gain the smallest amount of electrons). Atom A, in Figure 1, had 2 valence electrons and it lost those 2 electrons to have a charge of 2+ and 8 electrons in its valence shell. It did not gain 6 electrons, to have a charge of 6−, and 8 in its valence shell.

Key Questions

10. A sodium atom has 1 valence electron. How many electrons will it lose or gain? What will be the charge of a sodium ion?

11. A sulfur atom has 6 valence electrons. How many electrons will it lose or gain? What will be the charge of a sulfur ion?

12. What will be the charge of a calcium ion?

13. What will be the charge of a bromine ion?

Information – Ionic Bonds

Positively charged ions are called cations and negatively charged ions are called anions. Cations and anions are attracted to each other due to the charges on the atoms (positive and negative charges attract). This is an ionic bond; electrons are transferred from one atom to another forming two charged ions which are attracted to each other.

These ions from a 3-D structure or lattice structure, containing the simplest whole number ratio of cations and anions. Figure 2 is a lattice structure of sodium chloride, each sphere represents an ion. The simplest whole number ratio for NaCl is 1:1, hence the formula is written as NaCl. The dashed line in figure 2 shows that this is a 3-D structure.
Key Questions

14. In NaCl, what are the charges on each ion?

15. How does this explain the 1:1 ratio in the lattice structure?

16. Ionic compounds need a cation and an anion to form. Based on this, what two types of elements does an ionic compound contain? (Hint: think about metals, nonmetals and their location on the periodic table)

17. What is the smallest whole number ratio of magnesium ions to oxygen ions in the ionic compound magnesium oxide? (Hint: compare charges of the magnesium ion and the oxygen ion)

18. Write the formula for magnesium oxide using the smallest whole number ratio.

19. What is the smallest whole number ratio of magnesium ions to chlorine ions to make the neutral ionic compound magnesium chloride?

20. Write the formula for magnesium chloride using the smallest whole number ratio.

21. What is the overall charge of any ionic compound?
Information – Covalent Bonds

Covalent bonds form when electrons are shared between atoms to form a molecule. This sharing occurs to satisfy the octet rule and make the atoms more stable. There are no charges involved but remembering how many electrons are needed to satisfy the octet rule will help you tell how many electrons the atom needs to share.

Chlorine has 7 valence electrons. Two chlorine atoms can share electrons so that both atoms have 8 valence electrons.

Each dot in the above reaction represents an electron. The line, in the above product, represents a pair of electrons (2 electrons) that is shared between the two atoms. This is a single covalent bond. The extra pairs of electrons around the chlorine atom that are not shared are called lone pairs or nonbonding pairs of electrons.

Key Questions

22. A sulfur atom has 6 valence electrons. How many electrons does the atom need to share to satisfy the octet rule?

23. How many chlorine atoms will sulfur need to combine with? (Hint: a chlorine atom only needs to share 1 electron)

24. Since there are no charges, no cations and anions, in covalent bonding, what types of elements are found in covalent molecules? (Hint: think about metals, nonmetals and their location on the periodic table)

25. Sharing 2 electrons (one pair) was called a single bond. What do you think we call a bond that shares 4 electrons (two pairs)?

26. What do you think we call a bond that shares 6 electrons (three pairs)?
Information – Multiple Bonds

When atoms share multiple pairs of electrons, they are said to have multiple bonds. Oxygen molecules (O₂) contain double bonds (sharing 2 pairs of electrons) and nitrogen molecules (N₂) contain triple bonds (sharing 3 pairs of electrons).

\[
\begin{align*}
\text{O} & \quad + \quad \text{O} \\
\rightarrow \quad \text{O} &= \text{O} \\
\text{O}_2 & \quad \text{double bond}
\end{align*}
\]

\[
\begin{align*}
\text{N} & \quad + \quad \text{N} \\
\rightarrow \quad \text{N} &= \text{N} \\
\text{N}_2 & \quad \text{triple bond}
\end{align*}
\]

Information – Polar Covalent Bonds

A bond where the electrons are not shared equally between the two atoms is a polar covalent bond (the electrons are still shared). This occurs because each type of atom has a different attraction for an electron. This attraction is called electronegativity. The more electronegative an atom, the more it attracts an electron in a molecule. A bond that shares electrons equally between two atoms is a nonpolar covalent bond.

Key Questions

27. The most electronegative atom is fluorine in the top right hand corner of the periodic table; the least is cesium in the bottom left corner. Rubidium is more electronegative than cesium and potassium is more electronegative than both cesium and rubidium. Oxygen is less electronegative than fluorine and nitrogen is less electronegative than both oxygen and fluorine. Based on this information, what do you think the trend is on the periodic table? (Hint: discuss trend down a group and across a period)

28. For each of the following compounds, state if the bonds are ionic, polar covalent or nonpolar covalent. (Hint: look at the atoms involved and think about where they are on the periodic table)

\[
\begin{align*}
\text{CaCl}_2 & \quad \text{PCl}_3 & \quad \text{H}_2 & \quad \text{KF}
\end{align*}
\]


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Properties of Bond Types

You have recently been informed about properties of ionic and covalent bonds; now let’s explore some of the characteristics and physical properties of those types of bonds. If you do not remember the definitions of ionic, covalent and polarity go back and explore that information again.

Properties such as melting point, boiling point, solubility, electrical conductivity, and color can be used to distinguish between different bond types. You will be looking at a variety of solids and determining if they are ionic or covalent based on their properties.

Procedures:

You will be determining the type of bonds found in: Aspirin (acetylsalicylic acid), salt substitute (KCl), table sugar, rock salt, Epsom salt, naphthalene, and paraffin.

You will be looking at each compound’s appearance, volatility (odor), hardness, melting point, solubility in water, solubility in cyclohexane, and conductivity to determine the type of bonds. You will be making your own procedures to determine each of the listed properties. Make sure you write detailed procedures in the procedure section of your notebook. Things to think about: does amount of material matter, does time matter, what do you need to control for?

Record all of your data in the following table.

For the solubility tests, save any of the substances which are soluble in water for the conductivity test.

Melting point:
1. Put a pea size amount of sample in the bottom of a test tube.
2. Heat each test tube. Do not heat the test tube for more than 1 minute.
3. Since you can not accurately record a temperature, what other measurement could you use to compare the samples?

Conductivity: You will be using the LabQuest® handheld and Vernier® Conductivity Probe
1. For each compound that dissolved in water, make sure the test tube is 1/3 full. If not, add more water.
2. Make sure the hand held is on and set to 0-20000 on the probe.
3. Rinse probe with deionized water.
4. Put probe in test tube containing the first dissolved sample and record the reading on the screen.
5. Repeat steps 3 & 4 for each dissolved sample. Make sure you rinse the probe between each sample.

If you touch any of the chemicals make sure to wash your hands. Clean glassware before and after each test. Wear gloves when using cyclohexane. Dispose of the cyclohexane in the organic waste container in the fume hood. DO NOT pour cyclohexane down the drain!
Questions:

1. Using your knowledge of ionic and covalent bonds, classify each material as covalent or ionic.

2. Explain, in terms of types of bonds, the presence or absence of an odor for each substance.

3. Explain, in terms of types of bonds, the difference in melting points of the substances. What factors affect melting points? (What is happening when a substance is melting?)

4. Explain, in terms of types of bonds, the differences in solubility of the substances between water (which is polar) and cyclohexane (which is nonpolar).

5. Explain, in terms of types of bonds, the differences in conductivities of the substances.

Reference:
NEOCEA Teaching Key Chemistry Concepts, Summer 2008, The University of Akron
Chemical Equations Guided Inquiry Activity

Chemical Reaction Equations

Why?
Chemical reactions are around you every day, from the food you cook to the way your body works. There are a variety of different classifications of chemical reactions, which you will learn about in this activity. You will also learn how to write chemical equations and predict reactions along with how they follow the concept that matter is neither created nor destroyed.

Learning Objectives
- Recognize types of chemical reactions
- Balance chemical equations

Success Criterion
- Identify types of chemical reactions
- Write chemical equations
- Balance chemical equations

Prerequisite Knowledge
- Writing chemical formulas
- States of matter

Information – Chemical Equations

A chemical equation is a chemist’s shorthand for a chemical reaction. It shows, using symbols, what reactants are transformed into products during a chemical reaction. The following is an example of a chemical equation for the reaction of carbon with oxygen to form carbon dioxide.

\[ \text{C} + \text{O}_2 \rightarrow \text{CO}_2 \]

Notice the starting materials C and O₂, reactants, are on the left and the final material CO₂, product, is on the right. The arrow (→) that separates the reactants and products shows that the reactants are transforming into the products, the plus sign (+) is used to separate different reactants and/or products.

Notice also in the above equation that oxygen is written as O₂ and not just O while carbon is written as C. This is because oxygen is a diatomic molecule. If an element is diatomic, it binds to itself when in its neutral standard state. You will never see a neutral oxygen atom by itself; written as O, it will always be written as O₂. The elements that exist as diatomic molecules are:

H N O F Cl Br I
These atoms will never be found alone, when they are in their neutral form; they will always be bonded to another like atom. You can remember them by the name Mr. BrINCHIOF or their location on the periodic table (all but hydrogen are located in an L shape in the upper right hand corner).

Atoms that are not diatomic will be written as a single neutral atom, such as carbon in the above example. Another example is sodium metal. When it is neutral standard state it will be written as Na and not Na₂ because it is not one of the seven diatomic molecules.

**Key Questions (Do not worry about balancing equations, we will get to that later)**

1. Answer the following question based on the chemical equation: \( \text{NH}_3 + \text{O}_2 \rightarrow \text{H}_2\text{O} + \text{N}_2 \)
   a. What are the reactants?
   
   b. What are the products?

   c. Why are oxygen and nitrogen written as \( \text{O}_2 \) and \( \text{N}_2 \), respectfully?

   d. Why is \( \text{H}_2\text{O} \) not written as \( \text{H}_3\text{O}_2 \)? (Hint: Think of writing formulas and how you determine subscripts)

2. Answer the following questions based on the chemical equation: \( \text{Na} + \text{MgCl}_2 \rightarrow \text{NaCl} + \text{Mg} \)
   a. What are the reactants?

   b. What are the products?

   c. Why is \( \text{NaMg} \) not produced? (Hint: Think about the rules of bonding and writing formulas)

   d. Why is \( \text{NaCl}_2 \) not produced?
Information – Representing States of Matter

Chemists also need to know about the state of matter that the chemicals are in when the reaction takes place. The following is an example of how this is shown in a chemical equation.

\[ \text{KOH(s) + HNO}_3(\text{aq}) \rightarrow \text{H}_2\text{O(l) + KNO}_3(\text{aq}) \]

Each symbol in parentheses represents the state of matter that compound is in for the reaction. There are a variety of symbols you should be familiar with and they are found in Model 1. Not all of the symbols are used in every chemical equation, but you should recognize them when they are used.

Model 1 – Common Reaction Symbols

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Meaning(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\Delta)</td>
<td>Heat</td>
</tr>
<tr>
<td>(s)</td>
<td>Solid</td>
</tr>
<tr>
<td>(l)</td>
<td>Liquid</td>
</tr>
<tr>
<td>(g)</td>
<td>Gas</td>
</tr>
<tr>
<td>(aq)</td>
<td>Aqueous (dissolved in water)</td>
</tr>
<tr>
<td>↑</td>
<td>Gas given off</td>
</tr>
<tr>
<td>↓ or ppt</td>
<td>Precipitate (solid) is formed</td>
</tr>
</tbody>
</table>

Key Questions

3. Answer the following questions based on the chemical equation:
   \[ \text{Fe}_3\text{S}_3(\text{s}) + \text{HCl}(\text{g}) \rightarrow \text{FeCl}_3(\text{s}) + \text{H}_2\text{S}(\text{g}) \]
   a. What are the physical states of the reactants?

   b. What are the physical states of the products?

4. Write an unbalanced chemical equation for the reaction of gaseous methane (\(\text{CH}_4\)) with oxygen gas (\(\text{O}_2\)) to form carbon dioxide gas (\(\text{CO}_2\)) and liquid water (\(\text{H}_2\text{O}\)). (Hint: Make sure you include the physical states of each molecule)

5. What does the triangle above the arrow in the following equation tell you about the reaction?
   \[ \text{NaHCO}_3(\text{s}) \xrightarrow{\Delta} \text{Na}_2\text{CO}_3(\text{s}) + \text{CO}_2(\text{g}) + \text{H}_2\text{O}(\text{g}) \]
Information – Types of Reactions

Model 2 – Types of Reactions  (Note the Examples are not Balanced)

<table>
<thead>
<tr>
<th>Reaction Type</th>
<th>Characteristics</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Synthesis</td>
<td>Elements or simple compounds combine to form one more complex compound</td>
<td>( H_2 + O_2 \rightarrow H_2O )</td>
</tr>
<tr>
<td>Decomposition</td>
<td>One compound breaks into elements or less complex compounds</td>
<td>( H_2O \rightarrow H_2 + O_2 )</td>
</tr>
<tr>
<td>Combustion</td>
<td>Hydrocarbons (compounds made of C and H) react with oxygen to form carbon dioxide and water</td>
<td>( C_3H_8 + O_2 \rightarrow CO_2 + H_2O )</td>
</tr>
<tr>
<td>Single Displacement</td>
<td>A single element replaces another in a compound</td>
<td>( HCl + Zn \rightarrow ZnCl_2 + H_2 )</td>
</tr>
<tr>
<td>Double Displacement</td>
<td>The cation in one compound switches with the cation in another</td>
<td>( NaCl + KBr \rightarrow NaBr + KCl )</td>
</tr>
</tbody>
</table>

Key Questions

6. How are synthesis and decomposition reactions similar? Different?

7. How are single displacement and double displacement reactions similar? Different?

8. In the example reaction for double displacement (\( NaCl + KBr \rightarrow NaBr + KCl \)) why do you not form NaK as a product? (Hint: Think about charges and where the elements are found on the periodic table)

9. Identify the following types of reactions (reactions are not balanced)
   a. \( MgCl_2 + NaF \rightarrow NaCl + MgF_2 \)
   b. \( CuO + H_2 \rightarrow Cu + H_2O \)
   c. \( C_2H_4 + O_2 \rightarrow CO_2 + H_2O \)
   d. \( Al_2O_3 \rightarrow Al + O_2 \)
10. Fill in the missing parts of the following reactions and identify the type of reaction
   a. _______ + CaBr₂ → NaBr + Ca
   b. K + Cl₂ → _______
   c. K₂O + MgBr₂ → _______ + _______

**Information –Balancing Chemical Equations**

The *law of conservation of matter* states that matter is neither created nor destroyed only rearranged. All chemical equations must follow this law. Therefore, all the atoms on the reactants side of the equation must equal the atoms on the product side.

We balance chemical equations by adding *coefficients* in front of the compounds. *Coefficients* are whole numbers that tell us how many molecules of that compound are needed in the equation.

Remember, *subscripts* tell us how many of each atom are bound together to make a compound. Look back at information on bonding if you do not remember how to write a chemical formula using subscripts.

Here are some examples of coefficients versus subscripts:

3 H₂O  
The subscript 2 tells us that there are 2 hydrogen atoms for every oxygen atom  
The coefficient 3 tells us that there are 3 water molecules  
There are a total of 6 hydrogen atoms and 3 oxygen atoms in this expression

5 Mg(OH)₂  
The subscript 2 tells us that there are 2 hydroxide ions for every magnesium ion  
The coefficient 5 tells us that there are 5 magnesium hydroxide compounds  
There are a total of 5 magnesium ions, 10 oxygen atoms, and 10 hydrogen atoms in this expression

Now let’s look at the chemical equation for oxygen and hydrogen gas combining to form water:

H₂ + O₂ → H₂O

There are 2 hydrogen atoms and 2 oxygen atoms on the reactant side and 2 hydrogen atoms and 1 oxygen atom on the product side. This does not follow the law of conservation of matter! So, we must use coefficients to make the number of atoms on both sides of the equation equal.

H₂ + O₂ → 2 H₂O  
And 2 was placed in front of the water

Now there are 2 oxygen atoms on the reactant side and 2 oxygen atoms on the product side. There are now 2 hydrogen atoms on the reactant side and 4 hydrogen atoms on the product.
side. This still does not follow the law of conservation of matter; we need to add more coefficients.

\[ 2 \text{H}_2 + \text{O}_2 \rightarrow 2 \text{H}_2\text{O} \quad \Delta \text{A} \text{ was placed in front of the hydrogen} \]

There are still 2 oxygen atoms on the reactant side and 2 oxygen atoms on the product side. There are now 4 hydrogen atoms on the reactant side and 4 hydrogen atoms on the product side. Notice, when a coefficient of 1 is used we do not write the 1, it is assumed. This follows the law of conservation of matter and we are done balancing this equation!

Balancing equations is often a trial and error process. Keep trying and changing coefficients until you find a way that follows the law of conservation of matter. NEVER change the subscripts when balancing a chemical equation.

**Key Questions**

11. Balance each of the following chemical equations by filling in the coefficients.

   a. \( \underline{\quad} \text{CaCl}_2 + \underline{\quad} \text{Li}_2\text{O} \rightarrow \underline{\quad} \text{CaO} + \underline{\quad} \text{LiCl} \)
   
   b. \( \underline{\quad} \text{Al}_2\text{S}_3 + \underline{\quad} \text{Cu} \rightarrow \underline{\quad} \text{CuS} + \underline{\quad} \text{Al} \)
   
   c. \( \underline{\quad} \text{N}_2 + \underline{\quad} \text{H}_2 \rightarrow \underline{\quad} \text{NH}_3 \)

12. Complete and balance the following chemical equations. State the type of reaction for each equation.

   a. \( \text{HCl} + \quad \text{Mg} \rightarrow \quad \)
   
   b. \( \text{Na}_2\text{S} + \quad \text{Be(OH)}_2 \rightarrow \quad \)

   (Hint: the OH group has a negative one charge = OH⁻)

   c. \( \text{C}_2\text{H}_2 + \quad \text{O}_2 \rightarrow \quad \)

   d. \( \text{Al}_2\text{O}_3 \quad \Delta \rightarrow \quad \)

Types of Chemical Reactions

You have recently been informed about types of chemical reactions; now let’s explore some specific reactions for each type. If you do not remember the characteristics of synthesis, decomposition, combustion, single displacement and double displacement reactions go back and explore that information again.

There are a few characteristics that you can use to recognize that a chemical reaction has occurred. Some of these include; a change in temperature, emission of light, the formation of a solid from two liquids, formation of a gas and change in color.

There are two gases that you will make in this lab, hydrogen gas (H₂) and oxygen gas (O₂). Hydrogen gas is flammable and will make a popping sound when a flame gets near it. Oxygen gas supports combustion, so a splint that is glowing red hot will glow more brightly when in the presence of oxygen gas.

The charges of the ions you will need to write your products are: Fe³⁺, NO₃⁻, Ag⁺, OH⁻, SO₄²⁻ and Pb²⁺.

Procedures:

You will be writing balanced chemical equations for each reaction you conduct in the lab and determining the type of reaction. You will be given the reactants and you will need to predict what products you made.

Reaction 1:
1. Place a 1cm piece of magnesium metal into a 6-inch test tube.
2. Add 10 drops of 0.1 M Fe(NO₃)₃ (iron (III) nitrate solution) to the same test tube.
3. Record your observations.

Reaction 2:
1. Put 10 drops of 0.1 M AgNO₃ (silver nitrate solution) into a 6-inch test tube.
2. Add 10 drops of 6 M NaOH (sodium hydroxide solution) to the same test tube.
3. Record your observations.

Reaction 3:
1. Place a match-head size amount of zinc metal powder into a 4-inch test tube.
2. Add 2 mL of 6 M H₂SO₄ (sulfuric acid) to the same test tube. (CAUTION: This is a strong acid, handle carefully!)
3. Lightly cork the test tube.
4. Allow the reaction to proceed for 2 minute.
5. Light a wooden splint and carefully place the burning end just inside the top of the test tube, WITHOUT getting it wet or touching the chemicals.
6. Record your observations.
Reaction 4:
1. Pour 2 mL of 3% \( \text{H}_2\text{O}_2 \) (hydrogen peroxide) into a 4-inch test tube.
2. Add a match-head sized amount of catalyst \( \text{MnO}_2 \) (manganese (IV) oxide) to the same test tube. (This is a catalyst, NOT a reactant. It will not be included in the reactants for your chemical equation)
3. Gently cork the test tube.
4. Allow the reaction to proceed for 3-5 minutes.
5. Light a wooden splint and blow it out. While it is still glowing, quickly lower it into the opening of the test tube WITHOUT getting it wet or touching the chemicals.
6. Record your observations.

Reaction 5:
1. Put 5 drops of 0.1 M \( \text{Pb(NO}_3\text{)}_2 \) (lead (II) nitrate solution) into a 6-inch test tube.
2. Add 5 drops of 0.1 M \( \text{KI} \) (potassium iodide solution) to the same test tube.
3. Record your observations.

Reaction 6:
1. Place a 7 cm piece of magnesium metal in a crucible.
2. Determine the mass of the magnesium strip. (You should know the mass of the crucible, crucible with the Mg strip and the Mg strip)
3. Set up the crucible on a ring stand. See set up in Figure 1.
4. Take the piece of magnesium out of the crucible using a pair of crucible tongs. Put the magnesium in a Bunsen burner flame till it starts to burn. Drop the magnesium back in the crucible to finish burning. Be careful not to look too closely at the burning magnesium, its light is bright enough to be dangerous for the eyes.
5. After the magnesium has finished burning, let the material cool for several minutes.
6. Reweigh the crucible to determine the weight of the burnt magnesium.
7. Record your observations.

![Figure 1](source: Hek, R and Cunningham, J (1995). Hands On Chemistry: Laboratory techniques in the Classroom. New York: Center for Applied Research in Education)

Reaction 7:
1. Add 10 drops of ethanol (\( \text{C}_2\text{H}_5\text{OH} \)) to a DRY 250 mL Erlenmeyer flask.
2. Swirl the ethanol around in the flask to coat the sides.
3. Drop a lit match into the Erlenmeyer flask.
4. Record your observations. Notice anything left in the Erlenmeyer flask after the flame goes out.
5. Drop a second lit match into the Erlenmeyer.
6. Record your observations.
Questions:

1. Write a balanced chemical equation for each reaction. You will need to predict the
   products for each reaction, then balance. Include the states of matter after each
   compound/molecule.
   (Hints for writing equations:
   For reaction 4, the manganese dioxide is a catalyst, do NOT include this in your equation.
   Pay attention to the states of matter that you have, do you have a liquid left? What can
   that liquid be?
   For reaction 6, the magnesium is reacting with the oxygen in the air.
   For reaction 7, the ethanol is a hydrocarbon.)

2. State the reaction type for each reaction.

3. How did you determine if a chemical reaction took place?

4. Why did the mass in the crucible for reaction 6 increase after the reaction?

5. What was the liquid left in the Erlenmeyer flask in reaction 7?

6. Why did the second lit match in reaction 7 not stay lit?
Acid-Base Properties Guided Inquiry Activity

Properties of Acids and Bases

Why?

Acids and bases are around you every day, from cleaning products to the foods you eat. Many health and environmental issues deal with acids and bases, such as blood acidity and acid rain. Many chemical reactions can be explained using acid-base terms.

Learning Objectives

- Identify characteristics of acids and bases
- Determine strong or weak acids and bases

Success Criterion

- Recognize acids and bases from the molecular formula
- Write and label acid-base reactions
- State the difference between strong and weak acids and bases

Prerequisite Knowledge

- Chemical Equations
- Molarity

Information – Acids and Bases

An acid is defined as a chemical that donates a proton (H⁺) to another chemical. Some characteristics of acids include turning neutral litmus paper red, tasting sour, and reacting with metals such as zinc (Zn) and iron (Fe) to produce hydrogen gas (H₂). Remember do not taste chemicals in the lab!

A base is defined as a chemical that accepts a proton from another chemical. A base can also be defined as a chemical that produces hydroxide ions (OH⁻) in water. Some characteristics of bases include turning neutral litmus paper blue, tasting bitter, and feeling slippery on the skin. Remember do not touch chemicals in the lab without being instructed to do so!

Notice in Model 1, example 1 that on the product side of the reaction the chlorine is written as Cl⁻ and not Cl₂. This is because the chlorine is not in its neutral state but in its anionic state. (If you do not recall what an anion is review Types and Properties of Chemical Bonds.) Since it is not neutral, it is not written as a diatomic molecule.

Also notice that the negative charge on the chloride ion is balanced by the positive charge on the ammonium ion (NH₄⁺). The positive and negative charges of the two ions balance out and make the product side neutral. Notice in all of the examples the positive ions and the negative ions
cancel each other out. This will always happen when two neutral reactants are reacted in an acid-base reaction.

Model 1: Acid-Base reactions

1. $\text{HCl(aq)} + \text{NH}_3(\text{aq}) \rightarrow \text{Cl}^- (\text{aq}) + \text{NH}_4^+(\text{aq})$
   Acid     Base

2. $\text{HNO}_3(\text{aq}) + \text{H}_2\text{O(l)} \rightarrow \text{H}_2\text{O}^+(\text{aq}) + \text{NO}_3^- (\text{aq})$

3. $\text{NH}_3(\text{aq}) + \text{H}_2\text{O(l)} \rightarrow \text{NH}_4^+(\text{aq}) + \text{OH}^- (\text{aq})$

4. $\text{H}_3\text{PO}_4(\text{aq}) + \text{H}_2\text{O(l)} \rightarrow \text{H}_2\text{PO}_4^-(\text{aq}) + \text{H}_3\text{O}^+(\text{aq})$
   $s$ = solid, $aq$ = aqueous, $l$ = liquid

Key Questions

1. In Model 1, label each reactant as an acid or a base as demonstrated in the first reaction.

2. How did you determine which reactant was an acid and which reactant was a base?

3. How does losing an $\text{H}^+$ change the charge on the compound?

4. How does gaining an $\text{H}^+$ change the charge on the compound?

5. Toilet bowl cleaner feels slippery to the touch and turns neutral litmus paper blue. Does this product contain an acid or a base?

6. In Model 1, are there any compounds that act as both an acid and a base? Explain how this can or cannot occur.

7. Would you call potassium hydroxide ($\text{KOH}$) and acid or a base? Why? (Hint: Potassium hydroxide ionizes in water to give $\text{K}^+(\text{aq})$ and $\text{OH}^- (\text{aq})$)
8. Write a balanced chemical equation for the acid-base reaction of NH$_3$ with HBr. Identify the acid and the base on the reactant side.

9. Give an example of an acid and a base that you have used in your daily life.

Information – Conjugate Acid-Base Pairs

A chemical that can act as both an acid and base is called amphoteric. Water is an amphoteric compound that can either donate a proton (acid) and form OH$^-$ or accept a proton (base) and form H$_2$O$^+$. A pair of chemicals that differ only by a proton is called a conjugate acid-base pair. An example would be HCl and Cl$^-$ from reaction 1 in Model 1. HCl was determined to be an acid because it donates a proton; if the reaction is reversed Cl$^-$ can accept a proton so it is a base. Another example is NH$_3$(base) and NH$_4^+$ (acid) from reaction 1 in Model 1.

When labeling reactions, the reactants are labeled as acids and bases and the products are labeled as conjugate acids and conjugate bases. Look for conjugate acid-base pairs to label the products correctly. Let’s look at reaction 1 again:

\[
\text{HCl(aq)} + \text{NH}_3(\text{aq}) \rightarrow \text{Cl}^- (\text{aq}) + \text{NH}_4^+ (\text{aq})
\]

Acid Base

We can now label Cl$^-$ as the conjugate base (it can accept a proton if the reaction was reversed) and NH$_4^+$ as the conjugate acid (it can donate a proton if the reaction was reversed):

\[
\text{HCl(aq)} + \text{NH}_3(\text{aq}) \rightarrow \text{Cl}^- (\text{aq}) \quad + \quad \text{NH}_4^+ (\text{aq})
\]

Acid Base Conjugate Base Conjugate Acid

Key Questions

10. In Model 1, label each product as a conjugate acid or a conjugate base as demonstrated in the above example.

11. In Model 1, circle any amphoteric compounds.

12. Write the conjugate base of HCN.

13. Write the conjugate base of H$_2$SO$_4$.

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14. Write the conjugate acid of $F^-$. 

15. Write the conjugate acid of $\text{HCO}_3^-$. 

16. Write a balanced chemical equation for the acid-base reaction of $\text{H}_2\text{O}$ with $\text{HBr}$. Label the acid, base, conjugate acid and conjugate base. 

**Information – Strong and Weak Acids and Bases**

Acids and bases are often identified as being strong or weak. A strong acid or base completely ionizes in water. An example would be $\text{HCl}$ for an acid and $\text{NaOH}$ for a base. In the solution of $\text{HCl}$, there is very little $\text{HCl}$ and mainly $\text{H}_2\text{O}^+$ and $\text{Cl}^-$. We can also say that if 1.0 mole of $\text{HCl}$ is added to 1.0 L of water, in solution there would be 1.0 mole of $\text{H}_2\text{O}^+$ or the concentration of $\text{H}_2\text{O}^+$ would be 1.0 M. (Remember: molarity is calculated by moles of compound per liter of solution; $M = \text{mol} / L$)

Notice that in the reaction below, complete ionization is shown by the single arrow to show that only the products are found in the solution.

$$\text{HCl(aq)} + \text{H}_2\text{O(l)} \rightarrow \text{H}_2\text{O}^+(aq) + \text{Cl}^-(aq)$$

A weak acid or base only partially ionizes in water. An example would be $\text{HCN}$ for an acid and $\text{NH}_3$ for a base. In a solution of $\text{NH}_3$, there would be $\text{NH}_3$ and $\text{NH}_3^+$ and $\text{OH}^-$. Notice that in the reaction below, a partial ionization is shown by the two arrows to show that both the reactants and the products are found in the solution.

$$\text{NH}_3(aq) + \text{H}_2\text{O(l)} \rightleftharpoons \text{NH}_4^+(aq) + \text{OH}^-(aq)$$

Some common strong acids are hydrochloric acid ($\text{HCl}$), sulfuric acid ($\text{H}_2\text{SO}_4$), and nitric acid ($\text{HNO}_3$). Some common strong bases are sodium hydroxide ($\text{NaOH}$), potassium hydroxide ($\text{KOH}$), and lithium hydroxide ($\text{LiOH}$). There is a list of strong and weak acids and bases on pages 174-175 in your text.

Acids and bases can also be classified as electrolytes. Electrolytes are compounds that produce ions in solution; the solution can then conduct electricity. Some examples of electrolytes are $\text{NaCl}$, $\text{HCl}$, $\text{NaOH}$, and $\text{MgCl}_2$ because each of these will dissociate when dissolved in water.

Strong acids and bases are considered strong electrolytes, because they dissociate completely and will conduct more electricity. Weak acids and bases are considered weak electrolytes, because they only partially dissociate and conduct less electricity. A nonelectrolyte is a substance that does not dissociate in water and will not conduct electricity.
Key Question

17. What is the difference between a strong acid and a weak acid?

18. List two common strong acids and two common strong bases.

19. Which solution will have a higher concentration of $\text{H}_3\text{O}^+$, 1.0 M HCl or 1.0 M HNO$_2$? Why?

20. Label each as a strong, weak or non-electrolyte.
   a. HNO$_3$
   b. NaOH
   c. CH$_3$COOH (acetic acid)

Acid-Base Properties Laboratory

Properties of Acids and Bases

You have recently been informed about characteristics of acids and bases; now let’s actually explore some of those characteristics. If you do not remember the definitions of acids and bases go back and explore that information again.

To determine if something is an acid or a base we can use an indicator or litmus paper or the pH of the solution. An indicator is chemical that changes color based on the acidity or basicity of the solution it is in. The indicator you will use in this lab is phenolphthalein.

We have not yet discussed pH, but it is a scale that states how acidic or basic a solution is. We will talk more about pH in the next lab, for now record the values and answer the questions at the end of the lab on pH.

Procedures:

1. Clean and rinse a well plate with distilled water. Shake excess water out of the wells and dry.
2. Fill each well ⅔ full with a different solution to be tested. Make sure you know what solution is in each well. The solutions to be tested are 0.1 M HCl, 0.1 M NaOH, Tap water, Vinegar, Ammonia, Baking soda, Lemon juice, Salt solution, Sugar solution, Milk, and Windex.
3. Dip the tip of a stirring rod in the 0.1 M HCl. Touch the tip to a small piece of blue litmus paper. Record the color of the paper. Repeat for each solution making sure to clean the stirring rod between solutions.
4. Repeat step 3 for red litmus paper.
5. Repeat step 4 with pH paper, record the color of the paper and the pH value it represents.
6. Add one drop of phenolphthalein to the solution in each well. Record the color.
7. Clean and rinse the well plate with distilled water.
8. Again, fill each well ⅔ full with a different solution to be tested. Make sure you know what solution is in each well.
9. To each well plate add a small piece (0.5 cm) of magnesium ribbon. Record any observations.
10. To test the conductivity, you will be using the LabQuest® handheld and Vernier® Conductivity Probe. There will be pre-made solutions in test tubes for you to use.
   a. Make sure the hand held is on and set to 0-20000 on the probe.
   b. Rinse probe with deionized water.
   c. Put probe in test tube containing the first sample and record the reading on the screen.
   d. Repeat steps 3 & 4 for each sample. Make sure you rinse the probe between each sample.
   e. Describe each sample as strong, weak or non-electrolyte.
Questions:

1. What are the pH ranges of acids, bases and neutral solutions?

2. What color is phenolphthalein in acids? in bases? in neutral solutions?

3. Can an indicator tell you the exact pH of a solution? Why or why not?

4. Can litmus paper tell you the exact pH of a solution? Why or why not?

5. What type of solution (acidic, basic or neutral) reacted with the magnesium metal?

6. What type of solution (strong, weak or non-electrolyte) reacted faster with the magnesium metal?

7. Compare the pH values of strong versus weak acid and strong versus weak base solutions. How does pH vary with the “strength” of an acid or base, respectively?
pH and Neutralization Guided Inquiry Activity

pH and Neutralization Reactions

Why?

Many chemical reactions can be explained using acid-base terms. A pH value can help you determine how much acid or base is in a solution. The pH of pool water is checked to determine if it is safe to swim in. When we have an upset stomach, our stomach has too much acid in it and we often take antacids to neutralize the excess acid. The reaction taking place is a neutralization reaction. You will discover in the following material what a pH value is and what neutralization reactions are.

Learning Objectives

- Use the pH scale and interpret its meaning
- Identify and quantify the neutralization of an acid or a base

Success Criterion

- Interconvert values between hydronium ions and pH
- Calculate molarity or amount needed to neutralize an acid or a base

Prerequisite Knowledge

- Chemical Equations
- Molarity

Information - pH

The concentration of an acidic or basic solution is calculated by the concentration of the \( \text{H}^+ \) and \( \text{OH}^- \) ions in the solution, respectively. Since hydrochloric acid is a strong acid, a one molar solution (1 M HCl) contains 1 mole of \( \text{H}^+ \) ions per liter of solution. (Remember: strong means it dissociates 100% in water and molarity is calculated by moles of compound per liter of solution; \( M = \text{mol/L} \))

How acidic or basic a solution is, is represented by the pH scale. When calculating pH, the hydronium ion (\( \text{H}_3\text{O}^+ \)) concentration is used. To calculate pH the following formula is used: (Remember: [\( \text{H}_3\text{O}^+ \)] means the concentration of \( \text{H}_3\text{O}^+ \), the brackets represent concentration of what is inside the brackets, and \( \text{H}_3\text{O}^+ \) would also be the same as \( \text{H}^+ \) ions)

\[
\text{pH} = -\log[\text{H}_3\text{O}^+]
\]

This equation states that the pH is equal to the negative log of the concentration of hydronium ions in the solution.
Model 1 – pH Conversions

<table>
<thead>
<tr>
<th>Solution</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>$[\text{H}_3\text{O}^+]$</td>
<td>0.00035</td>
<td>0.0024</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$[\text{H}_3\text{O}^+]$ in scientific notation</td>
<td>$3.5\times10^{-4}$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pH formula</td>
<td>–log($3.5\times10^{-4}$)</td>
<td>–log($2.4\times10^{-3}$)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td>3.46</td>
<td></td>
<td>10.51</td>
<td></td>
</tr>
<tr>
<td>Power formula</td>
<td>$10^{-3.46}$</td>
<td></td>
<td></td>
<td>$10^{-6.24}$</td>
</tr>
</tbody>
</table>

Key Questions

1. Fill in the missing values in the Model 1 table. (Hint: plug all formulas in the first row into your calculator, see how all columns are related before trying to fill in the table)

2. According to Model 1, if you are given a hydronium ion concentration ($[\text{H}_3\text{O}^+]$) how do you calculate the pH? (Hint: you can write a formula)

3. According to Model 1, if you are given the pH how do you calculate the hydronium ion concentration ($[\text{H}_3\text{O}^+]$)? (Hint: you can write a formula)

4. The pH scale ranges from 0 – 14. Give the values for the hydronium ion concentration ($[\text{H}_3\text{O}^+]$) that this scale covers? (Hint: what is the concentration at pH = 0 and what is the concentration at pH = 14)

5. Which value on the pH scale has a higher hydronium ion concentration ($[\text{H}_3\text{O}^+]$)?

6. Give a reason why you think the pH scale is used more than the concentration of hydronium ions when discussing the acidity or basicity of a solution?

7. What is the difference between a strong acid and a concentrated acidic solution? (Look in Properties of Acids and Bases if you forget what a strong acid is)
Information – Autoionization

At 25°C, water undergoes autoionization by the following reaction

\[ \text{H}_2\text{O} + \text{H}_2\text{O} \rightarrow \text{H}_3\text{O}^+ + \text{OH}^- \]

The concentration of hydronium ions (\(\text{H}_3\text{O}^+\)) is \(10^{-7}\)M and the concentration of hydroxide ions (\(\text{OH}^-\)) is \(10^{-7}\)M. Since the two values are equal, pure water is said to be neutral. If the concentration of hydronium ions (\(\text{H}_3\text{O}^+\)) increases the solution becomes acidic, and if the hydroxide ion concentration (\([\text{OH}^-]\)) increases the solution is said to be basic.

Key Questions

8. What is the pH of a neutral sample of pure water that has \([\text{H}_3\text{O}^+] = 10^{-7}\)M?

9. If a solution has a pH less than 7, is the hydronium ion concentration (\([\text{H}_3\text{O}^+]\)) higher or lower than that of a neutral solution? Is this solution acidic or basic?

10. What would you expect the pH range of a basic solution to be?

11. What does the pH value represent?

12. Lemon juice has a pH of 2.1. Calculate the hydronium ion concentration. Is this solution acidic, basic or neutral?

13. A solution has a hydronium ion concentration of \(3.1 \times 10^{-9}\) M, what is the pH of this solution? Is the solution acidic, basic or neutral?

14. If a solution is neutral, what is the hydronium ion concentration? What is the hydroxide ion concentration?

15. If a solution is acidic, how does the hydronium ion concentration relate to the hydroxide ion concentration?
Information – Neutralization Reactions

When an acidic and a basic solution are mixed together they produce water and a salt. A salt is a general term for any ionic compound produced during this type of reaction not just table salt (NaCl). Look at the following example:

\[ \text{HNO}_3(aq) + \text{NaOH}(aq) \rightarrow \text{H}_2\text{O}(l) + \text{NaNO}_3(aq) \]

The sodium nitrate (NaNO₃) is the salt in this acid-base reaction. This type of reaction is called a neutralization reaction.

If equal moles of H⁺ ions (the acid) are combined with equal moles of OH⁻ ions (the base) the final solution will be neutral. For the above equation, 1 mole of HNO₃ is needed to neutralize 1 mole of NaOH.

When mixing an acid and a base to reach the neutralization point, a titration is often used. A titration is the process of mixing two solutions until the reaction between them is complete. The point where the reaction is complete is called the end point. To determine the end point of a titration, an indicator is used. An indicator changes color when a certain pH is reached in the reaction. An example of an indicator is phenolphthalein.

To determine the amount of base needed to neutralize a specific amount of acid, the following formula can be used:

\[ [\text{H}^+] \times V_A = [\text{OH}^-] \times V_B \]

Where \([\text{H}^+]\) represents the concentration of hydrogen ions (molarity unit – M), \([\text{OH}^-]\) represents the concentration of hydroxide ions (units of M), \(V\) represents volume (liters unit – L), \(A\) represents the acid, and \(B\) represents the base. If the volume and concentration of the acid are known and the concentration of the base is known, one can calculate the volume of the base needed to neutralize the acid. Remember at the neutralization point, the moles of acid equal the moles of base.

Here is an example:

If you have 25 mL of a 0.25 M HCl solution, how much of a 0.50 M NaOH solution would you need to neutralize it?

\[ [\text{H}^+] = 0.25 \text{ M} \quad \text{because HCl is a strong acid and dissociates completely} \]
\[ [\text{OH}^-] = 0.50 \quad \text{because NaOH is a strong base and dissociates completely} \]

\[ [\text{H}^+] \times V_A = [\text{OH}^-] \times V_B \]

\[ 0.25 \text{M} \times 0.025 \text{L} = 0.50 \text{M} \times V_B \]

\[ \frac{0.25 \text{M} \times 0.025 \text{L}}{0.50 \text{M}} = V_B \]

\[ 0.0125 \text{L} = V_B = 12.5 \text{mL} \]
Therefore, it would take 12.5 mL of a 0.50 M NaOH solution to neutralize 25 mL of a 0.25 M HCl solution.

This same formula \([H^+] \times V_a = [OH^-] \times V_b\) can be rearranged to solve for other variables. Just remember to watch your units.

**Key Questions**

16. Label the acid, base, salt and water in the following equation.

\[
\text{HBr(aq)} + \text{KOH(aq)} \rightarrow \text{KBr(aq)} + \text{H}_2\text{O(l)}
\]

17. Write the neutralization reaction for HI and LiOH. Label the acid, base, salt and water.

18. How much of a 0.75 M KOH solution would be needed to neutralize 55 mL of a 1.0 M HBr solution?

19. It took 30 mL of a NaOH solution to neutralize 25 mL of a 0.40 M HCl solution, what is the concentration of the basic solution?

20. Write the neutralization reaction for HCl with Ca(OH)_2. (Hint: make sure this is a balanced equation.

21. For the equation in question 20, how many moles of Ca(OH)_2 would be needed to neutralize 4 moles of HCl?

Neutralization Reactions

We have recently discussed the reaction of acids and bases. In the following lab you will be using the neutralization reaction to determine the concentration of an acid.

To determine concentration, you will be using the technique of titration. A titration is the process of mixing two solutions until the reaction between them is complete. The point where the reaction is complete is called the end point. You will be mixing an acid and a base together until the final solution is neutral. To determine the end point of a titration, an indicator is used. You will again be using phenolphthalein as an indicator; make sure you know what color change you will be looking for to determine when you reach the end point!

You will also be using a buret in this experiment. A buret is a piece of glassware that accurately dispenses a liquid. The markings on the buret are accurate to tenths place and you can estimate to the hundredths place (0.01), so make sure you are using enough significant figures. Your TA will show you proper use of the buret; make sure you understand how to use the piece of glassware properly before you start.

Remember, molarity is used when talking about the concentration of a solution. The following is the formula for molarity (M):

Both the acid and the base used in the experiment are strong; make sure you review what this term means.

Part 1: Simple Titration

Procedures:

1. Clean and rinse with distilled water a 250 mL Erlenmeyer flask and a 25 mL buret.
2. Add 20.0 mL of 0.1 M HCl to the Erlenmeyer flask.
3. Check and record the pH of the solution using pH paper.
4. Add 2-3 drops of phenolphthalein to the Erlenmeyer flask.
5. Fill the buret with 0.1 M NaOH. Remove any air bubbles from the tip by letting a few milliliters of liquid run out the tip into a waste beaker.
6. Record the initial volume in the buret.
7. Slowly add the NaOH to the HCl, using the buret, to neutralize the solution. See Figure 1 for the set-up.
8. Once you have reached the endpoint, check to make sure the solution is neutral using pH paper. If solution is still acidic continue adding NaOH. If your solution is highly basic, repeat the whole procedure.
9. Record the final volume of NaOH remaining in the buret.
10. Place 5 mL of the neutralized solution in a crucible.
11. Carefully boil off the liquid until the dish is dry. See Figure 2 for the set-up.
12. Repeat steps 2-9 again.
<table>
<thead>
<tr>
<th></th>
<th>Trial 1</th>
<th>Trial 2</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume of HCl in flask</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moles of $\text{H}_2\text{O}^-$ (moles of HCl)</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>pH of HCl</td>
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<td></td>
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</tr>
<tr>
<td>Initial volume of NaOH in buret</td>
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</tr>
<tr>
<td>Final volume of NaOH in buret</td>
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<td></td>
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</tr>
<tr>
<td>Volume of NaOH added to neutralize acid</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moles of OH$^-$ (moles of NaOH)</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Difference in moles of $\text{H}_2\text{O}^+$ &amp; OH$^-$</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>pH of neutralized solution</td>
<td></td>
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</tbody>
</table>

Part II: Determining the Concentration of an Unknown Acid

Procedures:

1. Clean and rinse with distilled water a 250 mL Erlenmeyer flask and a 25 mL buret.
2. Add 20.0 mL of HCl with unknown molarity to the Erlenmeyer flask.
3. Add 2-3 drops of phenolphthalein to the Erlenmeyer flask.
4. Fill the buret with 0.1 M NaOH. Remove any air bubbles from the tip by letting a few milliliters of liquid run out the tip into a waste beaker.
5. Record the initial volume in the buret.
6. Slowly add the NaOH to the HCl, using the buret, to neutralize the solution.
7. Once you have reached the endpoint, check to make sure the solution is neutral using pH paper. If solution is still acidic continue adding NaOH. If your solution is highly basic, repeat the whole procedure.
8. Record the final volume of NaOH remaining in the buret.
9. Repeat steps 2-8 again.

<table>
<thead>
<tr>
<th></th>
<th>Trial 1</th>
<th>Trial 2</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume of HCl in flask</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial volume of NaOH in buret</td>
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<tr>
<td>Final volume of NaOH in buret</td>
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<tr>
<td>Volume of NaOH added to neutralize acid</td>
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<tr>
<td>Moles of OH⁻ (moles of NaOH)</td>
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<tr>
<td>pH of neutralized solution</td>
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<td></td>
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<tr>
<td>Moles of H⁺</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Molarity of HCl solution</td>
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</table>
Questions:

1. Write the reaction for HCl and NaOH. Label the acid, base, conjugate acid, conjugate base, salt, and water. (Hint: some molecules will be labeled more than once)

2. In part I, what was the liquid you boiled away from the neutralized solution? What were the crystals that were left in the dish after the liquid had been boiled off?

3. Milk of magnesia is an antacid containing magnesium hydroxide, which is used to settle sour (acid) stomachs. Write an equation to show how the active ingredient (Mg(OH)₂) neutralizes excess hydrochloric acid (HCl). (Hint: make sure your equation is balanced)

4. If you have 4 moles of HCl how many moles of Mg(OH)₂ will you need to neutralize the acid?

5. What was the molarity of the unknown HCl solution in part II?

6. How would the calculation of the unknown acid concentration be affected if the final solution after the titration was slightly basic? Be specific. Would the calculated concentration be higher, lower or the same and why.
## APPENDIX H

### BONDING “FOLLOW-UP” WORKSHEET

#### Properties of Chemical Bonds

<table>
<thead>
<tr>
<th></th>
<th>Ionic</th>
<th>Covalent</th>
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</thead>
<tbody>
<tr>
<td>Bond Formation</td>
<td></td>
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<tr>
<td>Elements Involved</td>
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<tr>
<td>Physical State</td>
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<tr>
<td>Melting/Boiling Point</td>
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<tr>
<td>Solubility in Water</td>
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<tr>
<td>Solubility in Cyclohexane</td>
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<tr>
<td>Electrical Conductivity</td>
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<tr>
<td>Other Properties</td>
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<tr>
<td>Example</td>
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</tbody>
</table>

What are the two types of Covalent bonds? What are the differences between them?
APPENDIX I

INTERVIEW PROTOCOL

*Effectiveness of Guided Inquiry on Non-Science Majors Comprehension of Chemistry Content*

Interview Questions
Spring 2010

I. General Background

1. [Introduction by interviewer, purpose of the interview is to (1) assess student’s understanding of chemical concepts; (2) investigate student attitudes about the inquiry activities used in the class. Paper and pencils, periodic tables, list of math formulas and calculators will be available during the interview to all students interviewed. Standard reassurances about anonymity, effect on grades.]

Examples of Prompts:
That’s interesting. Tell me more about XXX.
You used the term XXX. In your own words, what does XXX mean to you?
[Try to introduce questions with “in your mind”, “in your opinion”, etc. to indicate that you are not fishing for a single correct answer.]

II. General Discussion of Guided Inquiry Activities

2. I would like your thoughts on the POGIL (Process Oriented Guided Inquiry Learning) Activities you completed during the lecture portion of your class. Possible probes:
   - Your comments were mostly positive. Do you have any negative comments?
   - Your comments were mostly negative. Do you have any positive comments?
3. I would like your thoughts on the Guided Inquiry Lab you completed during the lab portion of your class.

   Possible probes:
   - Your comments were mostly positive. Do you have any negative comments?
   - Your comments were mostly negative. Do you have any positive comments?

III. Discussion of Chemistry Topics

4. Selected questions used on the topic post assessments will be re-asked during the interview. Probing questions will also be added to address the students thought process on how they determined the answer and their understanding of the concepts.

   Possible probes:
   - You answered XXX, how did you come to that answer?
   - You answered XXX, why do you think that is the correct answer?
   - For math related questions: Why did you choose that formula?

Examples of Questions:
- What charge does the calcium ion have?
- Describe the formation of an ionic bond in terms of the electrons.
- What type of bond is present in a substance that has the following properties: electrons shared between two non-metals, can be a solid, liquid or gas at room temperature, has a low melting or boiling point, and is usually soft?
- How do you determine if a covalent bond is polar or nonpolar?
- State the type of chemical equation for the following reaction.
  \[ \text{Mg} + \text{Ca}_3(\text{PO}_4)_2 \rightarrow \text{Mg}_3(\text{PO}_4)_2 + \text{Ca} \]
- List the reactants in the following reaction.
  \[ \text{Mg} + \text{Ca}_3(\text{PO}_4)_2 \rightarrow \text{Mg}_3(\text{PO}_4)_2 + \text{Ca} \]
- What does the triangle mean above the arrow in the following equation?
  \[ 2\text{CH}_3\text{OH}(l) + 3\text{O}_2(g) \xrightarrow{\Delta} 2\text{CO}_2 \uparrow + 4\text{H}_2\text{O}(l) \]
- Balance the following chemical equation.
  \[ \underline{\_\_\_\_} \text{Al} + \underline{\_\_\_\_} \text{H}_2\text{SO}_4 \rightarrow \underline{\_\_\_\_} \text{Al}_2(\text{SO}_4)_3 + \underline{\_\_\_\_} \text{H}_2 \]
- What is the pH range for acids?
- In the following reaction label the base and the conjugate acid.
  \[ \text{H}_3\text{PO}_4(\text{aq}) + \text{H}_2\text{O} \rightarrow \text{H}_2\text{PO}_4^- (\text{aq}) + \text{H}_3\text{O}^+(\text{aq}) \]
- What is the pH of a solution that contains 3.2×10^{-7}M hydronium ions? (Show work)
- How many moles of sodium hydroxide (NaOH) would be needed to neutralize 2.0 moles of hydrochloric acid (HCl)?
IV. Closure

5. What grade do you expect to get in your Chemistry for Everyone class this semester?

6. Are there any other comments you would like to make about the activities, labs or lectures pertaining to the questions you have answered?

7. Are there any questions you would like me to answer?
   Thanks very much!!
INTERVIEW CODING SCHEMES

Codes for Interview Content Questions

Question 1: What charge does the calcium ion have?

Answer RED
1. Correct – Charge plus two
2. Wrong – Minus two
3. Wrong – Any other value
4. Don’t know/No answer given

Why GREEN
1. Don’t know
2. Because of the location on the periodic table
3. Looses two valence electrons
4. Because of electrons it has due to its location on the periodic table

How charge describes electrons BLUE
1. There are 2 electrons in outer shell
2. It has lost 2 electrons
3. It has gained 2 electrons
4. Don’t know
Question 2: Can you describe the formation of an ionic bond in terms of the electrons?

Answer RED
1. Don’t know
2. Wrong – Ions bonding
3. Correct – Electrons transfer and bonds form
4. Wrong – Change in element (charge, attracted to another, polar/nonpolar)
5. Wrong – Type of elements involved (metals, nonmetal)
6. Wrong – Share electrons

What term ion means BLUE
1. Elements have a positive or negative charge
2. Bond
3. In solution
4. Only one charge for ion either positive or negative not both
5. Don’t know

Question 3: Given the list of properties state the type of bonding present: electrons shared between two non-metals, it can be a solid, liquid or gas at room temperature, it has low melting and boiling points, and it is usually soft.

Answer RED
1. Correct – Covalent bond
2. Wrong – Any other answer
3. Don’t know/No answer given

Why GREEN
1. Don’t know/memorized
2. Electrons sharing and/or two non-metals
3. Low melting/boiling point, weak bond
4. All properties, nothing specific stands out
Question 4: How do you determine if a covalent bond is polar or non-polar?

Answer RED

1. Don't know
2. Wrong – Symmetrical – polar
3. Wrong – Non-symmetrical – polar
4. Wrong – Solubility in water – non-polar is soluble
5. Wrong – Symmetry of molecule but no designation of type of bond
6. Wrong – Positives and negatives come together/molecule balances out
7. Correct – Do not share electrons equally would be polar

What term polar/polarity means BLUE

1. Don't know
2. Shape
3. Solubility in water
4. Polar is positive, non-polar is negative
5. Pluses and minuses line up
6. Things are together if polar, non-polar farther away

Question 5: State the type of reaction for Mg + Ca₃(PO₄)₂ → Mg₃(PO₄)₂ + Ca

Answer RED

1. Correct – Single displacement
2. Wrong – Any other answer
3. Don't know/No Answer given

Why GREEN

1. Mg/Ca switch
2. PO₄ switches, goes with the other element
3. Compound and element on both sides
4. Ca give up electrons to magnesium
5. Switch occurs and something is left by itself
6. Change in subscripts for Mg or Ca

Question 6: Name the reactants for Mg + Ca₃(PO₄)₂ → Mg₃(PO₄)₂ + Ca

Answer RED

1. Correct – Mg and Ca₃(PO₄)₂
2. Wrong – Right side / Mg₃(PO₄)₂ and Ca
3. Wrong – Only listed one element or molecule as a single reactant
4. Wrong – only stated elements involved (Mg, Ca and PO₄)
Question 7: What does the triangle represent in

\[ 2\text{CH}_3\text{OH(l)} + 3\text{O}_2(g) \xrightarrow{\Delta} 2\text{CO}_2 \uparrow + 4\text{H}_2\text{O(l)} \]

Answer RED
1. Correct – Add heat
2. Correct – Heat used to cause reaction
3. Wrong – Heat transfers
4. Wrong – Solid

Question 8: Balance the equation \( \text{Al} + \text{H}_2\text{SO}_4 \rightarrow \text{Al}_2(\text{SO}_4)_3 + \text{H}_2 \)

Answer RED
1. Correct – \( 2\text{Al} + 3\text{H}_2\text{SO}_4 \rightarrow \text{Al}_2(\text{SO}_4)_3 + 3\text{H}_2 \)
2. Wrong – Any other coefficients that can simplify to get correct
3. Wrong – Any other coefficients that cannot simplify to get correct
4. Don’t know how/Can’t balance

How balance GREEN

What does balancing mean BLUE
1. Make equal
2. Same amount/number elements
3. Same moles
4. Same electrons
5. Same charges on each side

Question 9: What is the pH range for acids?

Answer RED
1. Correct – 0/1 to 6/6.9
2. Correct – 0 to 7
3. Wrong – Any other values
4. Don’t know/No answer given

What do the number represent GREEN
1. Don’t know
2. Low number more acidic
3. Acidity
4. Examples of acids or pH paper colors given
5. Concentration of H\(^+\) ions
6. How dangerous – lower number more dangerous
7. Organic or inorganic

265
Term acidic and basic mean BLUE
1. Don’t know
2. Break things down
3. Concentration of acid
4. Examples or properties given
5. They neutralize each other
6. How it reacts with other things
7. Dangerous

Question 10: Label the base and the conjugate acid in
\[ H_2O + H_3PO_4 \rightarrow H_3O^+ + H_2PO_4^- \]

Answer RED
1. Correct – Base is H_2O and Conjugate acid is H_3O^+
2. Base correct (H_2O) but Conjugate acid wrong
3. Base wrong but conjugate acid correct (H_3O^+)
4. Both wrong and not conjugates of each other
5. Don’t know/No answer given
6. Both wrong but conjugates of each other

Why GREEN
1. Base accepts H^+, reverse reaction the molecule formed gives up the H^+
2. H_2O is a base, guess on the conjugate
3. Gain or lose electron (either acid or base)
4. If it is an acid on one side it is a base on the other
5. Acids gain protons, since H_3PO_4 is the acid H_2O has to be the base

Question 11: Calculate the pH of a solution that contains \(3.2 \times 10^{-7}\) M hydronium ions.

Answer RED
1. Correct – 6.49
2. Wrong – –6.49
3. Wrong – any other value
4. Don’t know/No answer given

Equation used GREEN
1. \[ \text{pH} = -\log[H_3O^+] \]
2. \[ 10^{-\text{pH}} = [H_3O^+] \]
3. Just take the value out of scientific notation/No equation
Question 12: How many moles of sodium hydroxide would be needed to neutralize 2 moles of hydrochloric acid?

Answer RED
1. Correct – 2 moles
2. Wrong – Any other value
3. Don’t know/No answer given
4. Wrong on first attempt, but correct after created a balanced chemical equation

Why GREEN
1. Don’t know/Guess
2. Ratio of 1:1
3. Calculated molar mass of each and tried to make equal
4. Went through stoichiometry using molar masses as grams
5. From chemical equation using 2 as coefficient

Balanced chemical equation BLUE
1. NaOH + HCl → H₂O + NaCl
2. 2 NaOH + 2 HCl → 2 H₂O + 2 NaCl
3. Wrong – any other form of an equation
4. No real equation

Term neutralize means ORANGE
1. Watered down
2. Making balanced
3. Make less acidic
4. Makes pH equal to 7/not acidic or basic
5. H⁺ and OH⁻ are equal
6. Elements no longer react
7. Mix an acid and a base
Codes for Interview Attitudinal Questions

YELLOW  Previous knowledge of material
LIGHT PURPLE  Things students found helpful
DARK PURPLE  Things students did not find helpful
BROWN  Comments on working in group
LIGHT GREEN  Things students liked
DARK GREEN  Things students did not like
PINK  How much of activity was completed/comments on time
LIGHT BLUE  Things students found easy
DARK BLUE  Things students found hard
ORANGE  Comments on lab/lecture/packet overlap
RED  Changes student would make to activity/lab
BLACK  Student preference to lecture or activity