

## ABSTRACT

Title of Dissertation: USING COMPREHENSION STRATEGIES WITH AUTHENTIC TEXT IN A COLLEGE CHEMISTRY COURSE

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College science students learn important topics by reading textbooks, which contain dense technical prose. Comprehension strategies are known to increase learning from reading. One class of comprehension strategies, called elaboration strategies, is intended to link new information with prior knowledge. Elaboration strategies have an appeal in science courses where new information frequently depends on previously learned information.

The purpose of this study was to determine the effectiveness of an elaboration strategy in an authentic college environment. General chemistry students read text about Lewis structures, figures drawn by chemists to depict molecules, while assigned to use either an elaboration strategy, namely elaborative interrogation, or another strategy, rereading, which served as a placebo control.

Two texts of equal length were employed in this pretest-posttest experimental design. One was composed by the researcher. The other was an excerpt from a college textbook and contained a procedure for constructing Lewis structures.

Students ( $N = 252$ ) attending a large community college were randomly assigned to one of the two texts and assigned one of the two strategies. The elaborative interrogation strategy was implemented with instructions to answer why-questions posed throughout the reading. Answering why-questions has been hypothesized to activate prior knowledge of a topic, and thus to aid in cognitively connecting new material with prior knowledge. The rereading strategy was implemented with instructions to read text twice.

The use of authentic text was one of only a few instances of applying elaborative interrogation with a textbook. In addition, previous studies have generally focused on the learning of facts contained in prose. The application of elaborative interrogation to procedural text has not been previously reported.

Results indicated that the more effective strategy was undetermined when reading authentic text in this setting. However, prior knowledge level was identified as a statistically significant factor for learning from authentic text. That is, students with high prior knowledge learned more, regardless of assigned strategy.

Another descriptive study was conducted with a separate student sample ( $N = 34$ ). Previously reported Lewis structure research was replicated. The trend of difficulty for 50 structures in the earlier work was supported.

USING COMPREHENSION STRATEGIES WITH AUTHENTIC TEXT IN A  
COLLEGE CHEMISTRY COURSE

by

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## DEDICATION

To my wonderful wife, Maria-Rose,  
and our four wonderful children, Joshua, Brendan, Rachel, and Matthew.  
Your support, encouragement, love, and patience have meant the world to me.

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# CHAPTER 1: INTRODUCTION

## Purpose

Students have large amounts of reading in college, much more than in high school (Simpson & Nist, 2002), but how much do they learn from reading?

Undergraduate general chemistry is a science course with a heavy reading demand and its textbooks are known for containing dense technical prose. Can reading comprehension strategies help college chemistry students learn more from reading their textbooks?

The purpose of this study was to determine the effectiveness of students' use of reading comprehension strategies in an authentic college science classroom environment. College chemistry students participated in a reading-studying exercise about the construction of Lewis structures, figures commonly drawn by chemists to depict the structural formula of molecules.

Participants were presented with one of two types of text. The first was a researcher-composed text about certain Lewis structures. The text described 15 specific Lewis structures and provided a figure of each. The second type was more authentic text taken directly from the participants' chemistry textbook (T. L. Brown, LeMay, Bursten, & Burdge, 2003). Participants were assigned randomly to one of the two texts.

Two reading comprehension strategies were assigned and compared in this research: a rehearsal strategy and an elaboration strategy. Specifically, rereading was the rehearsal strategy of interest and "elaborative interrogation" was the elaboration strategy of interest. Rereading was operationalized by instructing students to read text

two times. Elaborative interrogation employed the use of so-called “why-questions” posed frequently for students to answer throughout the reading. These two strategies were selected because of their known effectiveness and because students can readily learn and employ them, as detailed later.

## Rationale

Throughout elementary and secondary school, students learn about matter and develop schema about the microphysical world of atoms, molecules, and ions (R. C. Anderson & Pearson, 1984). The sophistication of schema varies from student to student and depends on many factors, including student personal effort and achievement, local curriculum content and standards, as well as the content knowledge of their science teachers. National science education standards recommend that fundamental concepts of atoms and chemical bonding should be taught in secondary school (National Research Council, 1996).

These topics are also important in postsecondary chemistry courses. Bonding and Lewis structures are presented in all general chemistry textbooks. In an American Chemical Society college level general chemistry textbook, written by a team of chemists from industry and education, Lewis structures and chemical bonding received significant treatment (American Chemical Society, 2004). Thus, it can be inferred that the largest professional organization of chemists and chemistry educators considers the topic of Lewis structures to be important.

In college general chemistry classes, students learn extensively about atoms and bonding using the terminology and ideas of professional chemists. Understanding bonding is critical for all of postsecondary chemistry. The topic of chemical reactions,

for example, is highly dependent on knowledge of chemical bonding. Chemical reactions between substances occur when some bonds are broken and new bonds are formed. In order to understand chemical reactions, a central focus of all chemistry classes, students must first understand bonding and Lewis structures.

How do general chemistry students learn to draw Lewis structures? They typically learn by some combination of college activities such as attending lectures and laboratories, talking with their professors and peers, reading text, and solving practice problems. These learning activities are facilitated by comprehension strategies that they may use, including rehearsing, organizing, elaborating, and monitoring (Weinstein & Mayer, 1986).

Why is the drawing of Lewis structures an important chemistry topic to investigate? Lewis structures are graphic depictions of molecules. Being able to draw Lewis structures is an important skill because “in many ways the study of chemistry is the study of the molecule” (Hurst, 2002, p. 763). However, this skill can be difficult for students to learn (Ahmad & Omar, 1992; Carroll, 1986). To complicate matters further, the explanation of drawing Lewis structures and related topics is “treated more inconsistently than almost any other material” in popular college chemistry textbooks (Purser, 1999, p. 1013). Brady, Milbury-Steen, and Burmeister (1990) identified the skills and specific tasks used by college students when drawing Lewis structures. They also classified 50 different structures according to level of learning difficulty. This study is reviewed in detail below.

Reading topics such as Lewis structures in college level text is more challenging than reading about such topics in high school level text (Simpson & Nist,

2002). In college, there is often an expectation that some content is mastered outside of class, a phenomenon not encountered in most secondary school classes (Simpson & Nist). A student's ability to learn from text is shaped by numerous factors; key among them are the student's reading ability, prior knowledge of the subject matter, and, knowledge of the criterion task (T. H. Anderson & Armbruster, 1984; Caverly, Orlando, & Mullen, 2000; Nist & Simpson, 2000). Learning from reading is strengthened by the use of comprehension strategies, but these are usually effective only when students possess certain baseline levels of reading ability (Caverly et al.). Unfortunately, students do not always activate their prior knowledge about a topic nor do they always utilize comprehension strategies spontaneously and effectively (Garner, 1990; Pressley, McDaniel, Turnure, Wood, & Ahmad, 1987). There is some evidence to suggest that effective spontaneous strategy use tends to increase with age (A. L. Brown & Smiley, 1978). However, there is also evidence to suggest that college students have difficulty learning from text (Pressley, 2002). Science text, often being dense technical prose, can be especially challenging (Holliday, Yore, & Alvermann, 1994; Millis, Simon, & tenBroek, 1998; Simpson & Nist, 2002). Therefore, the use of strategies for learning is particularly important to consider.

The strategy known as elaborative interrogation is implemented by asking a reader to answer the question "why" at certain points during a reading. The process of answering the question is hypothesized to activate the reader's prior knowledge of the topic, to focus attention on the new material, and thus to aid in the accommodation of the new material (Pressley, Symons, McDaniel, Snyder, & Turnure, 1988).

In this research project, rereading and elaborative interrogation were randomly assigned to participants and compared for their effectiveness in enhancing student comprehension in an authentic college setting.

### Significance

Two aspects of this study are significant. First, the preponderance of related reported investigations has been conducted in nonclassroom situations using researcher-authored texts. These studies have made significant contributions to the understanding of elaborative interrogation. Frequently the text has been contrived for the study and was either a list of facts or facts contained in paragraph format (e.g., Pressley, et al., 1987; Pressley et al., 1988; Willoughby, Wood, & Kahn, 1994; Willoughby, Porter, Belsito, & Yearsley, 1999; Willoughby, Wood, & Kraftcheck, 2003; Woloshyn, Pressley, & Schneider, 1992). Several other studies have used more realistic text (e.g., Seifert, 1993; McDaniel & Donnelly, 1996). In the current study, the use of authentic text was one of a few instances of applying the strategy with a reading from a required textbook. Other research using completely authentic reading materials in authentic settings has only recently been reported (e.g., Hill, 1999; Smith, 2003).

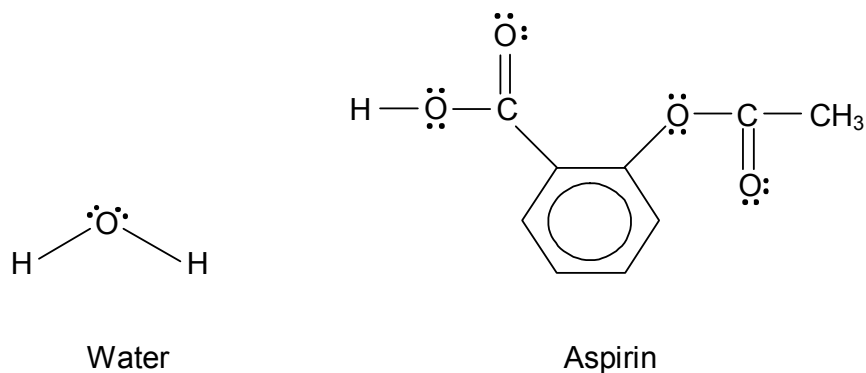
Second, previous studies exploring the use of elaborative interrogation have generally focused on learning facts contained in prose. Participants were typically tested on how many facts they recalled after reading text using the elaborative interrogation strategy. In the present work, the textbook reading included not only facts, but a procedure for constructing Lewis structures using important chemistry concepts. Thus, the textbook reading included a topic of procedural knowledge and

required students to understand and implement the procedure (Byrnes, 1992; Byrnes & Wasik, 1991). The application of elaborative interrogation to text explicating a procedure, such as that used to instruct the drawing of Lewis structures in chemistry textbooks, is not reported. There is some evidence to suggest that learning procedures from text involves different types of cognitive processing than learning facts from prose (Bovair & Kieras, 1991). The efficacy of elaborative interrogation in the learning of facts found in prose is well documented. The examination of the strategy use with a text that involves a procedure was unique.

### Chemical Bonding Background

The modern understanding of chemical bonding and structure is less than a century old. In the early 1900s, Gilbert N. Lewis, a noted and accomplished chemist, offered a new view of chemical bonding (Lewis, 1916). Although his approach may now appear to be a simplistic explanation of bonding, Lewis's system of assigning an octet of valence electrons to atoms by electron-sharing or electron-transfer is still, for the most part, reliable. (Note: Key chemistry terms are defined later in Chapter One.) To honor Lewis, chemists often refer to figures of chemical structures as "Lewis structures" (see Figure 1).

Over time, the method of drawing Lewis structures has been modified and enhanced, taking into account developments that explained experimentally determined data relating to bonds. In chemistry classes, students are often instructed to follow a set of steps that lead ultimately to a scientifically acceptable depiction of a molecular structure. The steps may vary from textbook to textbook and from professor to professor, but, in general, they involve essentially the same components:



*Figure 1.* Lewis structures of representative molecules.

(a) an accounting of valence electrons, (b) the arrangement of a “skeleton” of the atoms (also called a sigma skeleton), and, (c) placement and/or adjustment of electrons to achieve a logical end point by applying important chemistry concepts. One of those concepts, the octet rule, is a critical guideline to follow when determining chemical structure. Students are also instructed that there are some instances in which the rule is broken.

In college chemistry curricula, Lewis structures are normally introduced in the first semester of general chemistry and are then used in other topics throughout the course. Lewis structures are then utilized extensively during organic chemistry courses to draw molecules, understand their properties, and determine the mechanisms by which organic molecules react. Students who continue into biochemistry classes also utilize molecular structures on a regular basis. Other college science disciplines also rely on Lewis structures, for example biology, in which Lewis structures may be used to show biologically important molecules.

When learning to construct Lewis structures of molecules in chemistry classes, students are often presented with a methodology that begins with simple steps such as finding each element's symbol on the periodic table, identifying the family each is in, and by implication, determining the number of valence electrons each has. That number of electrons is then drawn on the four sides of the element's symbol (top, bottom, left, and right) in a systematic way. Electrons (symbolized by dots) that are alone on one of the four sides are considered available to participate in a covalent bond, a sharing of electrons by two atoms. Electrons that are paired are usually considered not available for bonding, but will be important as "lone pairs" or "unshared pairs" in the final Lewis structure. There are exceptions to these generalizations.

Appreciating all that a Lewis structure represents can help scientists and students understand the behavior and characteristics of substances. Students who understand how to draw Lewis structures will be prepared to learn more advanced chemistry concepts about molecules. For instance, drawing a correct Lewis structure allows inferences to be made about a molecule, including bond lengths, bond angles, molecular polarity, and stereochemical properties (e.g., Ems-Willson, 1999; Kuo, Jones, Pulos, & Hyslop, 2004). Additionally, chemists use Lewis structures when considering resonance structures or describing what occurs during chemical reactions. Knowledge of topics such as these is especially important for undergraduates learning organic and biochemistry.

In order to construct and interpret Lewis structures of molecules and polyatomic ions, students must have background knowledge of a number of chemistry



concepts and ideas, ranging from basic (e.g., element symbols) to sophisticated (e.g., orbital hybridization).

### Chemical Bonding in the Curriculum

Lewis structure instruction is found in all major college level general chemistry textbooks as well as in higher level college chemistry texts. College students, such as those who participated in this research investigation, may have also studied the topic of Lewis structures to some extent in secondary school. However, Lewis structure instruction at the secondary level varies widely depending on curriculum expectations and textbook. Many high school texts (e.g., LeMay, Beall, Robblee, & Brower, 2000) treat Lewis structure instruction with less detail than college texts. Some students may master the skill of constructing Lewis structure before college, while others may not be exposed to it at all. While Lewis structures may be introduced in some secondary level chemistry courses, it is also known that some high school students have misconceptions about issues related to chemical structures (Peterson & Treagust, 1989).

The National Science Education Standards (National Research Council, 1996) provide some guidance on precollege science content expectations. Concepts of chemical structure are emphasized in content standard B, physical science, in which the standards for grades 9 to 12 include structure and properties of matter. Students may encounter these concepts in classes that range from introductory physical science in grades 9 or 10 to introductory chemistry in grades 10 or 11 to advanced placement chemistry in grades 11 or 12. Higher level courses, such as advanced placement chemistry, usually treat the topic of chemical structure in a more sophisticated

manner similar to college level courses. The chemical structure content standard itself can be met when students acquire either general or advanced knowledge of chemical structures.

Some chemical educators have advocated for more inclusion of organic chemistry and biochemistry topics in high school chemistry, in part to expose students to more issues of molecular structure. Bell (1997) suggested the introduction of structure and polarity of organic molecules' functional groups as well as their intermolecular attractions, bonding geometry, and stereochemistry. Such topics would require knowledge and use of Lewis structures. Other chemical educators have emphasized that the topic of chemical structure is not only a physical science topic in the Standards (NRC, 1996), but that it is also implied in other content area standards such as life sciences, where the molecular basis of heredity is addressed (Ware, 1997).

The important impact of the Standards (NRC, 1996) on college education is an expectation for a baseline of background knowledge about chemical structure among first-year college students. Their sophistication in the topic may vary, even when they have completed curricula based on national standards. Archer (1997) has recommended that college educators must recognize these K to 12 science content standards and indeed adapt college level science courses to align with them.

It should also be noted that whether students have benefited from science reform efforts such as the National Science Education Standards (NRC, 1996) is uncertain. Lawrenz and Huffman (2002) found that some K to 12 teachers embraced curricular changes inspired by the standards, but others did not want to be involved.

In some schools, special funding was provided to initiate changes, but the changes did not necessarily persist when the funding stream ended. In a comparison of students who learned in reformed-curriculum classrooms with those who had not, the former group showed slightly higher scores in laboratory investigations, while the latter had slightly higher scores in scientific literacy (Lawrenz, Huffman, & Lavoie, 2001). Therefore, while the Standards address chemical structure, college chemistry faculty must be prepared for an undergraduate student population of widely varying background knowledge.

### The Community College Context of This Research

This research investigation was conducted at a large urban community college in a middle-Atlantic state of the U.S. Participating students were enrolled in the first-semester general chemistry course. This particular course has a substantial registration at the college. Many students take the course as part of curricula designed for transfer to a university where they will complete a bachelor's degree. The research sample consisted of a diverse group of individuals, composed of different races, age groups, countries of origin, and academic backgrounds.

It is interesting to note that the community college site for this study is considered one of the most diverse community colleges in the nation, in terms of students' countries of origin. About one third of the students are international, originating from over 170 different countries. In this study, half of the participants were international students, many of whom completed secondary-level chemistry in their country of origin.

As open-door institutions, community colleges admit students of all abilities and academic backgrounds, from the very strong to the weak. They enroll students whose secondary school achievement in science covers a wide range, whether based on Standards (NRC, 1996) or not. The acceptance of all students who apply is a policy unique to community colleges among higher education institutions. This guiding principle of community colleges provides access to higher education for many students, either because of their academic needs, financial needs, or their preferences for community college services (Lorenzo, 1994). In many states, community college enrollment rivals or exceeds enrollment in four-year institutions (e.g., Alexander, 2003). Therefore, finding methods to strengthen science learning is important for college chemistry students in both community college and university contexts.

## Research Questions

### *Framework of the Investigation*

Ten research questions were investigated in this study. The key questions focused on the effectiveness of reading comprehension strategies used by college level general chemistry students who studied how to construct Lewis structures. Two different texts were employed in the research. One was authored by the researcher, designated “text R” (i.e., *R* for researcher) and the other was an excerpt from a general chemistry textbook, designated “text T” (i.e., *T* for textbook). This textbook was the required book in the course in which the research participants were enrolled (T. L. Brown et al., 2003). The participants were randomly assigned to a text and also to a reading comprehension strategy, either rereading or elaborative interrogation, in a

pretest-posttest experimental design. In addition, participants' prior knowledge concerning topics related to drawing Lewis structures was measured with a test covering prerequisite chemistry concepts. Figure 2 depicts the timeline of activities in this investigation.

The dependent variable of interest throughout the research was the gain score achieved by participants. The gain score is the difference between the pretest and posttest scores. Both the pretest and posttest required participants to draw Lewis structures when given a chemical formula.

There were nine research questions relating to the text-strategy investigation in this study. Prior to this main focus on text and strategies, another research question was addressed in a replication of a previously reported investigation concerning the manner in which college students learn to draw Lewis structures (Brady et al., 1990). This replication formed the basis of the first research question.

### *The Brady et Al. Replication Research Question*

Brady et al. (1990) identified the skills students employ to draw Lewis structures and further classified each of 50 Lewis structures as being easy-to-learn,

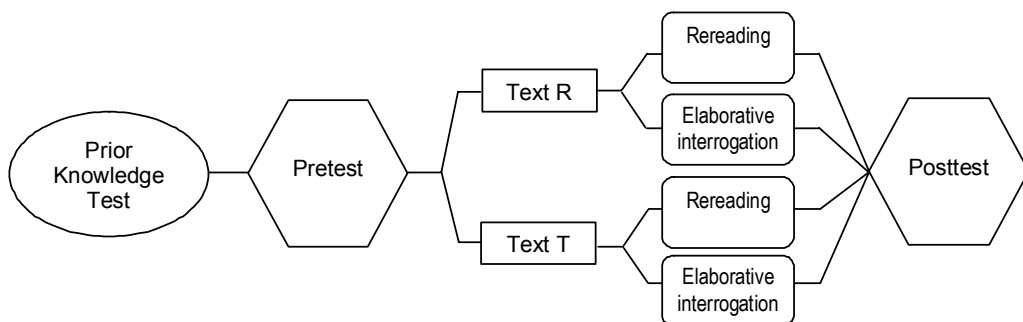


Figure 2. Sequence of events in text-strategy investigation.

average-to-learn, or difficult-to-learn. Replicating the Brady group's work was important for several reasons in the current investigation. First, it served to validate the content of the pretest and posttest, and the content of text R, all of which were composed by the researcher. Secondly, it offered a frame of reference by which to consider Lewis structure instruction.

The research question addressed in the Brady et al. replication was:

Question 1

How do students' scores on a Lewis structure test compare with previously reported results when level of instruction, nature of tests, and grading standards are comparable?

### *Text-Strategy Research Questions*

Three questions were addressed concerning participants' gain score performance on Lewis structure tests based on the random assignment to text and strategy. Text R was a factual-based text, which means that it presented facts about specific Lewis structures. Text T was a more authentic text, and contained procedural-based text, which means that it presented a process for drawing Lewis structures. These research questions and their associated hypotheses were as follows:

Question 2 and Hypothesis

Question: How does the elaborative interrogation strategy differ from the rereading strategy for college chemistry students who study the drawing of Lewis structures?

Hypothesis: There is no difference between mean gain scores on tests about Lewis structures for college students assigned to use the elaborative interrogation strategy and those assigned to use the rereading strategy.

Question 3 and Hypothesis

Question: How does factual text differ from procedural text for college chemistry students who study the drawing of Lewis structures?

Hypothesis: There is no difference between mean gain scores on tests about Lewis structures for college students assigned to read about Lewis structures from a factual text and those assigned to read about Lewis structures from a procedural text.

Question 4 and Hypothesis

Question: How do scores on Lewis structure tests vary when different strategies are used (viz., elaborative interrogation and rereading) for different reading formats (viz., factual text and procedural text)?

Hypothesis: There is no interaction between assigned type of text and assigned strategy for mean gain scores on tests about Lewis structures.

In Figure 3, the timeline of events in the investigation is again depicted (as in Figure 2), but in this case, the focus of research questions 2 to 4 have been highlighted.

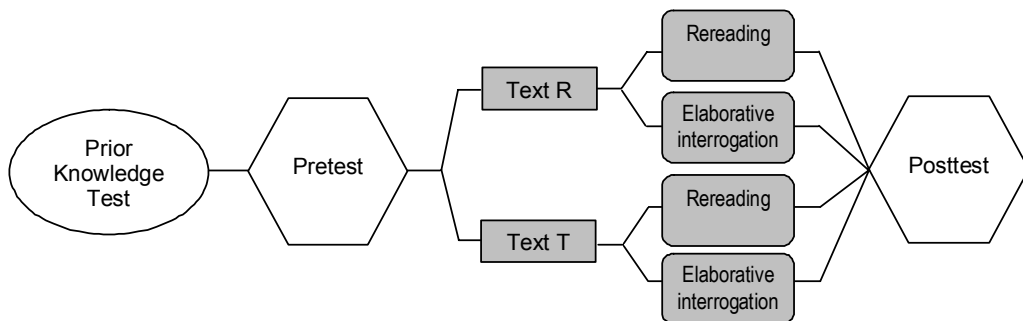


Figure 3. Research questions 2 to 4 compared gain scores for students randomly assigned to one of two texts using one of two strategies.

### *Text R Research Questions*

Three questions were addressed concerning students' gain score performance on Lewis structure tests based on their random assignment to strategy while reading text R and their prior knowledge level. Prior knowledge level was assigned as high or low based on a median split applied to the prior knowledge test results. These research questions and their associated hypotheses were:

#### Question 5 and Hypothesis

Question: How does the elaborative interrogation strategy differ from the rereading strategy for college chemistry students who study the drawing of Lewis structures by reading factual text?

Hypothesis: There is no difference between mean gain scores on tests about Lewis structures for college students assigned to use the elaborative interrogation strategy and those assigned to use the rereading strategy when reading a factual text.



### Question 6 and Hypothesis

Question: How do students with high prior knowledge differ from students with low prior knowledge when studying the drawing of Lewis structures by reading factual text?

Hypothesis: There is no difference between mean gain scores on tests about Lewis structures for college students with low prior knowledge and those with high prior knowledge when reading a factual text.

### Question 7 and Hypothesis

Question: How do scores on Lewis structure tests vary when different strategies are used by students with different levels of prior knowledge when reading factual text?

Hypothesis: There is no interaction between assigned strategy and prior knowledge level for mean gain scores on tests about Lewis structures for college students reading factual text.

In Figure 4, the timeline of events in the investigation is depicted with the key focus of research questions 5 to 7 highlighted.

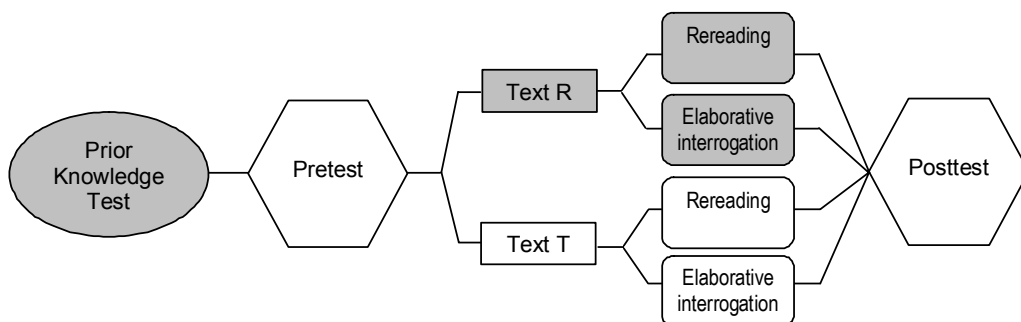


Figure 4. Research questions 5 to 7 compared gain scores for high- and low-prior-knowledge students randomly assigned to one of two strategies while reading text R.

### *Text T Research Questions*

Three questions were addressed concerning students' gain score performance on Lewis structure tests based on their random assignment to strategy while reading text T and their prior knowledge level, which was designated as high or low based on a median split applied to the prior knowledge test. These research questions and their associated hypotheses were:

#### Question 8 and Hypothesis

Question: How does the elaborative interrogation strategy differ from the rereading strategy for college chemistry students who study the drawing of Lewis structures by reading their textbook?

Hypothesis: There is no difference between mean gain scores on tests about Lewis structures for college students assigned to use the elaborative interrogation strategy and those assigned to use the rereading strategy when reading a course textbook.

#### Question 9 and Hypothesis

Question: How do students with high prior knowledge differ from students with low prior knowledge when studying the drawing of Lewis structures by reading their textbook?

Hypothesis: There is no difference between mean gain scores on tests about Lewis structures for college students with low prior knowledge and those with high prior knowledge when reading a course textbook.

## Question 10 and Hypothesis

Question: How do scores on Lewis structure tests vary when different strategies are used by students with different levels of prior knowledge when reading their textbook?

Hypothesis: There is no interaction between assigned strategy and prior knowledge level for mean gain scores on tests about Lewis structures for college students reading a course textbook.

Figure 5 shows the timeline of events in the investigation with the points of emphasis in research questions 8 to 10 highlighted.

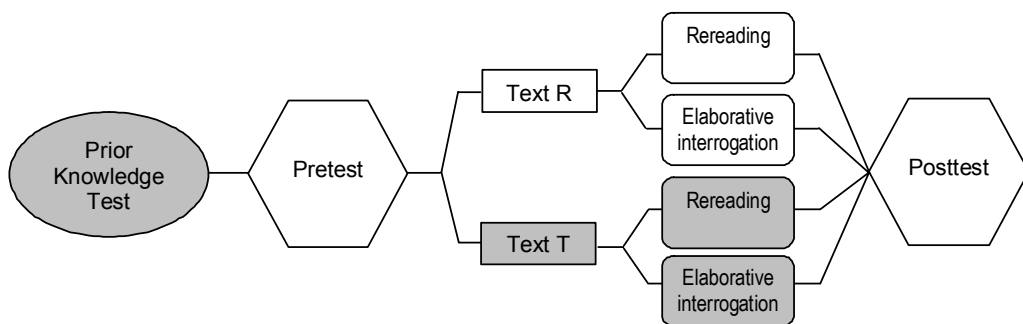


Figure 5. Research questions 8 to 10 compared gain scores for high- and low-prior-knowledge students randomly assigned to one of two strategies while reading text T.

## Definitions of Terms

Following are definitions of terms used in this investigation, first research terms, and then chemistry terms.

### *Key Research Terms*

1. *CH 100*: Chemistry 100. Denotes an introductory college chemistry course at the institution where the research was conducted. The content of the course is

generally considered to be equivalent to high school chemistry. Research participants self-identified as CH 100 completers on a survey.

2. *CH 101*: Chemistry 101. Denotes the first semester college level general chemistry course at the institution where the research was conducted. All participants in the text-strategy investigation were enrolled in CH 101.

3. *CH 102*: Chemistry 102. Denotes the second-semester college level general chemistry course at the institution where the research was conducted. All participants in the Brady et al. (1990) replication investigation were enrolled in CH 102.

4. *Elaborative interrogation*: A reading comprehension strategy that prompts readers to answer a why-question at various points during reading. In this research, students assigned to elaborative interrogation were instructed to write their why-question answers on the right side of the pages containing the text.

5. *Gain score*: The net number of Lewis structures learned by a research participant. In the text-strategy investigation, the gain score was determined by comparing each structure drawn by an individual on the pretest with those drawn on the posttest.

6. *High school chemistry*: A chemistry course offered in a secondary school. Research participants self-identified on a survey whether or not they had completed high school chemistry.

7. *Pretest and posttest*: These were identical instruments that each contained 15 formulas of compounds and polyatomic ions for students to draw. Based on the Brady et al. (1990) classifications, the tests had five easy-to-learn structures, five average-to-learn structures, and five difficult-to-learn structures.

8. *Prior knowledge test*: An 18-question multiple-choice test containing questions about prerequisite topics for learning to draw Lewis structures. This test was developed by the researcher and was based on the terminology used in the T. L. Brown et al. (2003) textbook excerpt concerning Lewis structures.
9. *Rereading*: A reading comprehension strategy understood to cause readers to rehearse new information. In this research, students assigned to rereading were instructed to read their text two times.
10. *Text R*: A researcher-authored text containing information about 15 specific Lewis structures. It is also referred to as factual text or factual-based text since it contains only declarative sentences.
11. *Text T*: An excerpt from the T. L. Brown et al. (2003) textbook, which was required in the general chemistry course at the institution where the research was conducted. It is also referred to as procedural text or procedural-based text since it contains instruction about the process that chemists use for drawing Lewis structures. This process is explained with imperative sentences in the text.
12. *Why-question*: An adjunct question that asks a reader to answer why something is true. In this study, the why-questions were embedded in the readings. In text R, why-questions were posed at the conclusion of each paragraph. In text T, the why-questions were posed at points where new material and prior knowledge were judged to meet.

### *Important Chemistry Terms*

The content material in this investigation consisted of college level general chemistry topics. It is not necessary to have an extensive background in chemistry to

read this document, although a basic understanding of the chemistry terms defined in this section is helpful. Other chemistry terms are used on occasion throughout the document. Where they are important for understanding researcher decisions or interpreting experimental results, they have been briefly explained within context.

1. *Chemical Bond*: An attractive force that causes two atoms to be held together. In this arrangement, each atom retains its essential structure of a nucleus surrounded by electrons. However, the valence electrons (i.e., outermost electrons) on the atoms form new energetically favorable pairings, thus concentrating negative charge in a new region. The attractive force of interest arises from the negatively charged valence electron concentrations between atoms and the positively charged nuclei at the center of each atom.
2. *Electron*: A subatomic particle with a negative charge. In an individual atom, electrons are arranged in various energy levels (also called shells) around the nucleus, which contains positively charged protons and neutral neutrons.
3. *Lewis structure*: A figure that depicts a molecule or polyatomic ion. In drawing Lewis structures, chemists use the letters of chemical symbols to represent atomic nuclei and lines or dots to represent electrons. Lewis structures are also referred to as molecular structures or dot structures.
4. *Molecule*: A neutral particle consisting of two or more atoms held together by chemical bonds. Neutrality results from the overall number of electrons being the same as the overall number of protons in the particle.
5. *Octet rule*: A rule used by chemists to determine the distribution of valence electrons among atoms in a compound or polyatomic ion. Electrons are distributed in

such a way so that each atom attains a stable arrangement. Early research showed that this arrangement often involved eight electrons, thus the name *octet* rule. Over time, the rule was refined to indicate an electron configuration matching any one of the noble gases (i.e., helium, neon, argon, krypton, xenon, or radon), all of which have very stable electron arrangements, although not necessarily involving eight electrons in every case.

6. *Polyatomic ion*: A charged particle consisting of two or more atoms held together by chemical bonds. The charge results the overall number of electrons in the particle being different from the overall number of protons.

7. *Shared pair of electrons*: A pair of valence electrons located together within a common region in between atoms to form a chemical bond. Such electrons are usually shown in Lewis structures as a line between element symbols, where one line represents two electrons. A shared pair can also be shown as two dots.

8. *Unshared pair of electrons*: A pair of valence electrons that does not participate in bonding. These electrons are often shown in Lewis structures since they have an impact on the structure's physical and chemical characteristics. They can be shown as a pair of dots or as a single line. More experienced chemists sometimes understand the presence of certain unshared electron pairs and omit them from Lewis structures. This is also not uncommon in Lewis structures of highly complex molecules. An unshared pair is also referred to as a lone pair.

9. *Valence electrons*: Electrons that reside on the valence (i.e., outermost) shell of an atom. Normally, only valence shell electrons are involved in bonding. Electrons

on the inner shells are sometimes called core electrons or kernel electrons. Generally, any reference to electrons in this study is to valence electrons.

## Limitations

The results of both the Brady et al. (1990) replication experiment and the text-strategy experiment may be of interest to other researchers and professors of general chemistry in community colleges and universities. However, there are some potential limitations as follows.

### *Brady et Al. Replication Experiment Limitations*

1. The research was designed and conducted as a descriptive investigation. The conclusions are based on the trends of students' correct answer rates, but no inferential statistical analyses were performed. This approach mirrored that as reported originally by Brady et al. (1990).
2. The students in the replication experiment ( $N = 34$ ) were farther along in the chemistry curriculum and, therefore, were likely to have had more overall study time to learn about drawing Lewis structures. In addition, the students in the replication were likely more academically successful in college level chemistry since they were enrolled in the second-semester course, CH 102, Chemistry 102, while Brady students were enrolled in the first semester of college level chemistry.
3. There may have been undetermined differences in using a different method to submit answers in the replication experiment compared to the original work. Brady et al. (1990) used a special computer program for students to construct their answers. The program was no longer available, so students in the replication



experiment used a pencil-and-paper format. Whether or not this caused any discernable difference in performance is not known.

4. In the original Brady et al. (1990) work, the participating students worked at their own pace to draw up to 50 Lewis structures. The exact number of structures completed by a particular student depended on the student's pace of work, accuracy of answers, and proficiency with the computer. Those who worked faster, answered structures correctly on the first try (the computer program re-presented the same question up to four times when a student submitted a wrong answer), and knew how to use the computer received more structures to complete. In the replication experiment, 10 structures (i.e., 20% of the Brady list) were randomly selected from the Brady group's list and all participating students received the same 10 structures. While the results are limited to the specific 10 structures selected, the importance of the replication was to examine the overall trend of answer correctness, not necessarily the percentage of students who drew a particular structure correctly.

#### *Text-strategy Experiment Limitations*

1. The research sample ( $N = 252$ ) consisted of half U.S. students and half international students, who originated from 49 different countries. The diversity of cultural and academic backgrounds made for a rich variety of students. The diversity of the sample represents a strength of this research, especially for institutions with large international populations. However, the results may not be applicable to more homogeneous student populations.

2. While it was the design of the experiment to compare the use of two different reading comprehension strategies, all that is known with certainty is the

strategy that was assigned to each participant. It is not known if participants actually employed the strategy assigned or if they used other strategies not assigned. The researcher observed participants carefully for evidence of compliance and noncompliance, but such evidence was found only in students' outward behavior. It is impossible to know what students were thinking as they read.

3. In the authentic setting of a classroom situation, it was not possible to practice or provide feedback to students concerning the methodologies of the strategies. Texts and strategies were randomly assigned so that there were four different reading/strategy combinations distributed during each session: (a) text R using the rereading strategy, (b) text R using the elaborative interrogation strategy, (c) text T using rereading, and (d) text T using elaborative interrogation. Providing specific strategy practice and feedback for one or both strategies in such a setting was neither practical nor advisable since it may have adversely influenced participants. All students received the same verbal and written instructions, which briefly described both strategies, but did not give examples. For the most part, this appeared to have been sufficient. However, strategy training and practice prior to implementation has been utilized in elaborative interrogation research, sometimes with demonstrable benefit (e.g., Woloshyn et al., 1992) and sometimes not (e.g., Ems-Wilson, 2000).

4. Other potentially important variables were not measured (e.g., student motivation), nor was it possible to determine the influence of such variables explored by others in reading education (e.g., Guthrie, Wigfield, & Perencevich, 2004). Nearly all students in the investigations appeared willing to participate. They were aware that

the topic was important in the general chemistry course, and that there was no impact on their grade by participating or not participating. Only a handful of students exercised their option not to participate in the study (and are not included in the reported  $N$ ). Nevertheless, other unmeasured variables may have had an impact on level of effort, concentration, and use of assigned strategy.

5. Since the research was conducted over a two-week period during 13 different laboratory sections, it is possible that some diffusion occurred across sections. To some extent, the potential for diffusion was mitigated by the selection of a variety of sections. Specifically, sections were selected at different campuses of the institution with some early in the morning, some in the afternoon, and some in the evening. There was no evidence that students participating later in the research calendar had higher scores on tests than students who participated earlier.

6. All of the treatments and testing were completed within two-hour sessions. Therefore, the conclusions concerning learning and strategy impacts apply to immediate effects. Long-term knowledge maintenance of Lewis structure construction skills was not measured and may be different from performance on the immediate tests.

### Assumptions

1. Students made their best efforts to answer questions on tests and, therefore, that test results accurately reflect the state of student cognition and learning.

2. Students used the strategies to which they were assigned and followed the directions on tests, readings, and surveys.

3. Students responded honestly to survey instrument questions, which asked about their personal and academic backgrounds.

4. All of the statistical assumptions for the descriptive and inferential analyses were met.

## CHAPTER 2: REVIEW OF THE LITERATURE

### Introduction

There are two bodies of research important to this investigation: cognitive strategies used by students when learning, and Lewis structures. Both of these topics are addressed in this literature review. In the strategy arena, the focus is on the types of cognitive strategies used by students learning new material, with particular interest in how college students learn. The main strategies of interest are rereading and elaborative interrogation; they will be addressed within the broader context of learning strategies in general. In the chemistry education literature review, the focus is primarily on research concerning the teaching and learning of constructing Lewis structures in college chemistry classes.

### Studying in College

#### *Factors Influencing Academic Success*

Studying is a critical part of the learning equation for college students. A full-time undergraduate student is typically in class 15 to 20 hours per week. Many professors and counselors recommend that students study outside of class. In fact, study skills texts often recommend that a college student should study two hours outside of class for every one hour in class (e.g., Ellis, 2000). Recent investigations of college students' use of time, however, have suggested that the actual amount of studying time is much less than this, probably in the range of 0.75 to 1.33 hours outside of class for every hour in class, where study time peaks during major examination periods (Cerrito & Levi, 1999; Zuriff, 2003). In other words, real study time fell into the range of 38% to 67% of recommended study time. Zuriff also

showed that time spent studying did not correlate with exam grades in the case of a college sophomore-level psychology course. In other words, those who studied longest did not necessarily earn the highest exam grades in this case.

What do students do during their study time? What separates the successful students from the unsuccessful students? Little definitive data have been gathered regarding this question of studying outside of normal classroom activities (H. M. Cooper & Valentine, 2001; Zuriff, 2003). Many different activities may occupy study time, including reviewing class notes, researching in the library or on the Internet, writing papers, practicing problems, and reading. However, many students are not prepared to tackle these studying activities when they enter college (e.g., Pressley, Yokio, van Meter, Van Etten, & Freebern, 1997).

Success in college studying derives from key aspects about the student, including the student's motivation, prior knowledge in the topic, knowledge of the criterion task, as well as reading ability (T. H. Anderson & Armbruster, 1984; Caverly, et al., 2000). Prior knowledge levels are shaped by an individual's experiences, both in the classroom and in everyday life (e.g., Kojima & Hatano, 1991). For college students in freshman-level courses, such as the participants in this research, prior knowledge content is based often on what they learned while attending their primary and secondary schools.

A criterion task is an activity that takes place after studying (Bransford, 1979). Many such tasks in college have some sort of measure or grade assigned to them. Such activities include taking tests, writing papers, or executing a procedure with equipment or instruments. The effectiveness of studying as measured by performance

on a criterion task is related to a student's knowledge of that task before studying begins. The more explicitly clear the nature of the task is before studying, the more a student will learn while studying (T. H. Anderson & Armbruster, 1984). Wade and Trathen (1989) found that providing explicit information about a criterion task benefited college students, especially those defined as having lower ability.

### *Comprehension Strategies*

Students perform studying tasks by using various comprehension strategies (also called "learning strategies"). Such strategies are "operations that enhance important cognitive purposes" (Pressley & McCormick, 1995. p. 24). They are consciously initiated and then controlled by the learner (Pressley & McCormick, 1995). Weinstein and Mayer (1986) defined five major categories of comprehension strategies: (a) rehearsal, (b) organization, (c) elaboration, (d) monitoring, and (e) motivational (see Table 1). The first three are focused on the learner's interactions with external facts, ideas, and concepts. The specific strategies in these categories were characterized as basic or complex by Weinstein and Mayer. The last two strategy categories, monitoring and motivational, describe the learner's metacognitive and internal qualities related to the study tasks.

If students are not prepared for their learning tasks when they arrive at college, part of the cause may be lack of knowledge about learning strategies (Nist & Simpson, 2000; Pressley, 2004). Such strategies are often not explicitly taught at the secondary level (Mayer, 1996) and this may put students at a disadvantage when they enter college. Some educational researchers (e.g., Duffy, 2002; Pressley & Block, 2002) advocate providing comprehension strategy instruction at all levels of school,

Table 1

*Comprehension Strategies and Examples*

(Based on Weinstein & Mayer, 1986)

Strategy	Description	Examples
Rehearsal	Selection and acquisition	<i>Basic:</i> Memorizing, rereading <i>Complex:</i> Copying, underlining, highlighting
Organization	Building internal connections	<i>Basic:</i> Grouping techniques, mnemonic devices <i>Complex:</i> Outlining, concept-mapping
Elaboration	Integration of new information with prior knowledge	<i>Basic:</i> Mental images, sentence-forming <i>Complex:</i> Summarizing, elaborative interrogation, note-taking
Monitoring	Metacognition	<i>General:</i> Self-checking, awareness of progress (e.g., SQ3R)
Motivational	Affective	<i>General:</i> Focusing, managing time

beginning in primary grades, and continuing through middle school, high school, and then college.

Since many study activities involve reading, it is especially important to understand student use of strategies directly related to reading (Caverly et al., 2000).

In college, reading demands are greater, both in terms of quantity (Simpson & Nist,



2002) and in term of cognitive demand (Nist & Holschuh, 2000). The successful student is one who completes these tasks with meaningful learning, a term Mayer (1996) defined as learning that results in good retention and good transfer.

Reading text for a college class is not the same as general reading (T. H. Anderson & Armbruster, 1984). Besides the usual tasks of decoding text and encoding information, there is also the added dimension of a target cognitive or procedural demand, that is, a criterion task. In other words, college students study to learn and to construct meaning or to perform an activity that reflects the learning. In the current research, participants read text about drawing Lewis structures and were also told in advance about the criterion task associated with the reading.

### *Utilizing Learning Strategies*

Wade, Trathen, and Schraw (1990) identified 14 learning strategies used spontaneously by college students when reading a lengthy and difficult text. These strategies included underlining, outlining, relating new information to prior knowledge, and rereading. However, students do not always utilize learning strategies spontaneously and effectively (Garner, 1990; Pressley et al., 1987). There is some evidence that effective spontaneous use of strategies improves with age (A. L. Brown & Smiley, 1978). Nevertheless, college students have difficulty learning from text, especially science text, which is often composed with dense technical prose (Holliday et al., 1994; Millis et al., 1998; Simpson & Nist, 2002). To address these challenges, some colleges offer optional courses about learning as well as special service centers to assist students in improving their learning strategy skills.

There are theoretical benefits to training students in the use of strategies (Duffy, 2002). Some strategies are simple for students to self-initiate (e.g., highlighting text); others may require extensive practice to master, for example, outlining (T. H. Anderson & Armbruster, 1984). Early in the study strategies literature, Stordahl and Christensen (1956) showed that untrained adult students using strategies such as underlining, outlining, or summarizing were no more successful on recall tests than students who reread materials. Rereading is considered a basic rehearsal strategy (Weinstein & Mayer, 1986) and is generally employed in research experiments with little, if any, training of participants. When reading is accompanied by an effective cognitive strategy, the reader may experience greater or deeper learning. This enhanced learning likely occurs because the reader engages in active processing of important information (DiVesta & Gray, 1972; Rickards & Friedman, 1978). In the absence of training or certain other habits (such as cognitive monitoring) students generally rely on self-generated learning strategies, which may be effective or ineffective or, at worst, may be entirely counterproductive (Garner, 1990; Holliday, Whittaker, & Loose, 1984; Pressley, 2002).

While there is ample evidence to demonstrate that students with sufficient prior knowledge, reading ability, motivation, and training can use strategies to improve and enhance their learning (Caverly et al., 2000), Wade and Trathen (1989) have offered a rival hypothesis concerning adult students. They investigated multiple aspects of learning with a focus on a reader's ability to distinguish important from unimportant information in text. Adult readers are generally able to do this better than younger readers (Johnson, 1970; Meyer & McConkie, 1973). Wade and Trathen

concluded that spontaneous strategy use may be the result of first recognizing important information, at least for the type of reading used in their research. In other words, students used comprehension strategies (e.g., note-taking, highlighting, or underlining) with material they considered to be important. All students in the Wade and Trathen study recalled more important information than unimportant information. However, higher-ability students learned significantly more than lower-ability students. Wade and Trathen concluded that all college students were able to make decisions about the importance of topics in a reading, although lower-ability students appeared to benefit from prereading questions intended to focus attention on the important information. Whether comprehension gains arise from recognizing importance or from using learning strategies may yet be undetermined. Several reports conflict with Wade and Trathen's conclusions about college students' ability to identify important information in text (e.g., Caverly et al., 2000; Pressley, Ghatala, Woloshyn, & Pirie, 1990). In direct contrast to Wade and Trathen, Caverly et al. reported that students with either low prior knowledge in a content area or low reading ability have difficulty making decisions about importance. Pressley et al. (1990) showed that when reading difficult text, college students did not know how to locate important information nor were they aware that they did not know. This line of research demonstrates some of the complexities of strategy research, which typically measures observable student behavior or performance. Such research cannot directly probe students' cognitive processing.

There are, then, many factors to consider in the use of strategies intended to enhance cognitive recall and comprehension, including knowledge of the strategy,

appropriate matching of the strategy with the learning task, and correct implementation of the strategy. In the next section, three such strategies are briefly considered: a complex rehearsal strategy (underlining), a complex organization strategy (outlining), and a complex elaboration strategy (note-taking). These are strategies that college students might consider using when learning new information in their science courses such as general chemistry. Following these descriptions, there is a more extensive consideration of elaboration strategies.

### *Representative Strategies*

#### *An Example of Complex Rehearsal: Underlining*

The purpose of engaging in rehearsal strategies is to encode new information in order to make it a part of working memory (Weinstein & Mayer, 1986). Underlining is the most commonly used strategy by college students (Caverly et al., 2000). The strategy is used to mark text that the reader considers important and desires to review later. This technique requires the reader to differentiate between important and less important content, presumably to facilitate rapid rereading at a later time. Making the decision that certain text is worthy of underlining is likely the key component in the effectiveness of this study technique. Students with high prior knowledge in the content area are better than weaker students at making decisions about importance (Caverly et al.). In terms of test performance, students do well on test items relating to what they underlined. Underlining, even when applied effectively, appears to work best for shorter text, that is, text with 500 or fewer words (Caverly et al.).

Any student can underline or highlight text. Doing so does not guarantee learning, however. Stahl, Simpson, and Hayes (1992) recommended that college students should be encouraged to use more sophisticated strategies when reading. In the current research, a more sophisticated strategy, elaborative interrogation, was employed in two of the four treatment groups.

*An Example of Complex Organization: Outlining*

Organization strategies serve both to encode new material and to construct relationships within the new information and ideas (Weinstein & Mayer, 1986). When outlining, for example, the learner organizes the to-be-learned material into a structured format according to a hierarchy of concepts or principles. Students require extensive training to use outlining effectively; without training, students do not benefit from outlining, especially those with lower reading ability (T. H. Anderson & Armbruster, 1984; Caverly et al., 2000).

In recent years, some educators and researchers have utilized computer-based outlining programs to assist students in constructing outlines (Anderson-Inman, 1996; Anderson-Inman, Redekopp, & Adams, 1992). Anderson-Inman et al. found that such programs are effective in improving student performance on content area tests.

In the current research, organizational strategies were not assigned to students.

*An Example of Complex Elaboration: Note-taking*

Elaboration is a strategy useful for building cognitive associations. In the basic sense, this refers to simple associations between ideas, for example, A is associated with B. At the complex level, this refers to associations between new material and prior knowledge (Weinstein & Mayer, 1986). Note-taking is a complex

elaboration strategy and is used by learners to record information and ideas, while either listening to a speaker or reading a text. Note-taking is different under these two conditions, namely in terms of the note-taker's control over the rate of information input. There is a separate line of research for each type of note-taking.

In theory, note-taking-while-reading provides a cognitive advantage because it requires the student to make decisions about what to compose (Caverly et al., 2000). This results in deeper active processing of the material than that which occurs by reading only. The strategy is useful with longer readings (i.e., 1000 words or more), and the quality of the notes taken is much more important than the quantity (Caverly et al.). Note-taking-while-reading appears to be most effective, especially with difficult material, when the notes are focused on the more important information. Students with poor reading abilities have difficulty identifying the more important information in text and thus often do not implement note-taking effectively.

In the current research, note-taking was not investigated, although a small number of participants did spontaneously engage in writing short notes, which were found upon inspection of the experimental reading documents.

#### *Further Research in Elaboration Strategies*

As a technique to construct associations between new information and prior knowledge, elaboration strategies become important when students have built a prior knowledge base in a given domain. Since new students arrive in college with at least 18 years of life experiences and 13 years of formal education, they are likely to have significant prior knowledge in many domains.

In some of the early literature on basic elaboration strategies, research was conducted to investigate how students recalled lists of details about certain people or the actions carried out by certain people. In other words, students were to create an association between a person and a detail or an action linked to that the person. These sentences were referred to in the literature as “man-sentences.” (Note: At the time such research was initiated, there was less sensitivity to the importance of using nonsexist language; as a result, all of the people in these sentences were male.) Examples of such sentences included, “The diamond was too expensive for the slow man,” and “The child was comforted by the short man” (Stein, Morris, & Bransford, 1978), “The hungry man got into the car,” and “The brave man ran into the house” (Stein et al., 1982).

Various methods were employed to help students remember the list of man-detail or man-action associations. Stein, Morris, and Bransford (1978) and Stein and Bransford (1979) showed that students benefited from additional text that clarified relationships in a precise way. In other words, additional textual elaboration was effective when it activated “knowledge that permitted the learner to understand the significance of the target words relative to the events in which they are embedded” (Stein et al., 1978, p. 713). For example, in the sentence about the child and the short man, this text (with the text authors’ additional elaborative information italicized here), “The child was comforted by the short man *who looked the child in the eye,*” was more effective in producing recall than “The child was comforted by the short man *who sat around a lot.*” Stein et al. (1978) termed the first case a precise elaboration and the latter an imprecise elaboration. In their work, the use of precise

author-provided elaborations produced the highest recall, greater than that produced by no elaboration, which was greater than author-provided imprecise elaboration.

Later, students generated their own elaborations while reading many sentences (Stein & Bransford, 1979; Stein et al., 1982). After reading a sentence out loud, students were asked to generate their own elaborations, which were later rated as precise or imprecise. More successful students (a classification based on test scores and teacher ratings) were more likely to generate precise elaborations than average or less successful students. All students remembered more associations from their precise elaborations. And, student-generated elaborations were more effective in increasing retention than author-provided elaborations.

In the Stein and Bransford (1979) experiment, students were prompted to elaborate on the sentences with a researcher question. Some were asked, “What else might happen in this context?” Another group was asked, “Why might this man be engaged in the particular type of activity?” (Stein & Bransford, 1979, p. 773). In the Stein et al. (1982) research, the instructions to the students were to “make up sentence endings” (Stein et al., 1982, p. 400).

Pressley et al. (1987) used a similar experimental model involving many sentences, but changed the instructions to the students. They asked students to explain why the sentence made sense. In other words, after reading a sentence such as, “The sleepy man bought the mug,” students were asked, “Why did that particular man do that?” (Pressley et al., 1987, p. 291). After stating an answer to such question, students’ recall of the associations increased more than in the cases of author-provided elaborations (e.g., “The sleepy man bought the mug *filled with coffee*”),



author-provided elaborations with a question (viz., “How does the last part of the sentence make clear why that particular man did that?”), or no elaboration.

Specifically, mean recall test scores were highest for the treatment group that answered the question, “Why did that particular man do that?” and second highest for group receiving author-provided elaboration plus the question, “How does the last part of the sentence make clear why that particular man did that?” The group receiving the author-provided elaboration alone performed almost as well as those asked the additional question, and the treatment group receiving no elaboration scored lowest.

Asking readers “why” is different than providing an elaboration or asking readers to provide their own elaborations. Such questions were referred to as a “why-questions.” The method of posing a why-question during the reading of text was dubbed “elaborative interrogation,” that is, elaboration stimulated by questioning. Pressley et al. (1987) showed that elaborative interrogation increased recall in subjects when they were tested about the man sentences.

The elaborative interrogation strategy has an appeal for use in science education. There is a critical need to establish associations in science between new information and prior knowledge. Elaborative interrogation is easily taught and understood by students, who are accustomed to answering adjunct questions while reading. Yet, it is a sophisticated strategy because it involves higher-level thinking. It is also different from typical adjunct questions in that the answers to why-questions cannot be answered by looking back into the text itself, as is the case with many adjunct questions. Readers must rely on knowledge they possess to answer why-

questions. Adjunct questions are known to draw the reader's attention to important concepts in the text (Hamaker, 1986) and they have been applied in various science settings, for example, in biology (Holliday & Benson, 1991; Spring, Sassenrath, & Ketellapper, 1986), with positive results.

This research in elaboration strategies laid the foundation for the strategy called elaborative interrogation. This strategy will be described in greater detail in the next section.

### Strategies Assigned in This Investigation

In the current research, elaborative interrogation and rereading were randomly assigned to students for use while they read text about Lewis structures. The following literature review of these two strategies sets the framework for why they were selected and how they were intended to operate in a realistic college science classroom situation.

Wade et al. (1990) made a distinction between strategies that produce an artifact and those that do not. Rereading is a strategy that involves mental operations, but leaves behind no artifact or other evidence that can be studied later. When students use elaborative interrogation, on the other hand, they, too, also perform mental operations, but they also produce written or spoken thoughts, which can be retained and examined later. As a result of this difference, these two strategies have been studied in different ways. Also perhaps because of this difference, elaborative interrogation has been studied more extensively in recent years.

In this section, the research addressing rereading will be addressed first followed by research concerning elaborative interrogation.

## *Rereading*

### *Introduction*

Rereading, or “repetitive reading,” as it is called in some sources, is a rehearsal strategy. Learners use rehearsal strategies to store new information in short-term or long-term memory (Bransford, 1979). The simplest form of rehearsal is repeating words out loud or silently. During rehearsal, learners cognitively reprocess facts or ideas and such reprocessing helps to foster comprehension (Haenggi & Perfetti, 1992). Rereading a text passage or selection provides students an opportunity to “elaborate, repair, verify, and strengthen” their understanding of material (Millis et al., 1998, p. 232). During the reprocessing event, cognitive effort is hypothesized to be directed differently than in the initial processing (Millis et al.). Specifically, more cognitive effort is directed at the construction of deeper meaning. Investigation of other reprocessing strategies has been reported in the literature, including repetitive listening (Bromage & Mayer, 1986), rewriting, and rereading class notes (Haenggi & Perfetti).

Often employed as a placebo control in strategy research, and frequently referred to as the “repetition control” (e.g., O’Reilly, Symons, and MacLachy-Gaudet, 1998; Pressley et al., 1988; Stordahl & Christensen, 1956; Willoughby, Waller, Wood, & MacKinnon, 1993), rereading has also been found in some cases to be equal to or more effective than other comprehension strategies, such as note-taking, outlining, or summarizing (e.g., T. H. Anderson, 1980; Howe & Singer, 1975; Millis et al, 1998). T. H. Anderson and Armbruster (1984) argued that the more effortful strategies, such as note-taking, outlining, and summarizing, can be more

effective for students after training. Some college reading faculty recommend rereading to their students when teacher and material demands are light, but suggest more effortful strategies when those demands are heavy (Caverly et al., 2000).

In the current research, rereading served as a placebo control for comparison with elaborative interrogation. Millis and King (2001) recognized that elaboration strategies are generally more effective than rereading and the elaborative interrogation literature contains many reports corroborating this (e.g., Pressley et al., 1988; Willoughby et al., 1993; Willoughby et al., 1994; Wood, Fler, & Willoughby, 1992). However, in certain conditions, results have been reported showing no significant differences on recall tests between students assigned to elaborative interrogation and those assigned to rereading (e.g., O'Reilly et al., 1998; Willoughby et al., 1993; Willoughby, Wood, & Kahn, 1994; Wood, Willoughby, Bolger, Younger, & Kasper, 1993).

As a comprehension strategy, rereading generally requires little training and, in fact, may be a spontaneous activity that readers employ “when comprehension hits a snag” (Millis & King, 2001, p. 41). It is also likely that many students plan to read text at least twice when they study and that such intent may influence their attention and cognitive effort (Barnett & Seefeldt, 1989). For example, such student readers may intend to develop general ideas during the first reading and then to focus on details during the second.

Reading time generally decreases with each subsequent reading when rereading immediately follows the first reading (Graf & Levy, 1984; Millis & King, 2001; Millis et al., 1998). Such a decrease is not as pronounced, however, when the

second reading of a text is delayed, for example, by a week (Krug, Davis, & Glover, 1990). Reading time is also influenced by whether the learning condition is announced as intentional (i.e., a criterion task, such as a test, will follow the reading) or incidental (i.e., no criterion task will follow the reading). Students tend to read faster if they believe they will not be tested (Millis & King, 2001).

Several key factors related to rereading have been reported in the literature, including: (a) the cognitive activities that occur during rereading (e.g., Millis & King, 2001; Millis et al., 1998); (b) whether it is better to reread immediately or after a delay (Krug et al., 1990); and (c) how many times it is advisable to reread (Amlund, Kardash, & Kulhavy, 1986). Each of these facets of rereading will be reviewed in the following sections. Each section concludes with a paragraph explaining how the literature influenced the design of the current research.

### *Cognitive Activities during Rereading*

College students read text to construct meaning, to carry out cognitive or procedural tasks, or to gain knowledge for a criterion task (T. H. Anderson & Armbruster, 1984; Caverly et al., 2000). Decoding written words and constructing meaning is sometimes described as occurring in three phases: (a) lexical access, (b) proposition assembly, and (c) text-level integration (e.g., Millis & King, 2001; Millis et al., 1998). In brief, these three phases, respectively, refer to (a) connecting a mental meaning to a written word, (b) developing and organizing individual ideas in the text, and (c) constructing meaning from the text.

Because no artifacts are created during rereading, research methods focus on measuring the time readers spend on sentences or passages and then drawing

inferences about their cognitive activities. For example, Millis et al. (1998) evaluated sentences in readings for lexical access by determining word frequency; for proposition assembly by counting propositions and new nouns; and for text-level integration by rating each sentence's importance. College students read and later reread the sentences one at a time by using a computer program that also recorded time. Analysis showed that during the second reading, students spent less average time per word compared to the first reading, but they spent more time reading the important sentences. In other words, readers were more focused on constructing meaning (i.e., text-level integration) during their second reading. Millis and King (2001) demonstrated that college students remembered 17% more of the information in text descriptions after their second reading compared to what they had remembered after the first reading.

In the current research, rereading was the comprehension strategy assigned to half of the participants with text R and half with text T. Students were allowed to read and reread at their own pace, as is commonly reported in rereading investigations (e.g., Barnett & Seefeldt, 1989; Krug et al., 1990; Millis & King, 2001; Millis et al., 1998) and overall time to complete the reading-rereading process was recorded. The role of rereading was to serve as a placebo control for comparison with students who were assigned to use elaborative interrogation. It was presumed that the findings of previous rereading research would apply to students in the current text-strategy investigation, namely, that the second reading would afford an opportunity to reprocess the content and to construct deeper meaning about the text.

### *Time Delay between Reading and Rereading*

It is hypothesized that many students engage spontaneously in immediate rereading in authentic settings (Millis & King, 2001; Wade et al., 1990). In both immediate and delayed conditions, the reading-rereading process is more effective than reading alone. Whether rereading provides more of a benefit from immediate or delayed implementation was the focus of Krug and associates (1990). Generally, delayed rereading led to better recall of ideas compared to immediate rereading, a phenomenon that Krug et al. postulated was explained by a deactivation hypothesis. By this they meant that, since less is remembered after a span of time (i.e., memory is deactivated), a reader applies more cognitive resources and effort during the rereading session and the result is greater overall comprehension.

Krug et al. (1990) also investigated whether there were any differences in using paraphrased materials during the rereading session instead of the verbatim passages used in the first session. They found that an immediate rereading of paraphrased text provided greater recall than immediate rereading of the verbatim text. When the rereading session was delayed, rereading of verbatim text produced the same memory result as rereading of paraphrased text.

In the current research, students assigned to the rereading strategy were instructed to immediately reread the verbatim assigned text. The instructions provided on the experimental materials indicated that students should choose a rereading format, either by paragraph or by complete passage, according to their personal preference.

### *Optimum Number of Readings*

Amlund, Kardash, and Kulhavy (1986) explored the impact of multiple readings in an immediate session. Students in their study read a 669-word text at a personally determined pace one time, two times, or three times, and were tested for recall of main ideas and details. Students who read the text twice performed significantly better on tests than students who read once, a result which might also be explained by more time on task. However, students who read three times, and presumably had the highest time on task, did not remember more than students who read twice. Amlund et al. concluded that two immediate consecutive readings were better than one reading and were also better than three immediate consecutive readings. Compared to the two-readings students, the three-readings students had lower scores on main idea test items but equal or higher scores on detail test items. Amlund et al. also showed these differences persisted over time.

Interestingly, what students expect about how many times they can read a text may also affect how they read, whether their expectations are actually experienced (Barnett & Seefeldt, 1989). In Barnett and Seefeldt, students who *thought* they would be able to read a 1,000-word text twice but were actually allowed to read it only once also did better on a factual recall test than those who were instructed and allowed to read the text just once. It was postulated that students' anxiety level was reduced during their reading when they had been instructed that they could read a text two times. However, these students did not do as well on transfer test questions, suggesting that their first reading was more concentrated on acquiring factual information. Students who expected and experienced two readings performed better



on both recall and transfer tests than students who expected two readings but experienced one.

In the current research, students assigned to the rereading strategy were instructed to read text twice. Students expected and experienced the opportunity to read two times. The verbal and written instructions emphasized reading the text two times, although compliance with this instruction was not directly verified. The expectation and experience of immediate reading-rereading presumably offered the maximum potential learning for students who were assigned to rereading in this study. It is conceivable, although unlikely, that some students may have reread more than instructed. The literature suggests that a third immediate reading of the text would not have provided any additional benefit if this did occur (Amlund et al., 1986).

#### *Method of Rereading: Oral or Silent*

McCallum, Sharp, Bell, and George (2004) have recently reported on reading rate and comprehension when students read text orally or silently. Previous work has been generally inconclusive about which method, oral or silent reading produces better comprehension (e.g., Miller & Smith, 1985; Rowell, 1976). In McCallum et al.'s research, elementary and middle school students read a text passage at their own individual paces. Those reading silently finished reading significantly faster than those reading orally. The latter group required, on average, 30% more time to complete the reading. However, there was no difference between the groups on comprehension test scores. These results suggest that silent readers process and learn

information faster than oral readers. Whether these results apply equally to adult readers is not reported.

In the current research, students were instructed to read and reread silently. This may be important to note because in previously reported research using rereading as a placebo control strategy, there has been a mix of oral and silent rereading (e.g., oral rereading in O'Reilly et al., 1998; Pressley et al., 1988; Willoughby et al., 1994; Woloshyn et al., 1990; Woloshyn et al., 1992; Woloshyn et al., 1994; and, silent rereading in Dornisch, 2003; Ems-Wilson, 2000; Hill, 1999; McDaniel & Donnelly, 1996; Ozgungor, 2002; Seifert, 1993; Smith, 2003).

### *Elaborative Interrogation*

#### *Introduction*

The elaborative interrogation hypothesis grew out of a body of research in learning strategies, where the goal is to construct associations between new information and prior knowledge when reading text. The hypothesis holds that when asked to answer a why-question about the to-be-learned target, readers will activate their schemata of the topic domain, and then actively process and generate cognitive connections between the new material and what they already know (Pressley et al., 1987; Willoughby et al., 1994). Encouraging learners to engage in their own generative processes is believed to increase comprehension (e.g., Wittrock, 1990).

In early work on elaborative interrogation, researchers explored the potency of asking why-questions to enhance retention of arbitrary facts contained in man-sentences (Pressley et al., 1987; Pressley et al., 1988). This technique was also compared to another elaboration strategy known for its effectiveness, namely, mental

imagery (Paivio, 1971). Student groups were divided among those who were asked why-questions and those who were instructed to create mental images, all with the goal of remembering the association of a modifier about the sentence subject (i.e., a man) with a predicate (i.e., a verb). In these sentences, two ideas are associated with the word *man*, an arbitrary adjective and an arbitrary action. Examples of simple man sentences with arbitrary adjectives and verbs included “The hungry man got into the car” and “The brave man ran into the house.” After reading a sentence, students were asked why they thought the man did the action. Their answers served as elaborations based on their own prior knowledge about actions people perform. This method of Pressley et al. (1987) represented a novel approach for increasing memory of adjective-action pairs in simple man sentences. When subjects generated their own elaborations in response to the question, they produced greater memory gains than did those who were provided with precise elaborations in earlier work (e.g., Stein et al., 1982; Stein et al., 1978).

The text utilized in the earliest experiments was prose about arbitrary facts. This was artificial text composed for the purpose of the study (e.g., Pressley et al. 1987; Pressley et al., 1988; Stein & Bransford, 1979; Stein et al., 1982). In later work, as will be demonstrated below, more realistic text was used (e.g., McDaniel & Donnelly, 1996). In recent years, authentic course texts have been used in research investigations (e.g., Hill, 1999; Smith, 2003). In the current investigation, two texts were employed. One was “artificial,” similar to the original research in that it was factual prose about Lewis structures. This text (text R) was composed by the researcher. The second reading used was authentic text, an excerpt from the textbook

required of the students enrolled in the general chemistry course in which the research was conducted (text T).

Subsequent elaborative interrogation experiments in the literature have focused on key factors relating to the strategy, including (a) what type of question to ask (Martin & Pressley, 1991); (b) what is the impact of knowing the criterion task (e.g., Woloshyn, Willoughby, Wood, & Pressley, 1990); (c) what is the role of prior knowledge in using elaborative interrogation (e.g., Willoughby et al., 1994; Woloshyn et al., 1992); (d) how does the quality of the reader's answer to the why-question matter (e.g., Pressley et al., 1988); (e) at what age can individuals employ the strategy effectively (e.g., Wood, Pressley, & Winne, 1990; Willoughby et al., 1999); (f) in what format should the to-be-learned material be presented (e.g., Seifert, 1993; Woloshyn et al., 1990); and (g) can the strategy be applied to both factual and inferential learning (e.g., McDaniel & Donnelly, 1996; Seifert, 1993). Each of these is considered separately in the following sections. Each section ends with a paragraph explaining how the literature influenced the design of the current research.

### *Type of Question*

Martin and Pressley (1991) explored the use of different why-question formats with the same to-be-learned targets, namely, facts contained in sentences about Canadian provinces. After reading each sentence, Canadian university students were asked why-questions in four slightly different formats, all consistent within one group. Specifically, questions were framed with two factors, expectancy (i.e., was the fact expected or unexpected) and referent (i.e., by using the province in the sentence or other provinces). Combining these two question factors, four question types were

constructed: (a) Why does that *make sense* given what you know about that *particular province?*; (b) Why does that *make sense* given what you know about *other provinces?*; (c) Why is that *unexpected* given what you know about that *particular province?*; and (d) Why is that *unexpected* given what you know about *other provinces?* Martin and Pressley (1991) termed these four question formats confirm-specific, confirm-other, unexpected-specific, and unexpected-other, respectively.

The rationale of posing differing why-question formats was that each should stimulate different thought processes in the students. Asking why something makes sense may cause different cognitive processing than asking why it is unexpected. Additionally, referring to the province in the question versus other provinces again should cause different cognitive processing. Martin and Pressley (1991) investigated the extent to which different question types enhanced or detracted from retention and recall through free recall and matching tasks. In both tasks, students who were asked the confirm-specific questions (i.e., “Why does this make sense given what you know about this particular province?”) scored highest. In the case of the recall task, this group’s mean score was significantly higher than all other groups and the reading placebo control group. In the case of the matching task, the confirm-specific group mean again was the highest, and significantly higher than both unexpected formats (i.e., unexpected-specific and unexpected-other). There was no significant difference between the scores of the confirm-specific and confirm-other groups.

The finding from this research was that a why-question that diverts attention from the to-be-learned fact does not facilitate learning (Martin & Pressley, 1991). The

confirm-specific question focused attention on the province-fact association more so than the other question formats, thus improving associative memory.

It should also be noted that the manner of asking and answering why-questions has varied in the literature. In many cases, the question is answered orally (e.g., O'Reilly et al., 1998; Pressley et al., 1987; Pressley et al., 1988; Woloshyn et al., 1992; Wood et al., 1990). In other cases, students answered why-questions in writing (e.g., Dornisch, 2001; McDaniel & Donnelly, 1996; Ozgungor, 2002; Seifert, 1993; Smith, 2003).

In the current research, the why-questions were similar to the confirm-specific format of Martin and Pressley (1991). In text R, the question asked was, "Why does this structure make sense?" and was posed each time a specific Lewis structure was described and presented. In text T, questions were posed after 15 specific facts stated in the text. All the text-T questions were the same, namely, "Why does this make sense?" The same question in the same format was posed each time in order to be consistent with most of the previously reported literature and to avoid introducing an extraneous variable to this investigation. Students answered why-questions in writing.

#### *Knowledge of the Criterion Task*

The more knowledge a student has concerning the criterion task before studying, the more focused the student can be while studying (T. H. Anderson & Armbruster, 1984). Woloshyn et al. (1990) investigated the effectiveness of learning strategies, including elaborative interrogation, when the criterion task was known (intentional learning) and when it was not known (incidental learning). One group of students was told that there would be a test and another group was not told, yet all

students were, in fact, tested. Students using elaborative interrogation in an incidental manner learned more than students using visual imagery or students who reread the text. In the case of intentional learning, students using elaborative interrogation performed equal to the rereading group on free recall and fact recall tests. On one type of test, an associative matching test, the elaborative interrogation students performed better than those who were assigned the rereading strategy. The important point from Woloshyn et al. is that elaborative interrogation may not be as potent in intentional learning situations where the criterion task is known.

In learning facts about Canadian universities, incidental-learning students performed equally well as intentional-learning students on a posttest concerning the to-be-learned facts about Canadian universities. When interviewed, some of the incidental-learning subjects admitted they suspected there might be a test, but most indicated they had not expected one.

In the current research, an intentional-learning model was employed. This was considered important because college students generally engage in intentional learning. Students were told a test would be given at the conclusion of the reading. In some strategy research, an incidental-learning model was believed to “promote the processing intended by the experimenter” (Pressley et al., 1988, p. 269) and was used in other studies as well (e.g., Pressley et al., 1989; Woloshyn et al., 1990). However, since most college reading is done in preparation for a criterion task, and it is known that students learn better when they know about the criterion task, the criterion task was clearly described to students in this experiment.

### *Role of Prior Knowledge*

Generally, prior knowledge is well established as an important factor affecting learning (Dochy, Segers, & Buehl, 1999), and especially in learning supported by the use of cognitive strategies (Caverly et al., 2000). A fundamental component of the elaborative interrogation hypothesis is that asking why-questions should stimulate active processing that causes cognitive associations to be constructed between new material and previously known material. In other words, asking a reader why something in the text is true should activate the reader's prior knowledge about that topic. Associating new knowledge with prior knowledge (which, by the way, is usually not explicitly stated in the text) should help the reader assimilate the new knowledge more effectively (Pressley et al., 1987; Pressley et al., 1988).

At least two studies confirmed that the efficacy of elaborative interrogation depends on a minimum knowledge base in readers (Willoughby et al., 1994; Woloshyn et al., 1992).

Woloshyn et al. (1992) explored the role of prior knowledge in the elaborative interrogation strategy by studying college students in two countries, Canada and Germany (specifically in West Germany, a country that existed at the time of their research, but no longer exists). The to-be-learned facts concerned information about Canadian provinces and West German states. Canadian students were believed to have higher prior knowledge than German students concerning Canadian facts. Likewise, it was presumed that German students had higher prior knowledge of German states compared to Canadian students. The experiment compared an elaborative interrogation group with a rereading group.



Students from each county were assigned either facts about their own country or unfamiliar facts about the other country. Examples of such facts included, “The first humane society was founded in the province of Quebec,” and “The state with the most university teachers is North Rhine Westphalia,” for Canada and West Germany, respectively. Reading was then conducted with the elaborative interrogation intervention or repetitive reading. The results showed that students with high prior knowledge had much better memory of facts in the elaborative interrogation intervention. This difference based on prior knowledge was also observed in the repetitive reading group as well. That is, students in the repetitive reading group with high prior knowledge outperformed subjects with low prior knowledge as was the case with the elaborative interrogation group.

Woloshyn et al. (1992) further compared results for the elaborative interrogation group having low prior knowledge (e.g., West Germans learning Canadian facts) with the rereading group having high prior knowledge (e.g., Canadians learning Canadian facts). Using the elaborative interrogation strategy did not provide a benefit to learners with low prior knowledge about a content area. In other words, the strategy could not compensate for a lack of prior knowledge. This is a finding consistent with other research concerning most learning strategies (Caverly et al., 2000).

Willoughby et al. (1994) pursued a similar question concerning the role of prior knowledge in the use of elaborative interrogation. In research also involving college students, Willoughby et al. used facts about animals in one experiment and facts about a fantasy novel in other experiments. In each case, a standard was used to

designate some facts as familiar and other facts as unfamiliar to the participating students, who employed one of several assigned strategies while reading: elaborative interrogation, mental imagery, or repetitive reading. An additional strategy was employed in the fantasy novel experiments: a keyword technique involving word association. After reading facts and applying the assigned technique, students were tested about the facts in a recall test. In the animal-facts experiment, some students received a picture of the animal as well in order to investigate the role of a context cue.

In the case of animals, 10 were used where the swift fox, house mouse, little brown bat, Townsend mole, and the Western spotted skunk were judged to be familiar animals. The pronghorn, coati, chickaree, American pika, and collared peccary were judged as unfamiliar animals. Familiarity or unfamiliarity was determined through testing of an equivalent population (Willoughby et al., 1993). Example facts included “When it is hungry, the swift fox eats rabbits, squirrels, and mice,” and “The collared peccary’s stomach has two compartments.”

Novel facts for other experiments in Willoughby et al. (1994) were based on a fantasy book series. Familiarity was defined as having read the books before the experiment. Students who had not read the books, which depict imaginary islands with unusual characteristics, were deemed to be unfamiliar with the content. Willoughby et al. found that elaborative interrogation was a more effective strategy for participants who possessed higher prior knowledge. Among those with high prior knowledge, the posttest mean score in the elaborative interrogation intervention was about the same as posttest mean score in the mental imagery intervention. Both

elaborative interrogation and mental imagery were more potent than repetitive reading when prior knowledge was high.

When prior knowledge was low, however, the results were much different. In this case, mental imagery was the more effective strategy, while elaborative interrogation had about the same effect as repetitive reading. Willoughby et al. (1994) postulated that this was the case because mental imagery involves all the facts at hand and a personally-generated image to mediate them, whereas elaborative interrogation requires the reader to go beyond the given facts.

Extending this line of research, Willoughby et al. (2003) explored the learning of the animal facts in differently structured formats. The animal experiments in Willoughby et al. (1994) contained facts in a predetermined organization created by the researchers; specifically, the facts were grouped by animal. In Willoughby et al. (2003), another organizational scheme, grouping by animal behavior, was also employed. This system was determined to be the one preferred by a majority of similar college students in a separate survey. Willoughby et al. (2003) observed an advantage for participants who received the facts in the fashion apparently preferred by the tested population. The difference between students with high prior knowledge and low prior knowledge was also reconfirmed in this research. Facts for the familiar animals were recalled at a higher rate on the posttest than facts for the unfamiliar animals.

In a related vein, Woloshyn, Paivio, and Pressley (1994) reported the use of the elaborative interrogation strategy with participants whose prior knowledge was or might be inconsistent with to-be-learned material. It was presumed that if correct

prior knowledge contradicts new material, then students will struggle in their learning.

Woloshyn et al. (1994) used science information as the to-be-learned targets with students in grades 6 and 7, and employed various types of text, including traditional, refutational, and inverted refutational. The refutational sentences contained an initiating refuting phrase such as, “although some people believe...,” followed by the science fact. The inverted refutational sentences began with the science fact and concluded with a refuting phrase. Some facts were considered consistent with prior knowledge and some inconsistent. These designations were made based on survey results involving elementary school students who were asked to choose correct statements from a long list of science facts taken from elementary school science books. An example of a sentence judged to be consistent with prior knowledge, in refutational format, was “Although some people think that the size of a star is always the same, the size changes.” An example of a sentence inconsistent with prior knowledge was, “Not all plants have roots, although some people think that all plants have them” (in inverted refutational format).

The elaborative interrogation strategy benefited students in learning facts whether consistent or inconsistent with their prior knowledge. Woloshyn et al. (1994) attributed the potency of elaborative interrogation for learning both types of facts to the effect of forcing students’ attention on the to-be-learned fact by asking why it is true. Students were told in advance that all statements in the treatment were true.

An interesting perspective on the importance of prior knowledge was found in McDaniel and Donnelly (1996). Their research, which primarily explored the potency

of elaborative interrogation in factual and inferential learning, also contained interesting data about the nature of student answers to why-questions. The to-be-learned material in McDaniel and Donnelly was science facts in the domains of astronomy, biology, and physics. The participants were college students. Unlike previous research, McDaniel and Donnelly reported the extent to which why-question answers were actually based on prior knowledge. They found a surprisingly low reliance on prior knowledge, even among students deemed to have a reasonable base of content knowledge. Among all students, prior knowledge was used in answering why-questions only about 5% of the time, on average. Among the expert students (defined as those who had completed at least 10 science courses in high school or college), the average use of prior knowledge in answering why-questions was about 12%. The remaining answers were based on information found within the text itself, implying a look-back process being used by students nearly all of the time. It may be that the look-back impulse in college students results from many years of answering adjunct questions and is too strong to overcome in initial use of elaborative interrogation. This aspect of the research of McDaniel and Donnelly is interesting in that a benefit was found from elaborative interrogation, although students apparently did not use their prior knowledge in their why-question answers to obtain that benefit.

In the current research, a test was given to participants in order to measure their prior knowledge concerning information related to Lewis structures. Such direct testing of students' prior knowledge in elaborative interrogation literature is not commonly reported, but has been recommended (Shapiro, 2004). Later, in the statistical analyses, a median split was performed to create two groups, a high-prior-

knowledge group and a low-prior-knowledge group. The effectiveness of the strategies for each group was then determined.

### *Quality of Why-question Answers*

Researchers have used different methods for judging the quality of answers to why-questions. The terms used to classify the answers vary among research groups, but the general idea is to distinguish between good answers and poor answers. In all experiments, some why-questions are not answered and left blank by some participants. Reported rates of blank answers range from 1% (Smith, 2003) to 27% (Pressley, 1988).

Pressley et al. (1988) used a classification system of “precise” and “imprecise” for why-question answers in two experiments (utilizing man-sentence facts). They employed a classification system of “adequate” and “inadequate” for other experiments (one utilizing facts about Canada and the other utilizing facts about males and females). The trends to emerge were that better why-question answers (precise or adequate) correlated with higher recall scores on specific facts than poorer why-question answers (imprecise or inadequate), and that any answer (precise/imprecise, or adequate/inadequate) correlated with higher recall scores than no answer at all. In other words, items for which the why-questions were answered adequately during the intervention were items that were more likely to be answered correctly on a posttest activity. Presumably, participants with higher prior knowledge had the foundation to answer why-questions better, but the very act of answering focuses attention on the facts to be learned (Pressley et al., 1988). The no-answer rates for the four experiments ranged from 16% to 27%.

Woloshyn et al. (1990) reported similar results in their research also involving college students using to-be-learned facts concerning Canadian universities. In both free recall and matching tasks, better why-question answers were associated with higher scores on specific facts than inadequate answers, which were associated with higher scores than no answer at all. Woloshyn et al. (1990) observed no-answer rates ranging from 8% to 14%. Generally similar adequate/inadequate results were reported by Martin and Pressley (1991) in their research using facts about Canadian provinces and by Woloshyn et al. (1992) in their research involving facts about Canada and Germany.

In a slightly different categorization method, McDaniel and Donnelly (1996) classified why-question answers as relying on prior knowledge or not. As reported above, they found that there was little reliance on prior knowledge in answering why-questions in their research. Greene, Symons, and Richards (1996) used an analysis system of precise/imprecise with an additional designation as to whether answers relied on prior knowledge or not. This system included “precise-using-prior-knowledge” and “imprecise-using-prior knowledge.” As with other research before theirs, Greene et al. found that precise why-question answers about specific facts had higher correlations to recall than imprecise or no response. Use of prior knowledge in an answer had a higher correlation with recall than not using it. Among those using prior knowledge, precise answers to why-questions correlated with higher recall than imprecise answers.

Seifert (1993) used yet another evaluation protocol for answers to why-questions in his research involving animal facts. He used the distinction of

“explanatory” and “nonexplanatory” as the initial differentiator, that is, answers that provided an explanation to the question and those that did not. Then, among the answers that were explanatory, he distinguished them as being correct or incorrect explanations. In other words, he had four categories, correct-explanatory, incorrect-explanatory, nonexplanatory, and blank. Interestingly, in several different procedures involving elaborative interrogation, Seifert reported no significant differences among the correlations between why-question answers and recall for any category of answer. That is to say, the quality of the answer appeared not to have any impact on recall whatsoever. However, it may be important to note that Seifert conducted research with subjects in grades 6 and 7 (issues regarding age appropriateness are addressed below).

Similar to Seifert (1993), Smith (2003) used a four-tier evaluation system to evaluate why-question answers. In this research involving facts about biology, why-question answers were judged as adequate-correct if they were correct and used appropriate scientific principles. Answers using scientific principles, but in too general a fashion to address the question were assigned the designation adequate-incorrect. The classification, inadequate, was used for why-question answers that did not clarify why the statement was true. The fourth category was no-response.

In some research, no data have been reported about the quality of why-question answers. Gaultney (1998) reported research involving the apparent use of elaborative interrogation in a reading about sports facts. Her conclusion was that elaborative interrogation provided a benefit to grades 4 and 5 students with average intelligence, but no benefit, and perhaps caused a detriment, to gifted students.



However, the description of the experiment indicated that students were simply instructed to ask themselves “why” when they read information that they did not understand. There was, apparently, no instruction to *answer* the why-question. There also was no report of any assumption that, once the why-question was posed, students would spontaneously attempt to answer it. Given the importance of attempting to answer the why-question in the elaborative interrogation strategy, many students in the Gaultney investigation may not have implemented the assigned strategy. In addition, Meij (1990) counseled that question-asking alone is not sufficient in learning. The elaborative interrogation strategy is potent only when a why-question is both asked *and* answered.

In the current research, why-question answers were assessed and ranked by using a system modeled on the evaluation approaches of Seifert (1993) and Smith (2003). Although their specific category designations were different, the systems were similar in that they each used four answer types, which could be described as: (a) correct answer using appropriate concepts or ideas in the domain of the reading, (b) not-complete or not-correct answer that still included concepts or ideas in the domain, (c) incorrect answer that did not use concepts or ideas in the domain, and (d) no answer at all. The four category designations used in the current research for these four answer types were adequate, inadequate, nonexplanatory, and blank, respectively. Adequate answers were correct answers that used chemistry concepts and ideas appropriately. Inadequate answers were defined as those with incomplete or incorrect use of chemistry concepts. Nonexplanatory answers were those that did not address the question with chemistry concepts. The percentage of blank answers was

consistent with previous research: 15% for one reading and 19% for the other. Unlike previous research, correlation analysis of why-question answer quality with recall was not possible since there was not a matched relationship among a single new fact, a corresponding why-question, and a particular recall test item.

### *Age Appropriateness*

Two studies cited above involved elementary students (Gaultney, 1998; Seifert, 1993) and found results inconsistent with the results of elaborative interrogation studies with adult college students. These results may raise questions about the utility of elaborative interrogation with younger students.

On one hand, younger students are accustomed to asking “why” from a very early age and this may mediate their use of the strategy (Willoughby et al., 1999). On the other hand, younger students have a smaller breadth of experiences and formal education, thus perhaps limiting their prior knowledge base in certain domains. Willoughby et al. (1994) did find positive results using elaborative interrogation with elementary students in grades 6 and 7.

Wood et al. (1990) reported a comparison of the elaborative interrogation strategy use with students in grades 4 through 8 involving the learning of man-sentence facts as well as animal facts in separate experiments. Results showed that there was increased benefit with age using elaborative interrogation. When analyzed by a median split, where the median age was 11 years and 7 months, older students achieved significantly higher recall when using elaborative interrogation with the man-sentences. This was not the case for other techniques such as mental imagery and provided-precise-elaborations, where the older and younger students scored

essentially the same. Wood et al. reported a high and positive age-performance correlation in the man sentence facts using elaborative interrogation.

In the experiments of Wood et al. (1990) involving sentences about animal facts, there was little difference in recall among subjects who read text with (a) no strategy, (b) precise elaborations, (c) mental imagery prompts, (d) precise elaborations and mental imagery prompts, and (e) why-questions. Recall was high for the why-question group suggesting that the strategy can indeed be helpful for students in grades 4 through 8; the recall level for this group rivaled that of the group assigned to use imagery. As with adults, levels of prior knowledge apparently made a difference. Although some of the man-sentence experiment results did not follow the trend, in general, good why-question answers had a higher correlation to recall than poor answers, which had a higher correlation to recall than no answers.

Willoughby et al. (1999) examined students in grades 2, 4, and 6, using 40 animal facts (some for familiar and some for unfamiliar animals) as the to-be-learned targets. Participants were divided into groups using elaborative interrogation, mental imagery, or keywords. Willoughby et al. found a three-way interaction of strategy, grade, and familiarity. In general, the grade 6 students had higher recall than grade 4 students who had higher recall than those in grade 2. Recall of familiar animals was higher in all grades compared to recall of unfamiliar animals. Recall results for elaborative interrogation students were virtually the same in all three grades as was the case for the keyword strategy. Interestingly, the imagery students showed increasing recall with age. Willoughby et al. postulated that increasing potency of imagery is associated with maturation of cognitive resources with age.

Overall, research indicated that elaborative interrogation can be a robust learning strategy for subjects of all ages, though benefits appear to increase with age. The strategy was effective when users possessed sufficient domain knowledge in the content area to activate it through why-questioning.

In the current research, participants ranged in age from 18 to 58, with a mean age of 24. The literature indicated that such students should be cognitively capable of implementing the elaborative interrogation strategy.

#### *Format of To-be-learned Material*

Typically, the to-be-learned target in much of the early elaborative interrogation literature consisted of facts presented in individual sentence format (e.g., Pressley et al., 1987; Pressley et al., 1988; Martin & Pressley, 1991). The man-sentences were the earliest examples. Woloshyn et al. (1990) reconstituted lists of related facts into paragraph formats, but as Seifert (1993) argued, these were paragraphs in form only. They were not well constructed, nor were they authentic paragraphs with a main idea followed by supportive sentences.

Seifert (1993) made one of the early attempts to use more authentic reading materials in elaborative interrogation research. In addition to testing for the facts as presented in the reading, he also asked his elementary school subjects a posttest question intended to require participants to make an inference from the reading. He found no difference in achievement on the factual questions or the inference question among participants using different reading strategies. However, it can be argued that his results were inconclusive at best. Seifert noted that the text provided information

to answer the intended inferential question and that having only one such question was insufficient.

More recently, there has been interest in using wholly authentic text with elaborative interrogation. Smith (2003) utilized authentic college level science text with biology facts about the human digestive system as the to-be-learned targets. Students read the materials using either the elaborative interrogation strategy or repetitive reading. Those using elaborative interrogation benefited with greater recall on a posttest than those who used repetitive reading. Hill (1999) also employed elaborative interrogation in an authentic setting with medical school students using online learning materials, but reported no benefit to students utilizing the technique.

In the current research, both artificial and authentic readings were used. Text composed by the researcher was intended to serve as a link to the previous research. It was a reading consisting of 15 paragraphs, each about one Lewis structure and followed by a figure of the structure. All paragraphs were constructed in parallel format. The authentic text was the text taken from the CH 101 (Chemistry 101) general chemistry textbook. Research using authentic text is potentially particularly interesting for researchers, teachers, and students.

#### *Nature of Recall Measures*

The early elaborative interrogation researchers generally reported the use of free recall or recall association posttests. In the latter, the sentences in the reading were used unchanged in the tests. Students were asked to match a man, an animal, a province, etc., with a statement or prompt. These were the same statements students had been provided in the readings.

Taking the test measure a step further, McDaniel and Donnelly (1996) investigated whether elaborative interrogation is an effective strategy for inferential learning, that is, learning that goes beyond the facts presented. Such questions are transfer-type questions compared to retention-type questions used in most of the previous literature. In a previous work (Donnelly & McDaniel, 1993), they had shown the effectiveness of analogical text in increasing inferential learning, although it did not improve factual learning. Beginning from the premise that literal text is better for factual learning and analogical text is better for inferential learning, their later work reported in 1996 investigated the potency of elaborative interrogation with both types of text, literal and analogical, and both types of learning targets, factual and inferential. They concluded that elaborative interrogation is an effective strategy for increasing both factual and inferential learning, whether the text is literal or analogical.

Seifert (1993) as well as McDaniel and Donnelly (1996) employed posttest questions that required an answer developed by inference from the facts presented in the reading. In the case of McDaniel and Donnelly, elaborative interrogation was found to be an effective technique for college students to improve both factual and inferential learning when reading scientific technical prose.

In the current research, the nature of the test items differed for the two different readings. Since the researcher-authored text contained facts about 15 Lewis structures as well as a figure of each structure, the posttest questions for students who read this text were retention-type questions. Students had seen the formulas and the structures in the reading and were asked to draw them on the test. On the other hand,

students assigned to the authentic text had read about the process for constructing Lewis structures. For these students, the questions on the test were inferential (i.e., transfer-type questions) since they were applying what they had learned to new situations.

### *Time on Task*

Time on task is of interest in this study, since two different strategies were employed with text. It is, therefore, important to note how it has been treated in previous research. In most of the elaborative interrogation literature, time on task was controlled. Participants were typically shown an individual sentence in a timed setting ranging from 7 to 20 seconds per sentence (e.g., Pressley et al., 1988, for 7.5 seconds in Experiment One; Willoughby et al., 1994, for 15 seconds in Experiment One; and Woloshyn et al., 1992, for 10 seconds in Experiment One). While this technique carefully controls time on task, it does not represent authentic reading situations nor does it recognize reading rate differences among students.

In the current research, students were permitted to read at their own pace. An upper limit of 40 minutes was imposed, but there was no limit on exposure to individual sentences or paragraphs. The mean reading time for all students ( $N = 252$ ) was 22 minutes, with only six students (i.e., less than 3%) reading for the full 40 minutes allowed. It was expected that students using elaborative interrogation (with instructions to read text one time and answer questions) would require the same amount of time as students using repetitive reading (with instructions to read text twice). However, this was not the case. Students using elaborative interrogation required significantly more time, on average, to complete the reading compared to

students rereading text, a result also reported by Ozgungor (2002). This issue will be addressed more thoroughly in Chapter Four.

### *Nonsupportive Evidence Concerning Why-questions*

Not all of the research addressing the elaborative interrogation strategy has found positive effects from its use. In research with second-year medical students (Hill, 1999), no benefit was found by assigning the use of elaborative interrogation with an online supplemental lesson. Likewise, Ward (1999) also found no advantage for students assigned to use elaborative interrogation on factual, novel, or problem-solving posttest questions. Both Hill and Ward utilized authentic learning materials in their work. The same was true of Ems-Wilson (2000) who investigated the strategy with college chemistry students learning about solvent properties.

In the case of Hill (1999) and Ward (1999), it is possible that the design of their research inhibited the elaborative interrogation strategy from showing a positive effect. Hill reported that the online lecture supplement used in the study was being implemented for the first time in class. The timing of the investigation, the low number of participants (*viz.*, 20), and students' reported lack of computer experience, may have all contributed to poor results. In addition, the design of the experiment allowed participants to determine their own placement and frequency of asking why-questions. Ward found no differences among several assigned learning strategies, but also reported that participating students exhibited low engagement in the research task. The experiences of both Hill and Ward provided cautionary insights for the present work.



O'Reilly et al. (1998) reported no advantage for college students using elaborative interrogation as compared to a so-called "self-explanation" strategy in learning science facts about the cardiovascular system. However, there may be a rival explanation for their conclusions. They reported three strategies in their experimental sample in learning facts from a reading about the cardiovascular system, namely elaborative interrogation, self-explanation, and repetitive reading. The self-explanation subjects outperformed both the elaborative interrogation and repetition groups. However, it could be argued that the self-explanation strategy, in fact, was actually an elaboration strategy or at least a form of it. The self-explanation group was prompted with a statement and two questions, compared to a single question for elaborative interrogation students. The self-explanation asked students to explain what the facts meant to them and *how they related to their prior knowledge*. Since this last point is essentially the goal of elaboration, this self-explanation strategy might better be described as a combination strategy, being elaborative with a metacognitive aspect as well. In any case, O'Reilly et al.'s results provide compelling evidence that stimulating cognitive associations between to-be-learned material and prior knowledge is effective, no matter what the technique is called.

## Lewis Structures

### *Introduction*

Chemistry is the science that studies matter. Matter is composed ultimately of atoms in the form of elements and compounds. There are millions of known compounds, which are formed by the combination of two or more elements. The nature of the combination varies from instance to instance, but there are two key

methods by which atoms combine: through transfer of electrons or through sharing of electrons. The former process is referred to as ionic bonding and the latter is called covalent bonding.

In chemistry classes, students learn extensively about compounds and bonding. In addition to learning concepts, students are also taught how to depict compounds and show their bonds, which hold atoms together. Lewis structures are those representations of molecules (or polyatomic ions) that show how atoms are arranged and how shared valence electrons form bonds.

### *Lewis Structure Research: Theory and Instruction*

Drawing Lewis structures is a detail-oriented skill that relies on prior knowledge of certain chemistry facts as well as an understanding of chemistry rules. Experienced chemists draw Lewis structures with ease, but this can be difficult for chemistry students (Ahmad & Omar, 1992; Carroll, 1986). Peterson and Treagust (1989) found that, among Australian grade-12 students learning to draw Lewis structures, 20% to 35% of them held misconceptions about various aspects of structures.

Chemistry educators have examined and reviewed the teaching and learning of Lewis structure construction and interpretation. This literature has various emphases, including (a) refinement of the procedures and concepts used in determining a structure (e.g., Ahmad & Omar, 1992; Carroll, 1986; Pardo, 1989), (b) clarification of situations where the normal rules are broken (e.g., Malerich, 1987), (c) simplification of the process for nonscience college majors (e.g., Miburo, 1998), as well as (d) admonition to be mindful that Lewis structures, as simple models,

contain limited information about true structures (Purser, 1999). Concerning this final point, Purser emphasized that Lewis structures by themselves do not necessarily inform chemists or students about important chemical issues such as bond formation on the subatomic level in the spaces chemists refer to as orbitals.

There have also been proposals to overhaul the Lewis structure notation and even change the thinking about how molecules are formed. Clark (2002) recommended replacing the currently-used representation for electrons, lines and dots, with equilibrium arrows and “blurs” to signify the dynamic nature of electrons. He argued that the use of lines and dots originated from a theoretical stance that electrons are static, a position held by many, including Lewis himself, in the early 1900s. Scientists now know that electrons are constantly moving and Clark argued that symbols for molecules could be altered to reflect better this reality to chemists and students.

Another group has proposed that the traditional octet rule should be modified or discarded (D. L. Cooper, Cunningham, Gerratt, Karadakov, & Raimondi, 1994). For nearly a century, the octet rule has guided chemists and students in understanding how bonds are formed. As the rule’s name implies, there is significance in a set of eight electrons “belonging” to an atom. In a Lewis structure, ownership of particular electrons is assigned to both of the atoms that share it. For example, in the Lewis structure for  $H_2$ , drawn as  $H-H$ , the line represents two electrons being shared by each hydrogen atom. Chemists say that the H on the left “has use of” two electrons and that the H on the right also “has” two electrons. In other words, when atoms share electrons, the electrons are considered to belong to both atoms. (The notion of

assigning electron ownership in this manner is a simplification sometimes used by chemists to explain more complex concepts.) The octet rule has evolved over the century and is now usually couched in terms of atoms achieving a stable configuration of electrons, specifically similar to the most stable elemental atoms, the noble gases (the family of elements on the far right end of the periodic table: helium, neon, argon, krypton, xenon, and radon). In the case of H—H, chemists say that each H has attained the electron configuration of helium.

The octet rule is obeyed in most bonding situations, but it is also broken in some instances. There are cases of bonds forming with more than eight electrons assigned to atoms and other cases where bonds form but atoms are assigned fewer than eight electrons. College level chemistry texts typically address octet rule exceptions as part of the instruction on constructing Lewis structures (e.g., T. L. Brown et al., 2003; Ebbing & Gammon, 2002; Kotz & Treichel, 2003). The exceptions can be rationalized using higher level chemistry concepts, such as orbital hybridization, atomic size trends, and resonance theory. D. L. Cooper et al. (1994) suggested replacing the octet rule with a so-called democracy principle. They stated it humorously as, “it is the democratic right of every valence electron to take part in chemical bonding if it wants!” (D. L. Cooper et al., p. 4414). Technically stated, any valence electron can participate in bonding if there is energetic basis for it to do so.

The complexity of structural issues was also reflected in the work of Suidan, Badenhop, Glendening, and Weinhold (1995), which used bonding theories and experimental evidence to argue that the likelihood of structures exceeding octets is less likely than previously held. They demonstrated that for substances such as the

polyatomic ion sulfate,  $\text{SO}_4^{2-}$ , the role of the resonance structure showing sulfur exceeding an octet with two double bonds and two single bonds (rationalized by the participation of  $d$  orbitals in hybridization) has less of a relationship to the true structure than other more unusual structures involving ionic bonding between sulfur and oxygen yet maintaining octets for all atoms. Suidan et al. cautioned against a rush to exceed octets for compounds involving elements of the third period and beyond, as is commonly taught in college level general chemistry texts.

### *College Chemistry Textbook Instruction*

An examination of three popular college level general chemistry textbooks for science majors showed similar approaches to the instruction about Lewis structures (T. L. Brown et al., 2003; Ebbing & Gammon, 2002; Kotz & Treichel, 2003). The thrust of the approach in T. L. Brown et al. was to account for the number of valence electrons, then arrange the atoms in a skeleton, and finally place electrons appropriately in the structure according to the octet rule. In their chapter addressing Lewis structures and bonding (Chapter 8, “Basic Concepts of Chemical Bonding”) there were eight major section headings:

1. Chemical bonds, Lewis symbols, and the octet rule
2. Ionic bonding
3. Covalent bonding
4. Bond polarity and electronegativity
5. Drawing Lewis structures
6. Resonance structures
7. Exceptions to the octet rule

## 8. Strengths of covalent bonds

The specific instructions for drawing Lewis structures appeared mid-chapter, in the fifth section. Throughout the text and sample exercises, T. L. Brown et al. explained the process by which Lewis structures are constructed and the decisions chemists make in the process. In the text, the focus was on understanding the process. T. L. Brown et al. used six different structures to illustrate the concepts of the process.

Among the previous seven chapters in T. L. Brown et al. (2003), material leading up to the Chapter 8 material was found in Chapters 2, 6, and 7, in which topics included atomic theory, electron properties, and periodic trends, respectively.

In the case of Ebbing and Gammon (2002), Lewis structures were introduced in Chapter 9. The chapter began with a brief discussion of ionic bonding, and then proceeded to covalent bonding, where Lewis structures were the central theme. There were 11 sections, in this order:

1. Describing ionic bonds
2. Electronic configurations of ions
3. Ionic radii
4. Describing covalent bonds
5. Polar covalent bonds; Electronegativity
6. Writing Lewis electron-dot formulas
7. Delocalized bonding: resonance
8. Exceptions to the octet rule
9. Formal charge and Lewis formulas
10. Bond length and bond order

## 11. Bond energy

The sixth section dealt most directly with the drawing of Lewis structures. In this section, the authors used six molecules and one polyatomic ion to illustrate the construction process.

Another popular college chemistry text, Kotz and Treichel (2003), introduced Lewis structures in Chapter 9. The chapter consisted of 11 sections, in this order:

1. Valence electrons
2. Chemical bond formation
3. Bonding in ionic compounds
4. Covalent bonding and Lewis structures
5. Resonance
6. Exceptions to the octet rule
7. Charge distribution in covalent bonds and molecules
8. Bond properties
9. Molecular shapes
10. Molecular polarity
11. The DNA story—Revisited

These authors used many more examples, 46 in all, to illustrate Lewis structure concepts.

All of these texts described the construction of Lewis structures as a stepwise process. The order of the steps was slightly different in each text, but the ideas were similar. The steps to draw Lewis structures are not an algorithm, but rather, as some authors have described, a “strategy” (Petrucci & Harwood, 1993). None of the three

texts examined described its steps as the absolute and only way to draw Lewis structures. T. L. Brown et al. (2003) referred to their steps as a “regular procedure.”

Their approach can be paraphrased as follows:

1. Count the number of valence electrons,
2. connect all the atoms with a single bond,
3. complete the octets for the outer atoms,
4. place remaining electrons on the central atom (even if this exceeds an octet), and then
5. shift electrons to make multiple bonds in order to complete octets, if necessary.

The Ebbing and Gammon (2002) approach was similar, although the process was expressed in four steps:

1. Count the number of valence electrons,
2. draw a skeleton of the structure,
3. place electrons on the outer atoms, and then
4. place remaining electrons on the central atom and shift to make multiple bonds, if necessary.

Kotz and Treichel (2003) provided a five-step procedure, in a different order, as follows:

1. Determine the central atom,
2. count the number of valence electrons,
3. draw single covalent bonds between the atoms,



4. place remaining electrons on the outer atoms as lone pairs so that octet rule is obeyed for them, and then
5. if the octet rule is not met for the central atom, shift lone pairs to form double or triple bonds until the rule is met.

Each text also dealt with other issues, including how to count valence electrons for polyatomic anions and cations, and how to determine the most likely arrangement of atoms in the structure (e.g., deciding that  $\text{H}_2\text{O}$  should be  $\text{H—O—H}$  and not  $\text{H—H—O}$ ). Although the details were somewhat different, and the starting points varied, each of these texts instructed students through essentially the same thinking processes.

All of these texts introduced another important topic, formal charge, after the procedure for drawing Lewis structures. Formal charge can be a helpful tool in determining the most likely manner of bond formation. It does not refer to a real charge, but rather a sort of “accounting” procedure” in the realm of electrons (Petrucci & Harwood, 1993, p. 366). In general, when considering more than one plausible Lewis structure, chemists favor the structure that minimizes the absolute formal charges on the atoms. A case where the formal charge on each atom is zero is usually considered an ideal arrangement of atoms and electrons. In T. L. Brown et al. (2003), the formal charge topic came immediately after Lewis structures. In both Ebbing and Gammon (2002) and Kotz and Treichel (2003), this topic came three sections after the introduction of Lewis structures.

Chemistry educators have debated about which is more important to follow when drawing Lewis structures, the octet rule or formal charges. Some have argued in

favor of the octet rule (e.g., Pardo, 1989) and others in favor of formal charge assignment (e.g., Carroll, 1986; Purser, 1999). While formal charge is important, it is also arcane, and can be confusing to general chemistry students. Furthermore, T. L. Brown et al. clearly give the octet rule preference over formal charge determination when deciding on the best Lewis structure. In explaining the case of the phosphate ion ( $\text{PO}_4^{3-}$ ), they wrote that students “should choose the [structure] that satisfies the octet rule” (T. L. Brown et al., p. 300) instead of the structure that minimizes formal charges.

In both texts R and T used in the current text-strategy research, no reference was made to formal charge. The authentic text (T. L. Brown et al., 2003) included information about the procedure to construct Lewis structures as well as a section concerning exceptions to the octet rule. The textbook’s instruction concerning formal charge was not included, both because of its inherently arcane nature and because the text authors, T. L. Brown et al., recommended adherence to the octet rule. The elimination of references to formal charge avoided potential student confusion about the topic and limited the new material focus to Lewis structure construction within the experimental time allowed.

The most recent experimental evidence and theoretical thinking about molecular structure are generally not reflected in college general chemistry textbook instruction on Lewis structures. At least one text has acknowledged the theoretical discussions in a footnote, but indicated that the issues are beyond the scope of general chemistry (T. L. Brown et al., 2003). Purser (1999) has noted that, of all topics in college chemistry textbooks, instruction about Lewis structures and especially related

bonding topics is more inconsistent from author to author than any other topic. In addition, Hurst (2002) contended that college textbooks include too many complex theories to explain bonding, thus making the topic difficult for freshman-level college students to learn.

### *How College Students Learn to Draw Lewis Structures*

In an investigation to understand how college students use information from their instruction when drawing Lewis structures, Brady et al. (1990) identified four major skills in the construction process: (a) identifying the central atom, (b) counting electrons correctly, (c) adjusting electrons within a structure, and (d) miscellaneous. They further identified 12 specific tasks within these four categories and classified them according to difficulty (see Table 2). To draw a given Lewis structure, chemists and students may use some or all of the skills, and usually only one task within a skill. The decisions made about which tasks to employ must be founded on knowledge of important chemistry concepts.

Students in the Brady et al. (1990) study used a computer program to compose Lewis structures for 50 different compounds and polyatomic ions. They were given up to four tries to get the answer right. For some compounds, all or nearly all students drew the correct structure on the first try (e.g., Lewis structures for hydrogen fluoride, HF, and the ammonium ion,  $\text{NH}_4^+$ ). Such compounds or polyatomic ions were classified as “easy” for college students to draw. In other cases, a majority, but not all, of the students got it right the first time. For example, 75% drew nitrogen trifluoride,  $\text{NF}_3$ , and 60% drew the carbonate ion,  $\text{CO}_3^{2-}$ , correctly on the first attempt. Brady et al. called these Lewis structures “average” in difficulty. Few or no

Table 2

*Skills Needed to Draw Lewis Structures*

(Based on Brady et al., 1990)

Specific task	Difficulty	Example and explanation
Identify the central atom		
Trivial case	Easy	CO: there is no central atom
Unique atom	Easy	H <sub>2</sub> O: the O (unique) is central
Ambiguous case	Average-hard	HCN: the central atom is not obvious
Count electrons		
Anion	Easy	SO <sub>4</sub> <sup>2-</sup> : add two for negative charge
Cation	Easy	NH <sub>4</sub> <sup>+</sup> : subtract one for positive charge
Adjust electrons within a structure		
Trivial case	Easy-average	PCl <sub>5</sub> : no adjustment needed
Octet case	Easy-average	PCl <sub>3</sub> : unshared pair on P completes octet
Promotion	Average-hard	CO <sub>3</sub> <sup>2-</sup> : a double bond is required
Excessive electrons	Average-hard	I <sub>3</sub> <sup>-</sup> : central atom exceeds octet
Odd electrons	Hard	NO: there are 11 valence electrons
Deficiency	Hard	BF <sub>3</sub> : central atom has less than octet
Miscellaneous		
Hydrogen Duet	Easy	H <sub>2</sub> O: H atoms share only two electrons

students could draw the correct Lewis structure for some formulas. For example, only one third completed the triiodide ion,  $I_3^-$ , correctly while no student could draw nitrogen monoxide, NO, on the first try. Such structures were labeled “hard.” Based on their analysis, Brady et al. then categorized 50 compounds and polyatomic ions commonly used in college level general chemistry as easy, average, or hard. These three categories will be labeled below as easy-to-learn, average-to-learn, and difficult-to-learn, respectively.

The Brady et al. (1990) work played two important roles in the current research. Their experiment was replicated with a sample of students ( $N = 34$ ) using 10 of Brady et al.’s 50 structures. The replication experiment was conducted in a paper-and-pencil format instead of a computer format since the computer program the Brady group employed was no longer available. As will be demonstrated below, the results of the current work validated the results of Brady et al. Following this experimental validation, then, 15 structures were selected from the Brady et al. list to serve as the Lewis structures on the pretest and posttest of the text-strategy experiment. Specifically, the 15 structures represented an equal mix of easy-to-learn, average-to-learn, and difficult-to-learn structures; in other words, there were five of each category on the pretest and posttest. With this mix of structures, the difficulty level of the tests was intended to be neither too challenging nor too simple.

## CHAPTER 3: RESEARCH DESIGN AND PROCEDURES

### Introduction

Ten research questions were examined in this study in two separate efforts. The first was a descriptive investigation designed to replicate previous research into the manner in which college students learn how to draw Lewis structures (Brady et al., 1990). The purpose of this first investigation was to determine whether the previously reported results would be obtained with a new sample of college students.

The second, and main, investigation focused on reading text with assigned strategies and addressed the remaining nine research questions. The purpose of this experiment was to compare the impact of two reading strategies, elaborative interrogation and rereading, on college chemistry students as they read about drawing Lewis structures.

In this chapter, the replication study is described first followed by the text-strategy investigation. All experimental materials described here can be found in the Appendices, beginning on p. 236.

### Replication of the Brady et Al. Research

#### *Introduction*

Brady et al. (1990) classified 50 Lewis structures as easy-to-learn, average-to-learn, or difficult-to-learn for college students, based on the rate at which college chemistry students answered them correctly on the first attempt when using a special computer-based instructional program. Informal feedback from college chemistry faculty suggested to the researcher that structures on the Brady et al. list were, for the most part, correctly categorized with several exceptions, which the Brady group also

acknowledged. For instance, they noted that compounds appearing at the beginning of the exercise were missed more frequently than others; they speculated that this may have been due to students' initial unfamiliarity with the program.

For each formula tested, Brady et al. (1990) tallied the percentage of students who were able to draw a correct structure on the first attempt. This was their definition of drawing a correct structure, that is, a successful first attempt. These data were used to classify each of the 50 structures as easy-to-learn, average-to-learn, or difficult-to-learn. If 85% to 100% of students could draw a structure correctly on the first attempt, it was classified as easy-to-learn; there were 11 such easy structures. The structures drawn correctly on the first attempt by 55% to 84% of students were classified as average-to-learn; Brady et al. found 23 average structures. The remaining 16 structures were classified as difficult-to-learn. The Brady et al. definition of a difficult-to-learn structure was applied to cases where 0% to 54% of students could draw the structure correctly on the first attempt.

### *Participants*

In the Brady et al. (1990) investigation, 47 first-semester college chemistry students participated after both a lecture presentation and a laboratory exercise concerning Lewis structures had been completed. They then utilized the special computer-based exercise to construct the assigned Lewis structures. There was presumably also an opportunity for students to read and study between the lessons and the exercise.

Students meeting the same profile were not available in this current replication effort. However, college chemistry students with a similar experience in

Lewis structure instruction were identified. Specifically, students at a large urban community college located in a middle Atlantic state were selected. They were situated in the early weeks of the second semester of general chemistry course. These students ( $N = 34$ ) were actually at a more advanced point in the general chemistry curriculum than the Brady et al. students. They had also received Lewis structure instruction in lecture and laboratory during the first semester of general chemistry. In addition, they had taken examinations on the subject. It is also probable that the current sample consisted of stronger students since the weaker first-semester students were less likely to be enrolled in the second-semester course. A holiday break had occurred in the academic calendar between semesters. The replication experiment was then conducted two weeks into the semester. Therefore, with similar but perhaps more extensive experience in drawing Lewis structures, the students in the replication investigation were anticipated to perform better than the Brady et al. subjects (i.e., show a higher percentage of correct answers on the test).

The 34 students chosen for this experiment included 52% males and 48% females, with ages ranging from 18 to 41 ( $M = 22$  years,  $SD = 5$  years). They were students who had done well during the first semester of general chemistry; the results of a self-reported survey showed that 35% had received an A in the first semester, 42% a B, and 23% a C.

### *Materials*

The original experiment in Brady et al. (1990) was administered using a computer-based application. In the replication experiment, a paper-and-pencil Lewis



structure test was used instead. (The computer software program used by Brady et al. was no longer available.)

Ten structures were selected from the Brady et al. (1990) list of 50 structures for the replication experiment test. The Brady group's list was arranged in order from the structure most frequently constructed correctly to the structure least frequently correct. The ranking of structures was based on the percentage of students that answered them correctly. For example, 100% constructed HF correctly, 94% correctly constructed  $\text{BO}_3^{3-}$ , and 93% correctly constructed  $\text{PF}_6^-$ , etc., descending to 0% correctly constructing NO. For this replication investigation, the 10 structures on the test were selected from, as closely as possible, every tenth percentage point on the Brady list. In other words, a structure for which 100% of their students had provided the correct answer on the first try, then a structure for which 90% had provided the correct answer on the first try, then 80%, and so on (see Table 3). Since there was no compound on the list between 18% and 0%, there could be no structure at the 10-percent level.

### *Procedure*

In Brady et al. (1990), students were given four chances to draw a correct Lewis structure for up to 50 different formulas. If an attempted answer was incorrect, the program indicated this fact to the student who was then prompted to try again. The actual number of formulas attempted varied among students, since the overall experiment was limited to the same amount of time for each student. The test in the replication experiment was announced in advance, and students were reminded that the topic was covered in their textbook. No additional instruction was

Table 3

*Formulas for Validation of Lewis Structure Categorization*

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Formula	Percentage of students giving a correct structure on the first attempt (in Brady et al., 1990)
HF	100%
CH <sub>4</sub>	88%
PCl <sub>4</sub> <sup>+</sup>	80%
N <sub>2</sub>	70%
CO <sub>3</sub> <sup>2-</sup>	60%
BrF <sub>4</sub> <sup>-</sup>	50%
OSF <sub>2</sub>	39%
I <sub>3</sub> <sup>-</sup>	36%
FNO <sub>2</sub>	18%
NO	0%

---

provided. Students were encouraged to review the topic in preparation for the test.

Testing was conducted by the professor teaching a second-semester general chemistry class during a regularly scheduled session. During the test session, students received a test paper containing 10 formulas with space to draw each formula's Lewis structure.

Students were allowed 20 minutes to complete the exercise.

## *Scoring*

The Lewis structures drawn by the students in this replication research were scored as either correct or incorrect; no partial-credit scores were assigned. In order to be counted as correct, a structure had to be drawn with the correct arrangement of atoms, the correct number of electrons, and the correct positioning of those electrons. This method reflected the Brady et al. (1990) scoring procedure in that the answers submitted by the students on the test sheet represented their “first attempts” for each structure. In other words, the students in this replication received no feedback, in contrast to the Brady et al. students who did receive feedback during their computer-based investigation. The remainder of the grading of students’ submitted structures in the replication experiment was parallel, then, to the Brady et al. scoring method of considering only the students’ first attempted answer.

To be consistent with Brady et al. (1990), their standards were applied in the grading of the replication test. In cases where more than one resonance structure was possible, any one was counted as correct, if the structures were equivalent (e.g., in the case of  $\text{CO}_3^{2-}$ ). However, one of the formulas on the replication test,  $\text{FNO}_2$ , has three conceivable resonance structures. Chemists recognize that two of them are more plausible than the third. The least likely resonance structure of  $\text{FNO}_2$  was counted as incorrect by Brady et al. (J. L. Burmeister, personal communication, March 26, 2004). Therefore, it was counted as incorrect here. Six students had written this errant resonance structure as their answer in the current research. In this way, the grading on the replication test mirrored exactly what was done by Brady et al.

The results of this replication are presented in Chapter Four.

## Text-Strategy Research

### *Introduction*

A sample of students attending a community college was randomly assigned to the four different treatment groups using the two reading strategies applied to two different texts. A pretest-posttest model using a  $2 \times 2$  factorial design was employed to evaluate the students' learning gains in the four treatments. Additional factors were also investigated, such as the role of prior knowledge and the quality of subjects' written responses to questions that were answered while reading.

Nine research questions (see Chapter One) were investigated in the text-strategy investigation portion of this research. These nine questions were subdivided into three groups of three questions. One experiment involving four treatments was conducted to address all nine questions. The answers to the research questions were derived from subdivisions of the results. For instance, all students' results were used to answer research questions numbered 2 to 4. Then, the results of those who read one text (about half of the full sample) were used to answer research questions numbered 5 to 7. And finally, the results of those who read the other text were used to answer questions numbered 8 to 10. In all cases, the dependent variable of interest was a gain score, that is, the difference in scores on the pretest and posttest.

### *Participants*

#### *Selection of Students*

The students in this research were enrolled at a large urban community college located in a middle Atlantic state. They were registered in the first semester college level general chemistry course designed for science majors, CH 101 (Chemistry 101).

As is typical at most colleges and universities, this general chemistry course includes a lecture component and a laboratory component. The lecture and laboratory meet three hours and four hours per week, respectively, during a 15-week semester. The experiment was conducted over a two-week period, about one third of the way through the course during 13 laboratory sessions. Each of these sessions had 12 to 25 students, with an average of 20 students per section. The chemistry faculty of the institution cooperated with the researcher to arrange for access to students.

A week before the experiment, an announcement was made in each of the 13 laboratory sections used in the experiment that an exercise would be conducted during the following meeting as part of the instructional preparation for Lewis structure topics covered later in lecture and laboratory. Since the exercise was included as part of the regular four-hour laboratory session, it was apparently convenient for students to participate.

During the researcher's introductory remarks and instructions in each experimental session, it was explained to students that their participation was not mandatory and that there would be no impact on their course grade by participating or not participating. Of the 260 students that the researcher encountered, only four opted not to participate. Another four students were 17 years old and thus not eligible to sign the consent form. Therefore, the number of participants was reduced to 252.

#### *Description of Sample*

The sample of 252 students consisted of 149 females (59%) and 102 males (41%), with one participant not reporting gender. This distribution of females and males mirrored the student population at the community college where the

experiment was conducted. The mean age of students was 24 ( $SD = 7$ ), with an age range of 18 to 58. A majority of participants were in the younger age range of 18 to 21. Colleges sometimes use the age designations of “traditional students” to refer to younger students recently out of secondary school and “returning students” to refer to older students who may have taken time off between secondary school and higher education. A convenient, if arbitrary, cutoff for this distinction is the age of 21. In other words, students 21 and under are labeled as traditional, and those who are older than 21 are labeled as returning. Using these definitions, the sample consisted of nearly equal proportions of traditional students ( $n = 131$ ) and returning students ( $n = 119$ ). Differences in academic backgrounds, maturity, and motivation between these groups can have an impact on the classroom environment.

College level general chemistry is typically not a student’s first academic encounter with chemistry. In this sample, 86% of students reported that they had completed high school chemistry and 36% reported completing a one-semester introductory chemistry course, CH 100 (Chemistry 100), at the college. This course, usually taught without a laboratory component, focuses on high school chemistry topics in order to prepare students for the two-semester college level general chemistry lecture-plus-laboratory course. Students who did not take high school chemistry are required to take CH 100 before taking the college level general chemistry course, CH 101. Some high-school-chemistry completers elect to take CH 100 as a refresher or for additional preparation. Among the 252 participants, 65 had completed both high school chemistry and CH 100. Only eight reported completing

neither high school chemistry nor CH100; admission into general chemistry in such a case normally requires special faculty permission.

This particular community college has a large population of international students, a phenomenon not uncommon among urban community colleges located on the East Coast of the U.S. The data in Table 4 demonstrate that the sample was split almost into half U.S. students and half international students; 49% were U.S. and 51% were international. The international students were born in 49 different countries. Many of these students completed their secondary education in their native country in their native language. The international origins by continent were 47 students from Africa (37%), 46 from Asia (36%), 18 from South America (14%), 13 from North America (10%), and 4 from Europe (3%). This diverse sample of students permitted additional analysis of strategy effectiveness with native U.S. and nonnative international students. The broad range of educational and cultural backgrounds is commonplace to the faculty, staff, and students of this community college. This research project may offer some insights about chemistry learning in all higher educational institutions, especially in cases with a diverse student population.

#### *Timing of the Experiment in the Course*

The timing of this experiment was intended to come before students had received instruction concerning the construction of Lewis structures in the general chemistry course, CH 101. In this way, their familiarity, if any, with the specific topic would come mostly from their prior experiences in science and chemistry courses, but not from a prior lesson in CH 101. Therefore, the experience of reading about Lewis structures in this experiment was the students' first CH 101 exposure to the topic.

Table 4

*Students' Countries of Origin*

Country	<i>n</i>	Country	<i>n</i>	Country	<i>n</i>
Bangladesh	2	Ghana	7	Niger	1
Barbados	1	Guatemala	1	Nigeria	4
Bolivia	5	Guyana	2	Pakistan	6
Brazil	1	Haiti	3	Peru	5
Burma (Myanmar)	2	India	11	Philippines	3
Burundi	1	Indonesia	1	Poland	1
Cambodia	1	Iran	5	Rwanda	1
Cameroon	7	Israel	1	Sierra Leone	7
Chile	1	Ivory Coast	3	South Korea	5
China	1	Jamaica	1	Sudan	1
Colombia	1	Japan	1	Taiwan	1
Cuba	1	Kenya	3	Togo	1
Dominican Republic	1	Lebanon	1	Trinidad and Tobago	2
El Salvador	3	Liberia	2	Ukraine	2
Eritrea	2	Malawi	1	United States	123
Ethiopia	6	Mexico	1	Vietnam	5
France	1	Nicaragua	2		



Since the general chemistry student population at most colleges and universities is typically academically heterogeneous, it was expected that there would be a wide range of prior knowledge levels concerning the topic. This academic heterogeneity is often exhibited in dimensions such as differences in time elapsed since high school chemistry completion, differences in high school chemistry curricula, differences in whether CH 100 was taken, and differences in individual academic achievement.

The to-be-learned target of drawing Lewis structures was located in Chapter 8 of the CH 101 textbook, T. L. Brown et al. (2003). As will be demonstrated in the next section, Chapters 1, 2, 6, and 7 contained important terms and concepts that compose the foundations of the Lewis structure instruction. Within Chapters 1 and 2 were found nearly half of the 27 technical terms later used in the Lewis structure section of Chapter 8. When asked to identify the last chapter they had read in their text, 98% of the participating students reported that had read at least as far as Chapter 2.

## *Materials*

### *Basis of Materials Development*

Three types of materials were employed in this experiment: (a) text readings, designated R and T, (b) a prior knowledge test, and (c) the pre- and posttests. Except for text T, all of the materials were developed by the researcher. Text T refers to the reading taken from the CH 101 course textbook. The content and length of text T served as the foundation for the development of all the other materials. Therefore, it is important to describe text T in more detail.

Text T was an excerpt from Chapter 8 of T. L. Brown et al. (2003). The text was typical of college level chemistry and employed numerous special symbols and technical vocabulary (Lamberg & Lamb, 1980). Specifically, there were 27 technical terms in text T (see Table 5). This experimental text passage was composed of two sections taken from Chapter 8. In the 87 sentences of text T, there were 221 instances of these 27 terms. The most commonly used term, *atom*, (including its plural and adjectival derivatives, *atoms* and *atomic*) appeared 51 times, for example.

Understanding these technical terms is critical for understanding text T and the process of drawing Lewis structures. These 27 terms and their related concepts were presented in earlier chapters of the T. L. Brown et al. (2003) textbook, specifically in Chapters 1, 2, 6, and 7. As such, these terms formed the prior-knowledge base required to understand the to-be-learned material. Four of the terms appeared for the first time early in Chapter 8, the same chapter as the instructions for drawing Lewis structures. Since one of these terms, *octet rule*, was essential for understanding the process for drawing Lewis structures, it was inserted into text T by the researcher. The distribution of the technical terms in text T by textbook chapter is shown in Table 5 and depicted graphically in Figure 6.

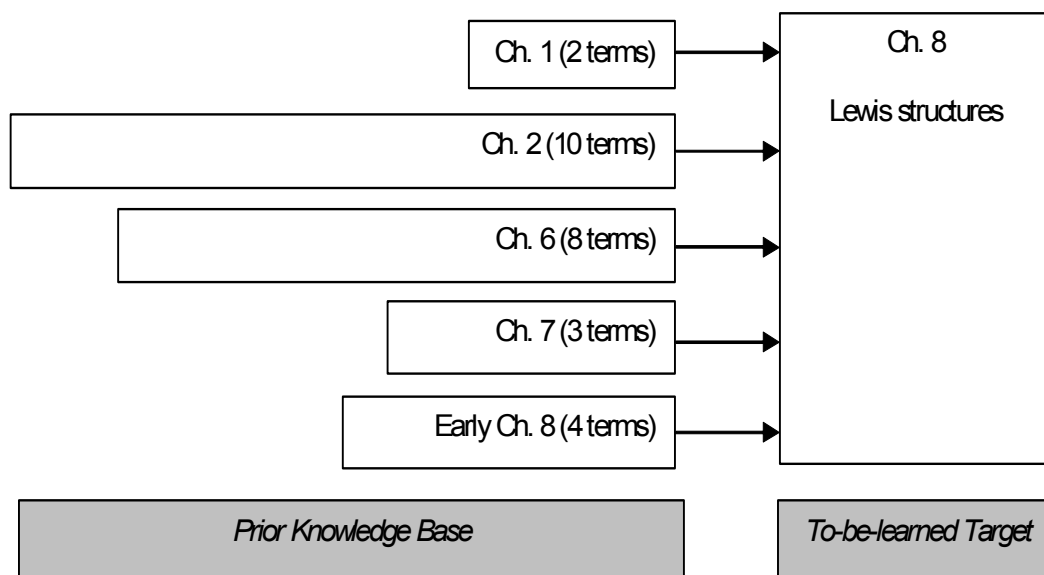
Student schema of the underlying concepts about molecular structure were expected to be formed before reaching Chapter 8 in the T. L. Brown et al. (2003) textbook. This formation of the schema and understanding of background knowledge would be the result of a composite of experiences in either high school chemistry, or CH 100, or both, as well as experiences within general chemistry itself, CH 101. It is likely that participants had been exposed to instruction dealing with some or all of

Table 5

*Technical Terminology Appearing in Textbook Lewis Structure Reading*

Term	Frequency in text T	First location in textbook
atom (or atoms, atomic)	51	Ch. 2
bond (or bonds, bonding, single, double, multiple)	14	Ch. 2
charge	5	Ch. 2
compound (or compounds, binary compound)	3	Ch. 2
covalent	1	Ch. 8
d [orbital]	2	Ch. 6
electron (or electrons, electron pair)	38	Ch. 6
electronegative	2	Ch. 8
element (or elements)	6	Ch. 1
formula (or formulas)	3	Ch. 2
group	8	Ch. 2
ion (or ions, ionic, anion, cation, oxyanions)	12	Ch. 2
molecule (or molecules)	9	Ch. 2
nonmetal	1	Ch. 2
octet (or octets)	17	Ch. 6
octet rule	4	Ch. 8
orbital (or orbitals)	5	Ch. 6
p [orbital]	2	Ch. 6
period	6	Ch. 7
periodic table	2	Ch. 2
s [orbital]	2	Ch. 6
size [referring to atoms]	3	Ch. 7
symbols	1	Ch. 1
transition metals	1	Ch. 6
unshared pair	3	Ch. 8
valence electrons	9	Ch. 6
valence shell (or valence shells)	11	Ch. 7

these 27 terms and concepts. Indeed, the National Science Education Standards (NRC, 1996) include atomic structure, compound structure, and chemical reactions among the content standards for grades 9 to 12. However, individual mastery of the terms and concepts was expected to vary widely, due to differences in time elapsed since high school chemistry or CH 100, different high school chemistry curricula, as well as varying ways in which Lewis structures are presented in high school texts.



*Figure 6.* Relationship of to-be-learned material with prior knowledge and location of technical terms in textbook.

One measure of the relative importance of each technical term in text T is its frequency of use. It is not surprising that the two most frequently used terms in text T are *atom* and *electron*, since molecules are composed of *atoms* bonded to one another

by attractive forces between nuclei and shared *electrons*. The five most frequently used terms in text T, in order of frequency, were:

1. atom (51 times),
2. electron (38 times),
3. octet (17 times),
4. bond (14 times), and
5. ion (12 times).

This frequency count included derivatives of each word, such as plural or adjectival forms. In total, these five terms were used 132 times in text T and accounted for 60% of the technical term usage. Each of these was treated in detail in preceding chapters in the T. L. Brown et al. (2003) textbook. For example, atoms were addressed in Chapter 2. Chemical bonds, as well as ions, were first discussed, in a basic manner, in Chapter 2. Electrons, their characteristics, behavior, and octets, were presented in Chapter 6.

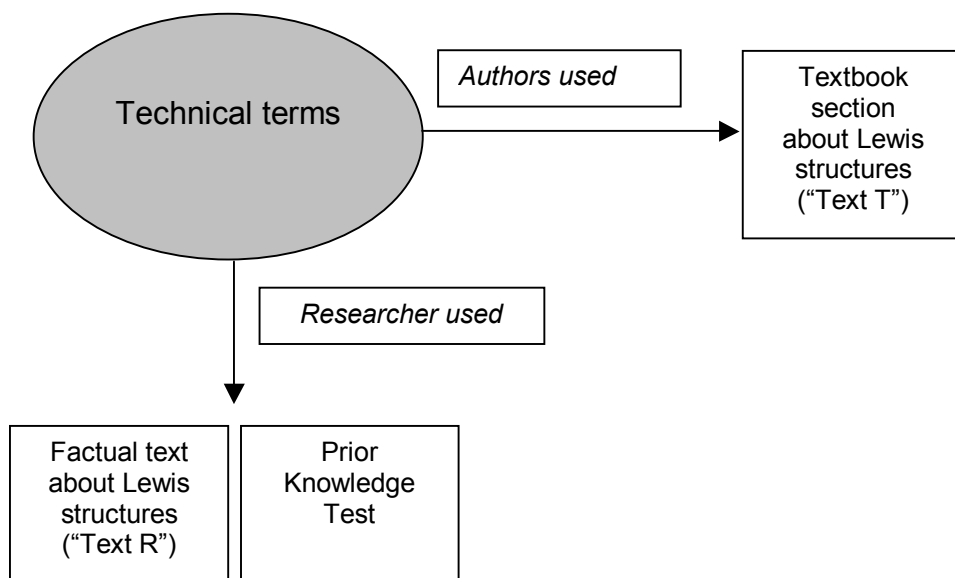
This analysis of text T and its contents formed the basis for the composition of all the remaining materials used in the experiment. Specifically, text R was composed by the researcher to be the same length as text T and to use similar terminology although the manner in which Lewis structures were explained differed sharply. Text T contained procedural text, meaning that it employed imperative sentences to explain a procedure. Text R was completely factual in that it provided facts about 15 specific Lewis structures. Table 6 compares the details of each text.

Table 6

*Comparison of Text R and Text T*

	Text R	Text T
Format	Factual only	Procedural and factual
Author(s)	Researcher	Brown, LeMay, Bursten, & Burdge
Words	1,445	1,431
Sentences	84	87

In addition, the prior knowledge test was developed to reflect the term usage in text T so as to accurately measure students' background knowledge of the technical terms they were about to encounter in either text, whichever was assigned (see Figure 7). And finally, the pretest and posttest were developed using another research-based analysis of college students learning to draw Lewis structures (Brady et al., 1990). The development of these materials is described in detail in the following sections.



*Figure 7. Development of factual text and prior knowledge test.*

### *Prior Knowledge Test*

A multiple-choice prior knowledge test was developed by the researcher for use in this experiment in order to measure participants' background knowledge and to assign a score level (high or low) to each student. The direct measurement of students' prior knowledge in the topic domain with this type of test has been recommended over other approaches such as researcher judgment or student surveys (Shapiro, 2004).

Comprehension strategies are known to be effective with individuals possessing sufficient prior knowledge about their reading topic (Caverly et al., 2000; Woloshyn et al., 1992). The prior knowledge assessment here provided information to test the efficacy of elaborative interrogation and rereading for individuals with different levels of prior knowledge concerning Lewis structures.

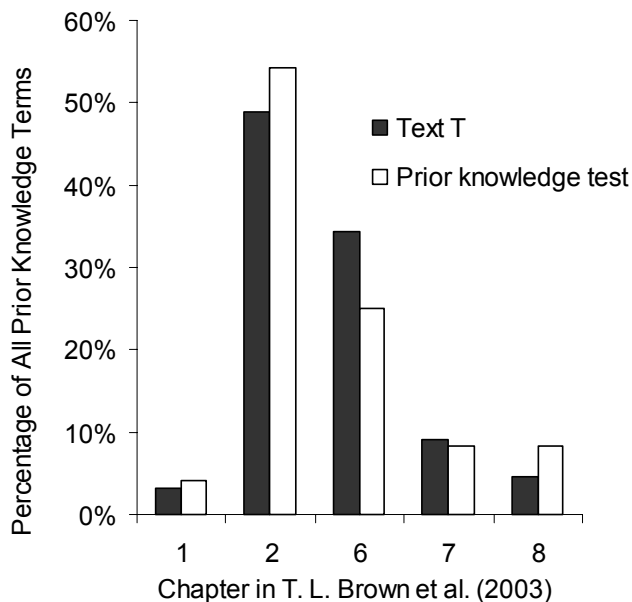
The prior knowledge test consisted of 18 multiple-choice chemistry questions, which were congruent with the 27 technical terms forming the prior-knowledge base of texts R and T. The use of terminology and concepts on the test was intended, as much as possible, to mirror that of the terms found in the reading passage. A total of 25 terms from the 27 found in the reading passage were on the prior knowledge test. They appeared in 94 instances on the test. The remaining two terms, *octets* and *valence shells*, appeared in the reading, but not on this test. Nevertheless, concepts related to these terms were covered on the prior knowledge test. For example, item 17 was a question about the octet rule and items 11, 12, 13, and 17 asked about issues related to valence electrons, which reside on the atom's valence shell.

The prior knowledge test included seven additional technical terms, which were not found in the experimental reading passages: electron configuration, ground state, isotope, mass, metal, neutron, proton, and reaction. Five of these terms (isotope, mass, metal, neutron, proton, and reaction) are not critical for the instruction of Lewis structures. Nevertheless, they are related to key terms and concepts such as atoms, electrons, octets, and ions. The other two terms, electron configuration and ground state, are important in the treatment of electron behavior and arrangement of electrons in atoms. In the instruction of constructing Lewis structures, the focus shifts to valence electrons in the electron configuration of ground state atoms. The prior knowledge test contained four references to valence electrons (questions 11, 12, 13, and 17).

The frequency of term use on the prior knowledge test was designed to be similar to the term frequency distribution in the authentic text passage. In text T, terms from Chapter 1 constituted 3% of the 221 term instances. On the prior knowledge test, Chapter 1 terms made up 4% of 94 instances of term use. In a similar manner, Chapter 2 terms made up 49% of the terms in the text T passage; they comprised 54% of the term instances on the prior knowledge test. This comparable use of terms was consistent for all of the technical terms constituting the prior-knowledge base. Figure 8 reflects the frequency of terms used on the prior knowledge test as compared with their frequency in the text T passage (when expressed as a percentage of overall term usage).

A final note of importance about the prior knowledge test concerns the number of questions. Although this test was constructed with 18 questions, two of the





*Figure 8.* Emphasis of prior knowledge terms, by chapter location, in text T and on prior knowledge test.

questions were omitted during the scoring because answers to those questions unexpectedly appeared on the classroom periodic tables which hung in several of the rooms where the experiment was conducted.

#### *Factual-based Text on Lewis Structures*

The text R reading consisted of facts about the Lewis structures for 15 molecules and polyatomic ions, which were taken from the Brady et al. (1990) list. The reading contained a paragraph about each structure followed by a figure of the structure. For example, the following text describes the hydrogen fluoride molecule, HF, as it appeared in the reading for the study participants.

Hydrogen fluoride, HF, is composed of a hydrogen atom and a fluorine atom. In the Lewis structure, the two atoms are connected by a single bond and the

fluorine has three unshared pairs of electrons. Being a particle with no net charge and having all electrons in pairs, HF is classified as a molecule. In Lewis structures, a hydrogen atom forms only one covalent bond and has no unshared pairs of electrons.

This reading about the hydrogen fluoride molecule represents the pattern used in all of the paragraphs about Lewis structures. There were five components to each paragraph: (a) introduction, (b) description, (c) classification, (d) assistive information, and (e) the figure of the Lewis structure.

The first component of the paragraph was an introductory sentence containing the name, the formula, and a list of the atoms in the structure. In the hydrogen fluoride example above, the introduction was: *Hydrogen fluoride, HF, is composed of a hydrogen atom and a fluorine atom.* In each of the 15 paragraphs, the introduction was one sentence.

The second part of the paragraph was a description of the Lewis structure's atom arrangement, bonds, and unshared electron pairs. This was either one sentence or more, depending on the complexity of the structure. In the case of hydrogen fluoride, this was one sentence: *In the Lewis structure, the two atoms are connected by a single bond and the fluorine has three unshared pairs of electrons.* In the case of a more complex molecule, chlorine trifluoride, ClF<sub>3</sub>, the description contained two sentences: *In the Lewis structure, each fluorine is joined by a single bond to the chlorine, which has two unshared pairs of electrons. Each fluorine atom has three unshared pairs.*

The third component of each paragraph was a sentence classifying the structure as a molecule or polyatomic ion. In the HF example, this sentence was: *Being a particle with no net charge and having all electrons in pairs, HF is classified as a molecule.*

The fourth element of each text-R paragraph contained assistive chemical information. This varied from structure to structure, but focused on some aspect that reinforced key concepts in the drawing of the Lewis structure. This assistive information was sometimes a detail about the characteristic of the Lewis structure or about related structures. In all cases, this information was provided in one sentence. In the hydrogen fluoride example, the assistive chemical information sentence was: *In Lewis structures, a hydrogen atom forms only one covalent bond and has no unshared pairs of electrons.* This sentence provided information to reinforce an important concept about hydrogen in Lewis structures.

In another example, that of the triiodide ion,  $I_3^-$ , a more complex structure that contains an atom exceeding an octet, the assistive chemical information sentence reflected this exception: *Like other large period 5 elements with d orbitals available for bonding, iodine is capable of exceeding an octet.*

The final component of each paragraph was one sentence that introduced the figure of the Lewis structure. Each of these sentences contained the words, *The Lewis structure of X is drawn as*, where the X was the formula of the structure being described.

In all, text R consisted of 84 sentences in 15 paragraphs with a total of 1,445 words.

The role of the chemistry concept of resonance in text R should also be addressed briefly. In brief, chemists use the term resonance to refer to a case in which more than one correct Lewis structure can be drawn for a molecule or polyatomic ion. On paper, resonance structures are two or more Lewis structure figures that have the exact same arrangement of atoms (i.e., the same sigma skeleton), but different arrangements of electrons. Chemists understand that the single true structure of the substance is actually some combination of the so-called resonance structures, where no one resonance structure by itself can represent this true structure. In cases of text-R reading where resonance structures exist, only the most important contributing structure or only one of several equivalent structures was shown in the text. It is likely that students in this study had little or no prior knowledge of resonance theory. That is a reasonable assumption since the topic of resonance is usually introduced in textbooks after the topic of Lewis structures (e.g., ACS, 2004; T. L. Brown et al., 2003; Ebbing & Gammon, 2002; Kotz & Treichel, 2003). It is also unlikely that students learned about resonance theory in secondary chemistry courses. This sophisticated concept is either not addressed or only mentioned in passing in high school chemistry texts (e.g., LeMay et al., 2000).

Text R contained declarative sentences as was the case for text used in previously reported elaborative interrogation studies. Sentences reported in the elaborative interrogation literature were declarative and in the active voice, for example, “The hungry man got into the car” (Pressley et al., 1988), “The University of New Brunswick was the first Canadian university to offer a degree in engineering” (Woloshyn et al., 1990), and “The Western Spotted Skunk lives in a hole in the

ground” (Wood et al., 1990). The sentences in text R for the present research were also declarative and in the active voice.

### *Procedural-based Text on Lewis Structures*

The text T reading was taken directly from the required textbook (T. L. Brown et al., 2003), which the research students used in their college level CH 101 general chemistry course. The to-be-learned target for the readers was the procedure for drawing Lewis structures for any molecule or polyatomic ion. This reading consisted of 1,431 words in 87 sentences over 30 paragraphs. Note that the length of the two texts was nearly the same; they differed in words by less than one percent. Text T consisted of a five-step procedure for drawing Lewis structures, exceptions to the octet rule, and four completed examples of the process. The reading passage was dense technical prose. In all, the Lewis structures for six molecules and polyatomic ions were shown in the text:  $\text{PCl}_3$ ,  $\text{HCN}$ ,  $\text{BrO}_3^-$ ,  $\text{NO}$ ,  $\text{PCl}_5$ , and  $\text{ICl}_4^-$ . These were provided as examples or illustrations of concepts and procedures used to draw Lewis structures.

Text T described a procedure that relies on a command of material that should have been previously learned. In the general chemistry text used by the students in this study, Lewis structure instruction appears in Chapter 8. Knowledge of information that appears in earlier chapters is necessary for mastery of drawing Lewis structures, for example, chemical formulas (in Chapter 2), electronic structure of atoms (in Chapter 6), and the periodic table (in Chapter 7). This placement of the Lewis structure topic in the textbook is typical of many college level chemistry texts.

To prepare documents for use in the experiment, the authentic text was captured electronically in a word processor by scanning the pages from the textbook, processing the result through an optical character recognition program, then this product was proofread to assure that the capture was accurate. The text was formatted on a page in landscape fashion. Section heading numbers and references to numbered tables or figures were deleted so that such references would not be distracting to readers. Four sample exercises appeared in text T. Practice exercises followed the sample exercises in the textbook, but they were omitted from text T for the experiment so that students would not attend to these exercises in some unpredictable fashion during the studying activity. Thus, these practice exercises were removed because of concern that the experimental hypotheses would be compromised by additional activities outside the scope of the strategies under investigation.

The topics in Chapter 8, where drawing Lewis structures was explained, included the following headings and subheadings, in this order:

1. Drawing Lewis structures,
  - a. Formal charge,
2. Resonance structures,
  - a. Resonance in benzene,
3. Exceptions to the octet rule,
  - a. Odd number of electrons,
  - b. Less than an octet, and
  - c. More than an octet.

In order to focus the reading of text T on drawing Lewis structures, the sections entitled Formal Charge, Resonance Structures, and Resonance in Benzene, were not included. They are important topics, but beyond the immediate scope of this experiment. The section entitled, Exceptions to the Octet Rule, was included in text T, because it provided a broad introduction to the full range of Lewis structures, which students would likely encounter in general chemistry.

To make the text on octet rule exceptions sensible to the readers in this experiment and not to assume information taught in the intervening omitted pages, two paragraphs were deleted. These paragraphs dealt with formal charges and resonance theory, and perhaps could confuse some study participants. In omitting these paragraphs, several minor edits were also made to delete reference to these paragraphs and to change a three-item numbered list into a two-item bulleted list. In the end, the exceptions included in text T concerned species with an odd number of electrons or species that exceed an octet, but not cases of structures having an atom with less than an octet. It should be noted that the pre- and posttests contained formulas with an atom that exceeds an octet and one odd-electron species, but no formulas with less than an octet.

The final text T for the experiment was authentic in words and Lewis structures as they appeared in the textbook. It did not contain the pictures, figures, adjunct articles, or practice problems, which appeared in these sections.

The text T reading contained both declarative and imperative sentences. In contrast, the to-be-learned target information in text R consisted of facts concerning 15 specific Lewis structures in declarative sentences. Of the 87 sentences in text T,

the vast majority were written in declarative sentences in active voice. However, the focus of the learning target in this reading was a procedure, which was delineated in imperative sentences early in the reading. Specifically, there were 10 imperative sentences that described the process for drawing a Lewis structure starting with a chemical formula of a molecule or polyatomic ion (e.g., H<sub>2</sub>O, water, or SO<sub>4</sub><sup>2-</sup>, sulfate ion). The explanation was divided into five numbered steps, where step 1 contained five imperative sentences giving instructions on counting valence electrons. Steps 2, 3, and 4 each contained one imperative sentence. Step 5 contained two imperative sentences. The imperative sentences in the procedural text were typical of those presented in other chemistry textbooks. However, the inclusion of imperative sentences in the targeted text was unique in elaborative interrogation research.

#### *Octet Rule Definition in Texts R and T*

In the T. L. Brown et al. (2003) textbook assigned to the students in general chemistry, the octet rule, a critical concept for understanding bonding and the drawing of Lewis structures, was introduced in an early section of Chapter 8. The authentic text for the experiment was taken from the middle of Chapter 8. Therefore, the definition of octet rule was inserted into an appropriate location in text T, specifically after the seventeenth sentence. The inserted sentence read as follows: *An important guideline to follow in drawing Lewis structures is called the octet rule which states that atoms tend to gain, lose, or share electrons until they are surrounded by eight valence electrons.* The same sentence was included, verbatim, at the beginning of text R.



### *Text Linkages to Prior Knowledge and Why-question Placement*

Once texts R and T were constructed, the next important step was to add why-questions to the elaborative interrogation version of the texts. The elaborative interrogation hypothesis postulates that asking readers to answer “why” at key points in a reading can stimulate a cognitive connection between the new to-be-learned material and previously learned material (Pressley et al., 1987; Pressley et al., 1988), as discussed earlier. In previous investigations, the placement of why-question has been at the end of sentences (e.g., Pressley et al., 1988; Willoughby et al., 1994), at the end of paragraphs and embedded within the text (e.g., McDaniel & Donnelly, 1996; Ozgungor, 2002), or in the margins of the text (e.g., Seifert, 1993).

The why-questions in text R of the current research were placed at the end of paragraphs. At the conclusion of the paragraph the elaborative-interrogation students were directed to answer a question, specifically, “Why does this structure make sense?” Space was provided on the right side of the landscape-style printed page for answering the questions in a manner similar to Seifert (1993).

The placement of the questions in text T was determined in a different manner. With 87 sentences and 30 paragraphs in text T, it was judged impractical and meaningless to place a why-question at the conclusion of each sentence or even at the end of each paragraph. Pausing 30 or 87 times to answer an adjunct question would not only be a lengthy process, it would also be disruptive to the flow of the text. The objective in asking why-questions is to stimulate reflection about the connections between new and previously learned material in order to develop comprehension. Not

all paragraphs in authentic text contain the same amount of material nor are they equally important.

In the scant literature in which elaborative interrogation is investigated using authentic text, different approaches have been employed to implement the elaborative interrogation strategy. In Hill's (1999) work with computer-based course text, medical school students read authentic text after receiving training in strategy use. The text was part of their required course reading. They were instructed to "frequently stop and ask yourself 'why,'" then "generate an answer" (Hill, p. 36). Therefore, the frequency and placement of why-questions were student-specific decisions. Individual students asked and answered why-questions at their own discretion throughout the computer-based exercises.

Smith (2003) also used authentic text from a college biology course-required textbook. Students were given separate paper with statements that paraphrased text paragraphs and were directed to explain why the paraphrased statements were true.

In the Ozgungor (2002) study involving authentic text from a popular science magazine, volunteer college students read text that contained questions at the conclusion of numerous, but not all, paragraphs. These questions were of specific "how" (nine of 14 questions), "what" (four questions), and "why" (one question) varieties. These questions, and space for their answers, were inserted into the text and appeared, with three lines for each answer, on the same pages as the text passage.

In the text T passage of the current research, the why-questions were asked, not at the end of each sentence and not at the end of paragraphs, but rather at key points in the reading where the targeted material and prior knowledge terms were

conjoined, as judged by the researcher. The goal of asking “why” at this nexus was to stimulate the reader’s cognition about prior knowledge ideas, as discussed earlier in greater detail. For example, the first why-question was posed after the following sentence in the text:

“Use the periodic table as necessary to help you determine the number of valence electrons in each atom” (T. L. Brown et al., 2003, p. 290).

This sentence contains three chemistry terms (periodic table, valence electrons, and atom) all of which were treated in detail in previous chapters. This sentence told the reader to use the periodic table to determine the number of valence electrons, but without specifically instructing how to do so or explicating what valence electrons are. Therefore, asking “why” after this sentence should cause the reader to think about how the number of valence electrons is ascertained. A model answer to this why-question is:

The family or group location of an element on the periodic table provides information about the number of valence electrons in the atom.

Such an answer would indicate that the reader understood how to use the periodic table to count valence electrons, a topic that was covered in Chapter 6 of the textbook (and most likely covered in many high-school-level chemistry classes).

Similar to the Ozgungor (2002) approach to questioning, the why-questions in this research were embedded within the reading and were answered on the same paper as the text was printed. However, the pages in the present research were printed in landscape style (Ozgungor used portrait style) with space for the why-question answers on the right side, similar to text R and in the manner of Seifert (1993). The

same question was posed at 15 new-material/prior-knowledge nexus points, specifically, “Why does this make sense?” The specific sentences of interest were underlined in the text and the reader was prompted to answer the why-questions with the directions, *go to question 1*, *go to question 2*, and so on. Arrows were included and pointed to the right side of the page where the questions were printed. This instruction was printed in reverse color, that is, white letters on a black background. To illustrate, the why-question for the example sentence above appeared as follows in the experimental materials:

Use the periodic table as necessary to help you determine the number of valence electrons in each atom. **GO TO QUESTION 1 →**

#### *Pretest and Posttest Instruments*

The pretest and posttest consisted of 15 formulas of compounds and polyatomic ions, specifically nine molecules, five anions (i.e., negatively-charged ions), and one cation (i.e., positively-charged ion) taken from the Brady et al. (1990) listing of Lewis structures. This distribution of molecules, anions, and cations was 60%, 33%, and 7%, respectively, and closely matched the distribution used in the Brady group’s investigation: 56% molecules, 38% anions, and 6% cations.

The two tests were identical so that any increases in scores could be attributed to the reading and strategy intervention. Students were not told in advance that the tests were identical. The 15 formulas on the tests were.

## *Procedure*

### *Experimental Design*

This text-strategy experiment was a  $2 \times 2$  factorial pretest-posttest design, where the student gain score (i.e., the difference between the pretest and posttest scores) was the dependent variable of interest. Two independent variables, each with two levels, were controlled in the experiment. Specifically, the type of text (i.e., text R or text T) and the strategy employed while reading (i.e., rereading or elaborative interrogation). In other words, two different reading methods were employed for both text R and text T. The first method was rereading. Students were instructed to read the text two times. The second reading strategy was elaborative interrogation. Students were instructed to read the text only once and answer why-questions at certain points in the selection. All students were informed that a test would be administered following their study of the reading material.

Experiment participants were drawn from a pool of general chemistry students at a large urban community college and were randomly assigned to readings and study methods.

The pre- and posttests required students to draw Lewis structures of compounds and polyatomic ions. The molecular formulas were given on the tests and blank spaces were provided for students to draw the structures. The items for the pretest and posttest were identical and were taken from the Brady et al. (1990) list of Lewis structures. These 15-question tests contained an equal mix of easy-to-learn (five items), average-to-learn (five items), and difficult-to-learn (five items) Lewis

structures as defined by Brady et al. The test items were arranged in theoretical order of increasing difficulty.

The dependent variable to be examined in the primary  $2 \times 2$  factorial design was a gain score, which reflected the amount of structures students learned during the intervention. The actual method for determining the gain scores will be discussed later in detail in Chapter Four.

### *Reading Strategy Assignments*

Two reading strategies were compared in this experiment, elaborative interrogation and rereading, the latter of which served as the placebo control. Both texts R and T were prepared in two versions, one for the elaborative interrogation strategy and one for the rereading strategy. Among the 252 students, 124 read text R and 128 read text T. The 124 text-R students each received one of the two reading strategies, rereading ( $n = 63$ ) or elaborative interrogation ( $n = 61$ ). The text T students also received one of the two strategies, rereading ( $n = 64$ ) or elaborative interrogation ( $n = 64$ ).

The printed elaborative interrogation readings for both texts R and T contained a message at the top of each page reminding students how they were supposed to read the text. Specifically, the instructions in both the text R and text T versions designed for elaborative interrogation were as follows:

“Read each paragraph ONCE. Answer the questions in the right margin when directed.”

Implementation of the rereading strategy required no special modification to the native text. In both texts R and T utilizing the rereading strategy, each page of the

reading contained an instruction at the top of the page to read the text twice in a manner of personal preference. Specifically, the instructions, which were identical in both texts, read:

“Read the material TWICE. (Read everything once, then re-read everything OR read each paragraph twice before going on to the next.)”

All students in this experiment were told that the criterion task, namely, a test covering the drawing of Lewis structures, would be administered at the conclusion of the reading.

### *Experimental Sessions*

The researcher visited 13 intact laboratory sections of CH 101 college level general chemistry. At the beginning of each session, the course professor briefly introduced the researcher, who then led the remainder of the session. Some of the professors remained in the room during the session, but others departed. Those who stayed did not participate in the experimental procedures. They occupied their time with other activities, such as grading papers or reading. The presence or absence of the course professor did not seem to influence student participation or effort.

Each experimental session lasted approximately 120 minutes. The activities of the session are detailed in the following sections, in the order they occurred. All of the materials used during the sessions are reproduced in the Appendices.

*Introduction and instructions.* The researcher introduced himself and attempted to establish a rapport with the students. The course professors had announced a week in advance that an exercise on Lewis structures would be conducted in lab. The researcher had provided a script to each lab instructor in

advance. Therefore, the appearance of the researcher at the laboratory session was not unexpected by the students.

The instructions for the experiment were carefully scripted and read by the researcher to the group. The instructions gave specific information for the tests, the reading, as well as for the criterion task in order to provide focus for students during the reading time (T. H. Anderson & Armbruster, 1984). This intentional-learning approach is similar to typical college studying (T. H. Anderson & Armbruster; Nist & Simpson, 2000; Pressley, 1987). After explaining the activities of the session, the researcher listed the session activities on the chalkboard, in this order: (a) quiz, (b) reading, (c) questionnaire, and (d) quiz.

The introduction and initial instruction period of the session typically lasted about 20 minutes.

*Prior knowledge test and pretest.* The first activity for students was described to them as a quiz intended to find out what they already knew about chemistry. Each student received one test document, which consisted of 33 questions. It was coded with a number that was used on all materials to track individual student's materials and data.

The first 18 questions in this test document constituted the prior knowledge test composed by the researcher for this experiment. It consisted of multiple choice questions concerning chemistry topics that students should understand in order to comprehend a text about Lewis structures as judged by the researcher. The next 15 questions constituted the pretest and consisted of a list of formulas for which students were instructed to draw the Lewis structures. A periodic table was provided with each



test for student reference. Later, after students' answers were scored, a prior knowledge test score was derived from items 1 to 18 and a pretest score was derived from items 19 to 33.

Students were permitted to work at their own pace on this prior knowledge test and pretest combination. As students completed their work, they were asked to turn their papers face down to signal to the researcher that they were finished. When all students had completed their work, the papers were collected. The distribution, completion, and collection of the prior knowledge test and pretest took approximately 30 to 35 minutes in each session.

*Reading treatment.* After the prior-knowledge-test/pretest documents were collected, each student was given a reading packet with the identification code matching the test materials. Although there were four readings treatments, the cover instructions were identical for all students. At the conclusion of the instructions, students were given an opportunity to ask questions. (There were rarely any questions asked.) Students were then instructed to begin reading. The researcher recorded the time that the reading began.

As students completed their readings, they raised their hands. The researcher would then go to each student individually, take the reading materials, look at the clock, and record the ending time on the front page of the reading packet. Students were permitted to work at their own pace, but a maximum of 40 minutes for the reading period was enforced. Only six students (i.e., less than 3%) utilized the full 40 minutes.

Allowing students to read at their own paces was intended to replicate an authentic college learning environment. As students were randomly assigned to treatments, it was expected that each group would have a representative number of faster, average, and slower readers, and that the mean time-on-task would be similar for each group. This goal was integrated into the design of texts R and T, which contained approximately the same number of words. The elaborative-interrogation students read once and wrote answers to questions. The time for these activities was expected to be approximately the same as that for the rereading students who read their text twice.

*Demographic survey sheet.* After the reading materials were turned into the researcher, each student was given a demographic survey sheet. This survey was enclosed in a folder with the posttest. Students were told to complete the survey and then do the test.

The demographic survey served two purposes. The first purpose was to collect key information about the individuals in the study. The second purpose was to extinguish any short-term memory advantages for the material studied last during the reading of the text.

*Posttest.* The posttest consisted of 15 formulas for which Lewis structures were to be drawn. After each formula, space was provided to draw the structure. The formulas were identical to those on the pretest. Students were provided with a fresh copy of the periodic table for reference.

No time limit was imposed for completion of the posttest. Some students completed it quickly; others spent more time working on it. Actual working times for the posttest were not recorded.

*Experiment session summary.* To reiterate the activities of the experiment session, each meeting consisted of the following:

1. introduction and instructions,
2. prior knowledge test and pretest,
3. reading treatment,
4. demographic survey sheet, and
5. posttest.

*Periodic tables.* It should be noted that the periodic tables used in this study had the information typically provided to college chemistry students during tests. Within each element's box was a symbol (e.g., H for hydrogen), the atomic number of the element (e.g., 1 for hydrogen), and the element's atomic weight (e.g., 1.00794 for hydrogen). The family numbers (i.e., 1A, 2A, 1B, 2B, etc.) were listed across the top of the table. Information found on some comprehensive periodic tables (e.g., element names, electron configurations, common valences, etc.) was not included. Some of the information on comprehensive periodic tables would have provided an advantage to students in constructing Lewis structures.

### *Data Analysis*

#### *Primary Comparisons for Analysis*

The primary comparison in this research project involved two manipulated independent variables, type of text and type of strategy. A gain score was the

dependent variable of interest and represented the net number of Lewis structures learned by the student. (The determination of the gain score is described in greater detail below.) The 2(strategy employed, elaborative interrogation and rereading)  $\times$  2(text, R and T) factorial design provided for an analysis of variance comparison of the two strategies across the texts for college chemistry students. In addition, the text-strategy interaction was examined as well.

In general, when conducting analyses of variance in a  $2 \times 2$  design, the sample size is recommended to be 31 students per cell with  $\alpha = .05$ , power = .80, and effect size = .50 (Hinkle & Oliver, 1983). Of course, these values are somewhat arbitrary and established through convention rather than through absolute derivative process. In the analyses of research Questions 2 to 4 in the current research, there was a minimum of 61 students per cell. Therefore, with over 120 students per level, keeping  $\alpha = .05$  and effect size = .50, the power in this investigation was anticipated to be closer to .95 (Hinkle & Oliver).

This first ANOVA, performed as a two-tailed test, examined three research questions, where Questions 2 and 3 addressed the potential main effects and Question 4 addressed the potential interaction:

#### Question 2

How does the elaborative interrogation strategy differ from the rereading strategy for college chemistry students who study the drawing of Lewis structures?

### Question 3

How does factual text differ from procedural text for college chemistry students who study the drawing of Lewis structures?

### Question 4

How do scores on Lewis structure tests vary when different strategies are used (viz., elaborative interrogation and rereading) for different reading formats (viz., factual text and procedural text)?

### *Comparisons within Text R and within Text T*

In addition to the analysis of the full sample as described above, students were divided into two subgroups for further analyses: those who read text R and those who read text T. Each of these subgroups, consisting of 124 and 128 students respectively, was analyzed in separate two-tailed  $2 \times 2$  ANOVAs, where the dependent variable was the same, that is, the gain score of Lewis structures learned. The first independent variable was the strategy employed in the reading, as was the case for research Questions 2 to 4, either elaborative interrogation or rereading. The second independent variable in these analyses, however, was prior knowledge level. Students were classified as having high or low prior knowledge by a median split based on their prior knowledge test score ( $N = 252$ ,  $Mdn = 9.50$ ). Those above the median were defined as having high prior knowledge and those below were considered to have low prior knowledge. Both text R and text T students were evenly split into high and low prior knowledge subgroups. For text R students ( $n = 124$ ), there were 62 high-prior-knowledge students and 62 low-prior-knowledge students. For text T students ( $n = 128$ ), there were 64 high-prior-knowledge students and 64 low-prior-knowledge

students. For the text-R subgroup, this 2(strategy employed, elaborative interrogation and rereading)  $\times$  2(level of prior knowledge, high and low) ANOVA addressed the following research questions, where Questions 5 and 6 reflected the potential main effects and Question 7 addressed the potential variable interaction:

Question 5

How does the elaborative interrogation strategy differ from the rereading strategy for college chemistry students who study the drawing of Lewis structures by reading factual text?

Question 6

How do students with high prior knowledge differ from students with low prior knowledge when studying the drawing of Lewis structures by reading factual text?

Question 7

How do scores on Lewis structure tests vary when different strategies are used by students with different levels of prior knowledge when reading factual text?

For the subgroup that read the procedural text T, this 2(strategy employed)  $\times$  2(level of prior knowledge) analysis of variance addressed the following research questions, where Questions 8 and 9 reflected the statistical main effects and Question 10 addressed the variable interaction:

Question 8

How does the elaborative interrogation strategy differ from the rereading strategy for college chemistry students who study the drawing of Lewis

structures by reading their textbook?

#### Question 9

How do students with high prior knowledge differ from students with low prior knowledge when studying the drawing of Lewis structures by reading their textbook?

#### Question 10

How do scores on Lewis structure tests vary when different strategies are used by students with different levels of prior knowledge when reading their textbook?

#### *Summary of Analyses*

To summarize, three two-tailed analyses of variance were conducted with the experimental data in order to answer nine research questions. In the first analysis, all students' gain scores were used in a  $2(\text{strategy}) \times 2(\text{text})$  ANOVA. Then, students' scores were divided into two subgroups based on the type of text used, R or T. Within each text subgroup, an additional  $2(\text{strategy}) \times 2(\text{prior knowledge level})$  ANOVA was performed, where prior knowledge level was assigned by a median split of prior knowledge test scores.

#### *Scoring*

##### *Independent Raters*

Two independent raters assisted the researcher in scoring the materials in this experiment. The raters were trained by the researcher to use a scoring rubric for rating Lewis structures and why-question answers. These raters were honors undergraduate students, who were highly recommended by a chemistry professor. The raters were

not aware of the purpose of this research project or the significance of the answers they were grading. Training and practice with the raters lasted about 90 minutes for scoring Lewis structures and 60 minutes for rating why-questions. The ratings were recorded on standardized forms developed by the researcher. Interrater reliability was .96 on the grading of Lewis structures and .83 on the grading of why-question answers. Differences were discussed and final rating assignments were made by consensus.

### *Scoring Lewis Structures*

*Grading rubric.* Lewis structures were evaluated by the raters using a rubric designed by the researcher. The rubric evaluated the major steps in drawing Lewis structures and provided for a maximum of five points per structure. First, the number of electrons appearing in the structure was counted. Then, the sigma skeleton (i.e., the arrangement of atoms) was evaluated. If both the number of electrons and the sigma skeleton were correct, then the rater next evaluated the structure for its adherence to the octet rule. If, however, either the electron count or the sigma skeleton was incorrect, then the rater assigned only one point to the answer and went no further with the rubric. If neither the electron count nor skeleton was correct, the item was given no points. Specifically, the rubric consisted of the following six steps.

1. Count the number of valence electrons in the final answer. If correct, score 1 point.
2. Examine the arrangement of atoms in the structure. If correct, score 1 point.



3. If both the number of valence electrons and the atom arrangement are incorrect, stop. Score the answer a total of 0 points.
4. If the number of valence electrons is correct, but the atom arrangement is incorrect, stop. Score the answer a total of 1 point.
5. If the number of valence electrons is incorrect, but the atom arrangement is correct, stop. Score the answer a total of 1 point.
6. If both the number of valence electrons and the atom arrangement are correct, examine the arrangement of bonds as follows.
  - a. If the electron arrangement is correct, add 3 points for a total of 5 points. Stop.
  - b. If the electron arrangement is incorrect, add no additional points, giving a total of 2 points. Stop.
  - c. If the electron arrangement is correct, but a minor error has occurred (e.g., an element symbol is incorrect), add 2 points for a total of 4 points. In the instance of two minor errors, add 1 point for a total of 3 points. Stop.

The final step of the rubric, step 6, was weighted higher than the others because it involved higher order thinking and the application of more chemistry principles.

All Lewis structures on the pretest and posttest were assigned a score ranging from zero to five. For purposes of evaluating students' comprehension, the range of scores provided information about progress made in learning the procedure for drawing structures. For purposes of evaluating the learning strategies used in the research, a correct structure was defined as one receiving five points and an incorrect structure was defined as one receiving fewer than five.

*Definition of gain score.* The gain scores for students were determined by examining their performance on each pretest item with its matching posttest item and classifying the relationship (see Table 7). For instance, the first formula on the tests was HF, hydrogen fluoride. If a student missed it on the pretest but answered it correctly on the posttest, the structure in such a relationship was defined as having been "learned" and the student was given a score of one. If a student missed a structure on both the pretest and the posttest, the structure was designated as "not learned." However, if a student drew the correct structure on both the pretest and on the posttest, the structure was classified as "already known." In the instance of drawing a structure correctly on the pretest but then incorrectly on the posttest, the structure was deemed "unlearned." The final possibility was that a student left an answer blank on both the pretest and the posttest. Such a structure was classified as "not attempted." Structures that were not learned, already known, or not attempted received no points toward the gain score. A point was deducted for each unlearned structure.

Table 7

*Five Pretest-Posttest Matched-Item Relationships*

Pretest answer	Posttest answer	Structure learning result	Gain score
Incorrect	Correct	Learned	Add 1
Incorrect	Incorrect	Not learned	0
Correct	Correct	Already known	0
Correct	Incorrect	Unlearned	Subtract 1
Blank	Blank	Not attempted	0

*Scoring Why-question Answers*

*Grading standards.* All 252 students in the text-strategy investigation drew Lewis structures on the pretest and posttest, but only about half of the students ( $n = 125$ ) utilized the elaborative interrogation strategy while reading. The remaining students ( $n = 127$ ) used the rereading strategy. Each of the elaborative-interrogation students used materials with space on the right side of the page to write their answers to why-questions as described earlier in this Chapter.

The grading of why-question answers was based on a four-category standard consisting of adequate, inadequate, nonexplanatory, and blank as the ratings. This system was similar to others used in elaborative interrogation research (e.g., McDaniel & Donnelly, 1996; Greene et al., 1996; Seifert, 1993; Smith, 2003).

An adequate answer was defined as a suitable response to the question. In other words, the student expressed an answer with relevant chemistry concepts and facts composed in sentences or phrases. An inadequate answer was defined as a not-

suitable response to the question. That is, the student used incorrect reasoning or inappropriate chemistry concepts or facts to answer the question. Alternatively, the student may have employed the right concepts, but did not provide a key component necessary for the best answer. In other words, an answer was classified as inadequate if it contained wrong information or not enough correct information. A nonexplanatory answer was defined as something written in the answer space, but not addressing the why-question. Such an answer may take the form of a single word or term (such as “octet”) or it also may take the form of a statement which had nothing to do with the chemistry content (e.g., “It doesn’t make sense”). Such answers were distinguished from a blank, that is, no answer whatsoever.

During the training of the raters, the researcher presented a model answer for each why-question answer. The raters and the researcher discussed other answers that might be equally acceptable. Unlike the grading of Lewis structures, which had a discrete correct answer, the answers to why-questions were less definite. Raters used their knowledge of chemical principles to evaluate answers. As previously stated, the interrater reliability was .83. Differences in evaluations were resolved by consensus.

#### *Data Processing*

The data for this experiment were organized on paper by student identification code and then entered into an electronic database using form interfaces created in Microsoft Access, version 2002. Statistical analyses were completed with SPSS for Windows Student Version, release 11.0.0. Other analyses, such as test item analyses and pretest-posttest item comparisons were done in Microsoft Excel, version 2002. Graphics for figures were created in SPSS, Microsoft Excel, or Microsoft Word.

## CHAPTER 4: RESULTS

### Introduction

Two investigations were conducted in the current study. The first addressed a single research question involving the replication of a previously reported experiment about how college chemistry students learn to draw Lewis structures. The second experiment encompassed nine research questions, which addressed the effectiveness of two learning strategies assigned to college chemistry students while reading text about Lewis structures.

The first investigation employed a descriptive model and was designed to replicate work done by Brady et al. (1990). Similar results were found suggesting that certain Lewis structures are more difficult for college students to learn than others. The trend of structure difficulty reported by Brady et al. was also found with the replication sample. These results are described in detail below.

In the second investigation involving two texts and two learning strategies in four different treatments, students assigned to the rereading strategy learned statistically significantly more than students assigned to elaborative interrogation among those reading the researcher-authored factual-based text (text R). However, there was no statistically significant difference in the effectiveness of these two strategies for students reading authentic procedural-based text (text T). In the case of authentic text, students with higher prior knowledge learned significantly more, supporting the importance of background preparation for students in college level general chemistry courses. Since large numbers of students in several subgroups were available, additional unplanned analyses were performed. For the most part, the

results were consistent across the subgroups, but there were some interesting variations. These will be reported in more detail below.

Analysis of the text-strategy experiment results on a structure-by-structure basis also showed that the Brady et al. (1990) trends about structure difficulty levels were again apparent. In other words, the Brady group's results continued to manifest themselves in the learning of Lewis structures in the second investigation.

The following sections explore the experimental results, first for the replication investigation, and then for the text-strategy experiment.

### Lewis Structure Difficulty Levels

The Brady et al. (1990) investigation identified distinct skills and tasks performed by college general chemistry students when learning to draw Lewis structures. In the current replication procedure, 10 structures were chosen from the Brady et al. list of 50 structures for the test. Students who had received comparable instruction ( $N = 34$ ) were tested using a pencil-and-paper format.

The results showed a trend similar to that found in the Brady et al. (1990) sample (see Figure 9). For example, most students in both cases answered hydrogen fluoride, HF, and methane, CH<sub>4</sub>, correctly and the fewest number of students drew nitrogen monoxide, NO, correctly. Except for two structures, more students in the replication sample provided correct answers for each formula than students in the Brady et al. sample. This was expected since the students in the replication sample had progressed further in the general chemistry curriculum. Nevertheless, general chemistry students do not become experts in drawing Lewis structures. It is a critical topic, but only one of many studied in general chemistry. The topic is often reviewed

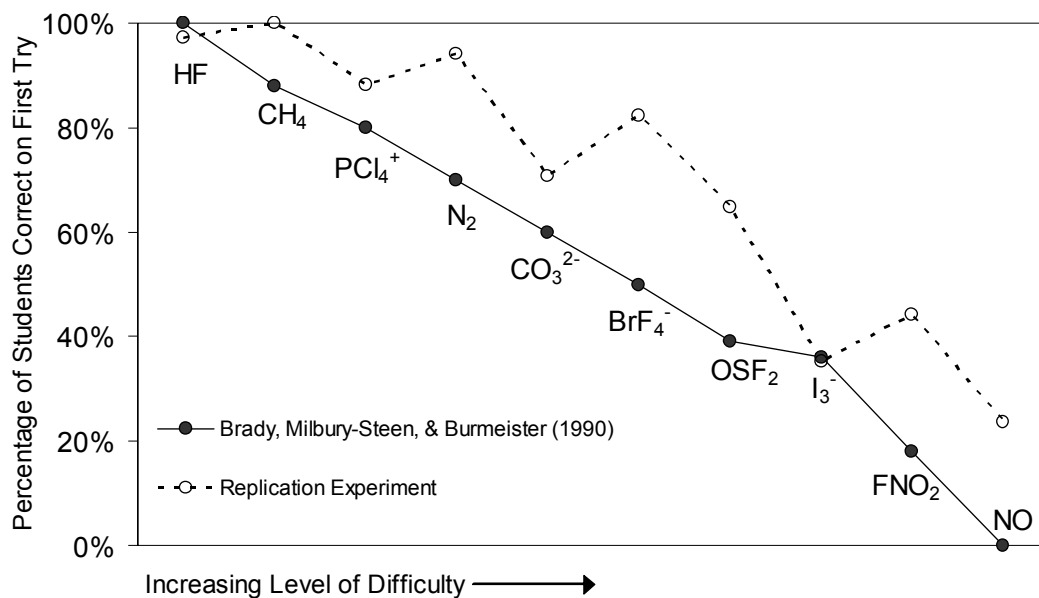


Figure 9. Results of replication experiment were similar to Brady, Millbury-Steen, and Burmeister (1990).

in higher level courses, such as organic chemistry, where student skill in drawing structures is honed.

From these data, it can be concluded that the structures on the Brady et al. (1990) list are generally arranged in order of increasing difficulty. This is important because it validated expectations that students in college level general chemistry should be competent in drawing the Lewis structures presented on tests following instruction about the process. In addition, these results validated the pretest and posttest, which were used in the text-strategy investigation. All of the structures on those tests were also selected from the Brady et al. list.

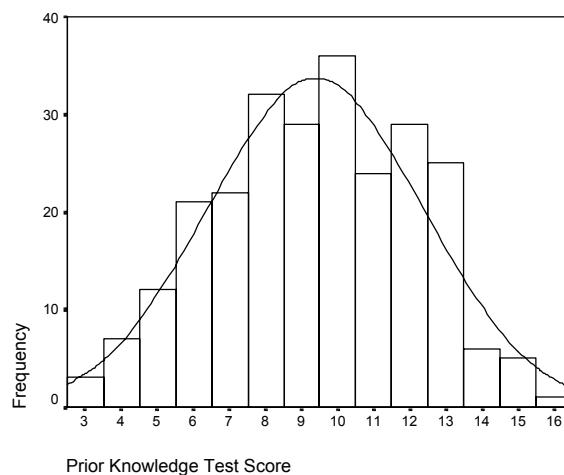
## Text-Strategy Investigation

### *Characteristics of the Sample*

The second investigation in this research involved was a text-strategy experiment. Before an in-depth review of the results are presented, it is important to establish that random assignment of students to the four treatments resulted in similar demographic profiles for each group. In order to have confidence that comparisons made later in the chapter are valid, the treatment groups' similarities will be demonstrated.

#### *Prior Knowledge Test Scores*

Prior knowledge is known to be an important factor in the efficacy of learning strategies. Therefore, the prior knowledge of the 252 students in this investigation was measured with a test developed by the researcher. The results of the test indicated that the prior knowledge scores of the students were normally distributed (see Figure 10). Scores on the test ranged from 3 to 16, with a mean score of 9.40 ( $SD = 2.76$ ). Expressed in percentages, the scores ranged from 19% to 100% ( $M = 56%$ ).



*Figure 10.* Histogram of prior knowledge test scores.



There were several important demographic categories where no significant differences were found among students on the mean prior knowledge test scores. These included which text was read and which strategy was assigned. No differences for text,  $F(1, 250) = 0.037, p = .48$ , and strategy,  $F(1, 250) = 0.49, p = .48$ , validated that the random assignments resulted in homogeneous experimental groups. These categories with no differences also included country of origin (U.S. or international), high school chemistry (completion or noncompletion), and age category (traditional student or returning student).

#### *Comparison of Students Based on Text Assignment*

Each student read one of two texts: R, composed by the researcher, or T, an excerpt from the assigned course textbook. Table 8 displays the data concerning the readers of text R ( $n = 124$ ) and text T ( $n = 128$ ) as well as the overall sample ( $N = 252$ ) for broader comparisons to the whole. These data establish that the demographics for the students based on text assignment were similar in terms of age, gender, country of origin, and preparation for general chemistry. The experimental measures in Table 8 (i.e., time and prior knowledge test score) are also not statistically different. For time to read,  $F(1, 250) = 0.016, p = .90$ , and for mean prior knowledge test score,  $F(1, 250) = 3.01, p = .084$ .

Table 8

*Comparison of Students Assigned to Each Text*

	Full sample	Text R	Text T
<b>Demographics</b>			
Students	252	124	128
Mean Age	23.9 years	23.6 years	24.1 years
<b>Gender</b>			
Female	59%	59%	59%
Male	41%	41%	41%
<b>Country of origin</b>			
U.S.	49%	51%	47%
International	51%	49%	53%
<b>Preparation for CH 101</b>			
HS Chemistry	87%	84%	89%
CH 100	36%	38%	35%
<b>Experimental measures</b>			
Mean time to read	22 min ( <i>SD</i> = 6)	22 min ( <i>SD</i> = 7)	22 min ( <i>SD</i> = 6)
<b>Mean prior knowledge test</b>			
score	9.39 (59%)	9.35 (58%)	9.42 (59%)

### *Comparison of Students Based on Strategy Assignment*

Participants were randomly assigned to one of two strategies, elaborative interrogation or rereading. Table 9 displays the data for the two groups as well as the overall sample. These data establish that the demographics for the students based on strategy assignment were generally similar in terms of age, gender, country of origin, and preparation for general chemistry. Some of the demographics appear to be less homogeneous than in the case of text assignment (cf. Table 8). However, there were no significant differences in the distributions. There were two cases where the percentages appeared different on initial inspection, namely gender and country of origin. Further examination for homogeneity showed that the apparent differences were not statistically significantly different. Specifically, in the case of gender,  $\chi^2(1, N = 252) = 0.49, p = .48$ , where 57% of the elaborative-interrogation group was female ( $n = 71$ ) and 43% was male ( $n = 53$ ), and 61% of the rereading group was female ( $n = 78$ ) with 39% male ( $n = 49$ ). For strategy assignments by U.S. or international designation,  $\chi^2(1, N = 252) = 2.11, p = .15$ , where 54% of the elaborative-interrogation group was U.S. ( $n = 67$ ) and 46% was international ( $n = 58$ ), while the rereading group consisted of 44% U.S. students ( $n = 56$ ) and 56% international students ( $n = 70$ ).

For the experimental measure of mean prior knowledge test score, there was no significant difference between the two groups, with  $F(1, 250) = 0.49, p = .48$ .

Table 9

*Comparison of Students Assigned to Each Strategy*

	Full sample	Elaborative interrogation	Rereading
<b>Demographics</b>			
Students	252	125	127
Mean age	23.9 years	23.8 years	23.9 years
<b>Gender</b>			
Female	59%	57%	61%
Male	41%	43%	39%
<b>Country of origin</b>			
U.S.	49%	54%	44%
International	51%	46%	56%
<b>Preparation for CH 101</b>			
HS Chemistry	87%	86%	87%
CH 100	36%	36%	37%
<b>Experimental measures</b>			
Mean time to read	22 min ( <i>SD</i> = 6)	25 min ( <i>SD</i> = 7)	19 min ( <i>SD</i> = 5)
<b>Mean prior knowledge test</b>			
score	9.39 (59%)	9.51 (59%)	9.27 (58%)

There was a significant difference between the two strategy assignments on the measure of mean time required to read. The elaborative interrogation students required significantly more time to read ( $M = 25$  min,  $SD = 7$ ) compared to students assigned to the rereading strategy ( $M = 19$  min,  $SD = 5$ ). This was indicated by  $F(1, 250) = 50.67, p = 1.2 \times 10^{-11}$ . The mean reading time for elaborative interrogation students was essentially the same whether they were assigned text R ( $M = 25$  min,  $SD = 8$ ) or text T ( $M = 24$  min,  $SD = 6$ ). This significant difference in reading time between the rereading and elaborative-interrogation groups occurred in spite of efforts to design materials that would control for time. The six extra minutes, on average, used by the elaborative-interrogation students was 30% more time than that used by the rereading students. It should be noted, however, that there was no correlation between time and gain score for the sample, where  $r = -.005, p = .937$ . There was also no correlation between time and gain score among the elaborative interrogation students ( $r = .072, p = .426$ ) or among the rereading students ( $r = .040, p = .656$ ).

### *Role of Strategies in Learning Lewis Structures*

Text-R students assigned to the rereading strategy learned significantly more than text-R students assigned to elaborative interrogation. A more effective assigned strategy was undetermined for text T, the authentic text excerpt. In other words, a main effect for strategy was not observed in the text-T group. There was no statistically significant difference between the mean gain score for text-R and text-T students,  $F(1, 250) = 3.21, p = .074$ . In this section, these results are explained and are also examined in terms of sample subgroups.

### *Strategies for Learning from Factual Text*

Text R was composed in such a way as to present information about Lewis structures in the form of declarative factual sentences, thereby being similar to declarative factual sentences used in previously reported research about elaborative interrogation. While recall of *facts* was the to-be-learned target in the previous research, here the targets were *figures* of molecules and polyatomic ions. The to-be-learned figures were included within text R, each appearing after the paragraph that described it.

The research addressing text R was constructed as a pretest-posttest  $2 \times 2$  factorial design, where two strategies were assigned for the reading and the students were categorized as having high prior knowledge or low prior knowledge based on a median split of prior knowledge test score results. Three research questions were addressed. Specifically, Questions 4 and 5 addressed the potential main effects (strategy, prior knowledge) and Question 6 addressed the potential interaction (strategy  $\times$  prior knowledge). There were 124 students randomly assigned to a strategy to use while reading text R. The text-R students were split in half with 62 categorized in the high prior knowledge category and 62 in the low. The sample cell configuration is shown in Figure 11.

		STRATEGY	
		Rereading	Elaborative interrogation
PRIOR KNOWLEDGE	High	$n = 32$	$n = 30$
	Low	$n = 31$	$n = 31$

*Figure 11.* Cell sizes in  $2(\text{strategy}) \times 2(\text{prior knowledge level})$  design for text R.

Students were compared on the dependent variable, gain score, which represented the number of Lewis structures learned during the treatment, minus the number of unlearned structures. Possible scores ranged from -15 to +15 for each student, although the actual range for text R students was -4 to +11 ( $M = 4.18$ ,  $SD = 2.90$ ).

An ANOVA was conducted to answer research Questions 4 to 6 using the gain score as the dependent variable for comparison. The results are shown in Table 10. The ANOVA indicated a significant main effect for assigned strategy,  $F(1,120) = 8.48$ ,  $p = .004$ , in favor of rereading, for which the students had a significantly higher gain score ( $M = 4.90$ ,  $SD = 2.87$ ) compared to those who were assigned to use elaborative interrogation ( $M = 3.43$ ,  $SD = 2.76$ ). Figure 12 shows that the rereading strategy was more effective for text-R readers whether they had high or low prior knowledge.

Table 10

*ANOVA Summary Table for Gain Scores in Strategy  $\times$  Prior Knowledge for Text R*

Source	Sum of squares	df	Mean square	F
Strategy	66.454	1	66.454	8.48**
Prior knowledge level	23.678	1	23.678	3.02
Strategy $\times$ Prior knowledge level	3.487	1	3.487	0.45
Error	940.881	120	7.841	
Total	3200.000	124		

\*\*Significant at  $\alpha = .01$

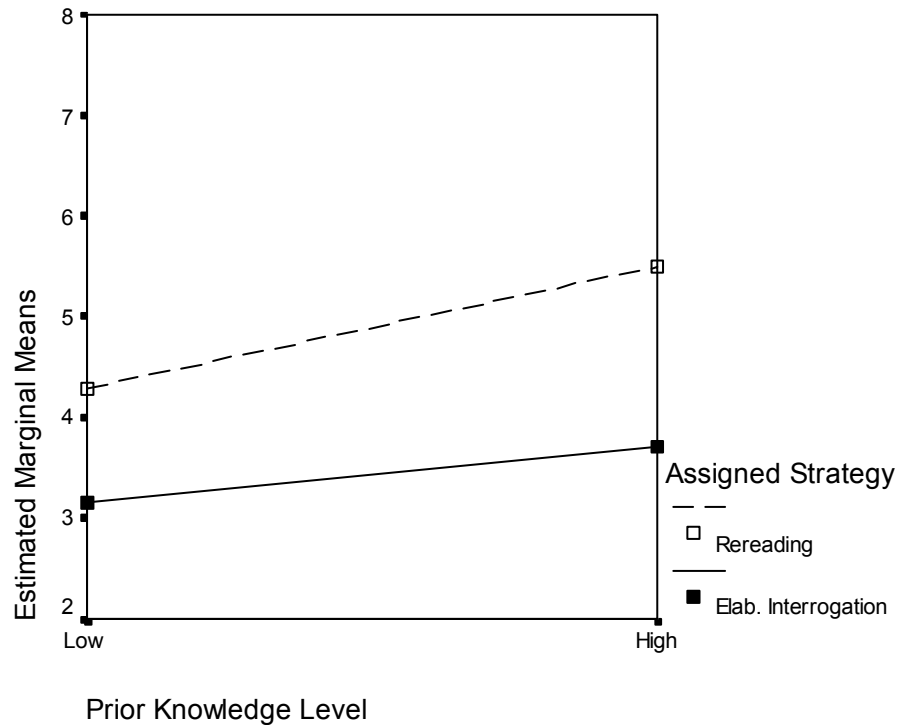


Figure 12. Plot of gain score means for text-R students.

Several subgroups of students are of interest in the current research because they have practical importance for classroom practice and institutional services. ANOVAs were conducted for subgroups based on gender, country of origin, and age range. The ANOVA results are presented in Table 11. There were no significant interactions. For the most part, the results of the subgroups reflected the overall sample of text-R students taken as a whole. In two cases, level of prior knowledge was a significant main effect, namely for female students and for international students. Females with high prior knowledge had a significantly higher mean gain ( $M = 5.29, SD = 2.71$ ) than females with low prior knowledge ( $M = 3.88, SD = 2.66$ ). High-prior-knowledge international students had a higher mean gain score ( $M = 4.52, SD = 2.85$ ) compared to those with low prior knowledge ( $M = 2.93, SD = 2.63$ ).



Table 11

*Research Questions 5 to 7 ANOVA Results for Student Subgroups*

		Strategy	Prior knowledge	Interaction
	<i>n</i>	<i>F</i>	<i>F</i>	<i>F</i>
All text-R students	124	8.48**	3.02	0.45
Gender				
Female	73	2.51	4.30*	0.20
Male	50	5.30*	0.53	0.00
Country of origin				
U.S.	63	10.88*	0.30	0.05
International	61	0.56	4.65*	0.90
Age Group				
Traditional	65	8.43**	1.28	0.47
Returning	59	1.29	1.76	0.07

\* $p < .05$ . \*\* $p < .01$ .

*Strategies for Learning from Procedural Text*

The nature of text T was unique for an elaborative interrogation investigation. The main focus of the reading was a series of imperative sentences about the procedure chemists use when drawing Lewis structures. This was different from the usual case of declarative factual sentences used in elaborative interrogation investigations. In the case of text T, the learning goal was this procedure, which is not an algorithmic process but rather a general process involving key judgments based on

chemistry knowledge. While some Lewis structure figures were shown in this reading, there were not as many as in text R. Except for two cases ( $\text{PCl}_3$ , phosphorus trichloride, and  $\text{NO}$ , nitrogen monoxide), the structures shown in text T were not on the pre- or posttest. This was in contrast to text R, which contained all identical structures as the tests. The structures in text T were there for illustrative purposes.

The research with text T was constructed as a pretest-posttest  $2 \times 2$  factorial design, where two strategies were assigned during the reading and the students were categorized as having high prior knowledge or low prior knowledge based on a median split of prior knowledge test score results. Three research questions were addressed. Specifically, Questions 8 and 9 addressed the potential main effects (strategy, prior knowledge) and Question 10 addressed the potential interaction (strategy  $\times$  prior knowledge). There were 128 students randomly assigned to one of the strategies to use while reading text T. Half ( $n = 64$ ) of the text-T students were categorized as having high prior knowledge and the other half low ( $n = 64$ ). The sample's cell configuration is shown in Figure 13.

Students were compared on their gain scores, which represented the number of Lewis structures learned during the treatment. Gain scores could range from  $-15$  to

		STRATEGY	
		Rereading	Elaborative interrogation
PRIOR KNOWLEDGE	High	$n = 30$	$n = 34$
	Low	$n = 34$	$n = 30$

Figure 13. Cell sizes in  $2(\text{strategy}) \times 2(\text{prior knowledge level})$  design for text T.

+15 for each student; the actual range for text T students was -4 to +12 ( $M = 3.49$ ,  $SD = 3.16$ ).

An ANOVA was conducted to answer research Questions 8 to 10 using the gain score as the dependent variable for comparison. The results are shown in Table 12.

Table 12

*ANOVA Summary Table for Gain Scores in Strategy × Prior Knowledge for Text T*

Source	Sum of squares	df	Mean square	F
Strategy	3.647	1	3.647	0.38
Prior knowledge level	88.022	1	88.022	9.27**
Strategy × Prior knowledge level	1.313	1	1.313	0.14
Error	1176.900	124	9.491	
Total	2829.000	128		

\*\*Significant at  $\alpha = .01$ , two-tailed.

The ANOVA indicated a significant main effect for readers of text T in favor of participants who had high prior knowledge ( $M = 4.31$ ,  $SD = 3.26$ ) over those with low prior knowledge ( $M = 2.67$ ,  $SD = 2.86$ ), where  $F(1,124) = 9.27$ ,  $p = .003$ . Figure 14 shows the relationship of the mean gain scores for the low- and high-prior-knowledge text-T students.

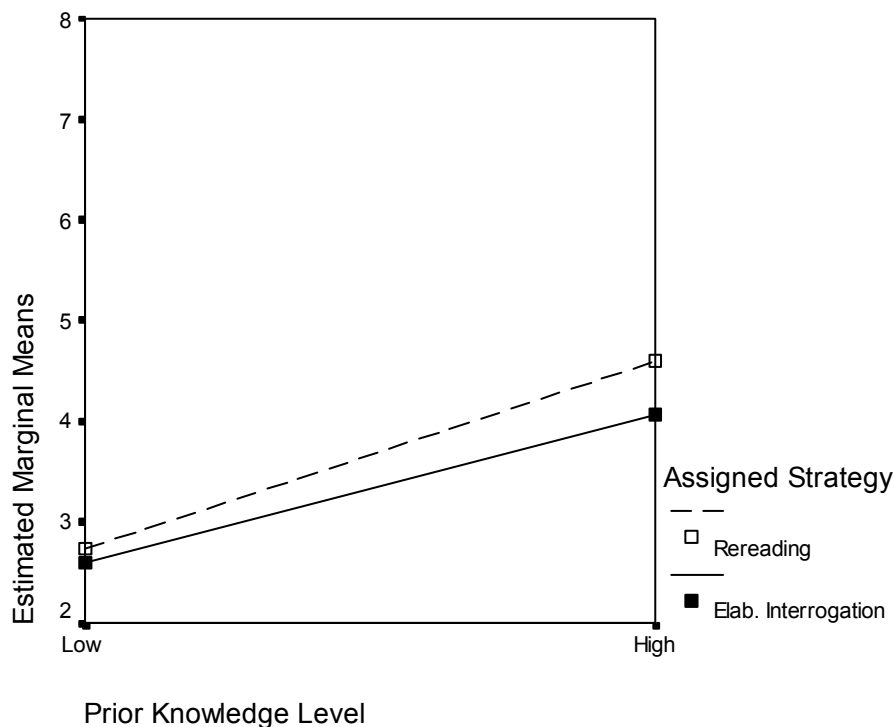


Figure 14. Plot of strategy  $\times$  prior knowledge level for text-T students.

Several subgroups of participants are of interest in the current research because of their practical importance for classroom practice. Gain scores in the 2(strategy)  $\times$  2(prior knowledge level) were submitted to ANOVA for the subgroups of gender, country of origin, and age range. The results are presented in Table 13.

The results of the research with text T are likely the most relevant for classroom application because they deal with an actual textbook in an ecologically valid situation. An examination of Figure 14 and the ANOVA results in Table 13 clearly highlight the importance of prior knowledge in learning a college level science topic such as drawing Lewis structures from a course textbook. Those with high prior knowledge achieved significantly higher gain scores ( $M = 4.31, SD = 3.26$ ) compared to those with the low prior knowledge ( $M = 2.67, SD = 2.86$ ). Among the subgroups,

Table 13

*Research Questions 8 to 10 ANOVA Results for Student Subgroups*

		Strategy	Prior Knowledge	Interaction
	<i>n</i>	<i>F</i>	<i>F</i>	<i>F</i>
All text-T students	128	0.38	9.27**	0.14
Gender				
Female	76	3.06	2.46	1.60
Male	52	0.62	8.60**	0.40
Country of origin				
U.S.	60	10.87**	8.86**	0.19
International	67	2.97	5.05*	0.08
Age Group				
Traditional	66	0.03	3.07	0.27
Returning	60	0.06	5.99*	0.52

\* $p < .05$ . \*\* $p < .01$ .

males with high prior knowledge had significantly higher gain scores ( $M = 4.50$ ,  $SD = 3.09$ ) than males with low prior knowledge ( $M = 2.05$ ,  $SD = 2.14$ ). This result was not observed for females assigned to text T. A significant difference in performance was also found for U.S. and international groups of students with high prior knowledge compared to those with low prior knowledge. In the case of U.S. participants, strategy was also a significant main effect, with students assigned to rereading having significantly higher gain scores ( $M = 4.71$ ,  $SD = 2.53$ ) than students assigned to

elaborative interrogation ( $M = 2.75, SD = 2.89$ ). The role of prior knowledge in learning about Lewis structures will be examined in detail below.

*Overall Text-Strategy Results*

In viewing the overall experiment with both texts and both strategies in the  $2(\text{text}) \times 2(\text{strategy})$  design, students assigned to the rereading strategy had statistically significantly higher mean gain scores. Cell distribution is shown in Figure 15. As was demonstrated above, the distribution of student demographics and experimental measures is homogeneous for both text assignment and strategy assignment.

Students were compared on gain scores, which ranged from a high of 12 to a low of  $-4$  (see Figure 16). The mean gain of the sample was 3.83 ( $SD = 3.05$ ). The ANOVA (see Table 14) results indicated a significant main effect for strategy,  $F(1,248) = 5.13, p = .024$ . This effect reflected a significant difference between students assigned to the rereading strategy and those assigned to elaborative interrogation. The students assigned to the rereading strategy had a significantly higher gain score ( $M = 4.25, SD = 2.96$ ) compared to those assigned to elaborative interrogation ( $M = 3.40, SD = 3.09$ ).

		STRATEGY	
		Rereading	Elaborative interrogation
TEXT	R	$n = 63$	$n = 61$
	T	$n = 64$	$n = 64$

Figure 15. Cell sizes in  $2(\text{text}) \times 2(\text{strategy})$  experimental design.

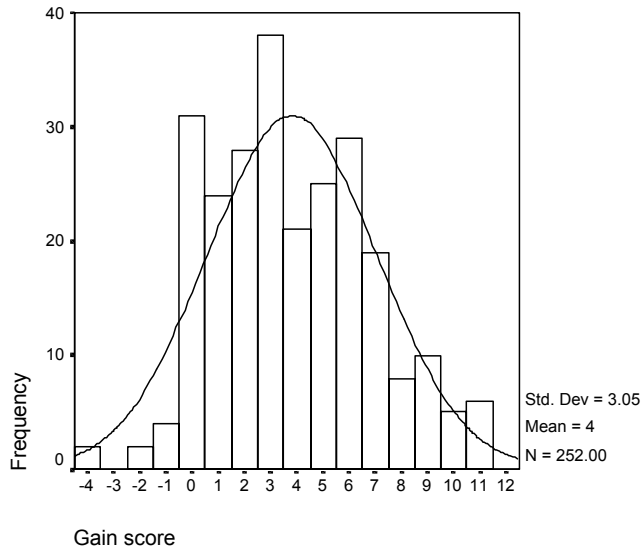


Figure 16. Histogram of gain scores.

Whether students read text R or T, there was no significant difference in their mean gain scores. Text-R students had a mean gain of 4.18 ( $SD = 2.90$ ) and text-T students had a mean gain of 3.49 ( $SD = 3.16$ ), where  $F(1,248) = 3.17, p = .076$ . Figure 17 shows that the rereading strategy was more potent with the factual-based

Table 14

*ANOVA Summary Table for Gain Scores in Text  $\times$  Strategy Comparison*

Source	Sum of squares	df	Mean square	F
Text	28.550	1	28.550	3.17
Strategy	46.194	1	46.194	5.13*
Text $\times$ Strategy	24.370	1	24.370	2.71
Error	2234.581	248	9.010	
Total	6029.000	252		

\*Significant at  $\alpha = .05$ , two-tailed.

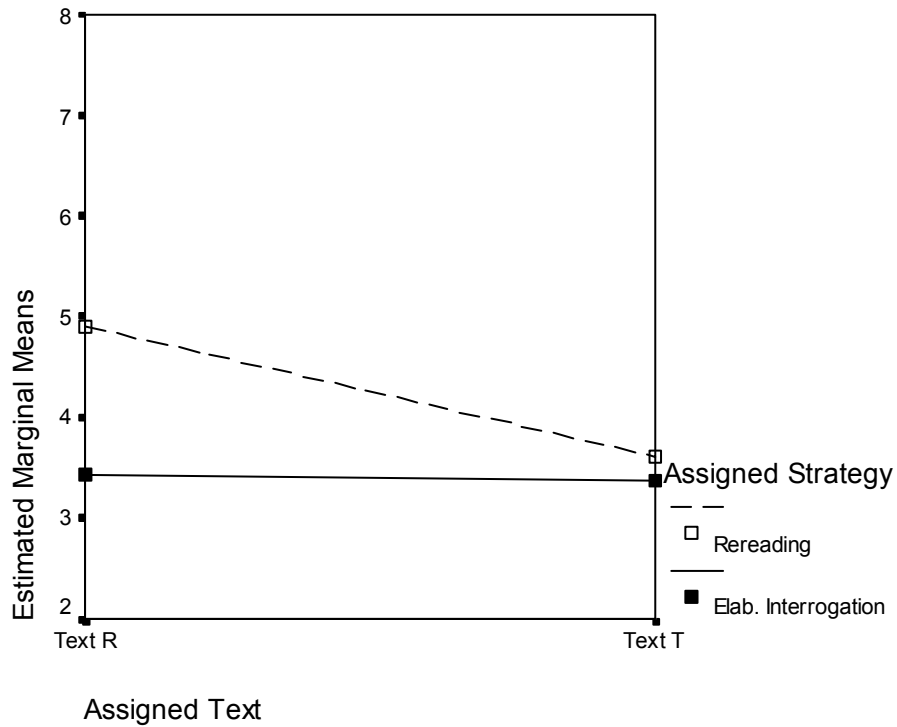


Figure 17. Plot of mean gain scores for text  $\times$  strategy.

text R compared to the procedural-based text T on which both strategies resulted in similar mean gain scores. There was no significant interaction,  $F(1, 248) = 2.71, p = .10$ .

These results for text R, the factual text, run contrary to some reported research involving the learning of facts from prose while assigned to use elaborative interrogation. In those cases, elaborative interrogation tended to provide a benefit over rereading involving the learning of facts. In the current research, rereading was statistically equally as effective as elaborative interrogation for the sample in the learning of Lewis structures.



Gain scores in the 2(text) × 2(strategy) were submitted to ANOVA for the subgroups based on gender, country of origin, and age range. The ANOVA results are listed in Table 15.

An interesting difference emerged in the gender subgroups. For females ( $n = 149$ ), there were two main effects, text and strategy, in favor of text R and the rereading strategy. There was no main effect for males. However, the interaction was significant; males' mean gain score with text R was higher when they were assigned to use rereading, but their mean score on text T was higher when they were assigned to use elaborative interrogation.

#### *Student Compliance with Instructions*

It should be noted that the criterion task for the treatments in this investigation was different from that in previous elaborative interrogation research, where recall-of-facts tests were generally utilized. In this research, the goal was the recall of Lewis structures after reading. Since this task involved drawing a figure and students were shown the figures in the text R treatment materials, it is conceivable that students who were assigned to the rereading strategy engaged in additional spontaneous strategy use, for example, mental imaging, which is itself a form of elaboration. It is impossible to know if such strategy use occurred since it is a mental operation. Researcher observations of student behavior as well as students' questions during the treatment provided support that students were generally adhering to the instructions.

To determine if any other strategies, specifically those that leave artifacts, may have been used, experimental materials were analyzed for possible evidence. The papers of 21 rereading students (i.e., 17% of those assigned to the strategy)

Table 15

*Research Questions 2 to 4 ANOVA Results for Student Subgroups*

		Text	Strategy	Interaction
	<i>n</i>	<i>F</i>	<i>F</i>	<i>F</i>
All students	252	3.17	5.13*	2.71
Gender				
Female	149	3.95*	4.95*	0.01
Male	102	0.20	0.58	7.04**
Country of origin				
U.S.	123	2.96	18.00**	0.10
International	128	0.09	0.26	2.86
Age Group				
Traditional	131	5.42*	3.84	3.63
Returning	119	0.00	0.97	0.37

\* $p < .05$ . \*\* $p < .01$ .

contained minimal underlining or highlighting (rehearsal strategies). This compared with 26 elaborative interrogation students (i.e., 21% of those assigned to the strategy), whose papers also contained underlining or highlighting.

### *Role of Prior Knowledge in Learning Lewis Structures*

#### *Correlation between Prior Knowledge and Gain Score*

Prior knowledge level was a statistically significant factor in learning how to draw Lewis structures from the authentic procedural text (see Table 12, p. 147). This

has important implications for classroom practice. In this section, students' prior knowledge is explored in more detail.

To explore further the possibility of a relationship between prior knowledge and gain score, correlation coefficients were determined. In the case of text-R students ( $n = 124$ ), the correlation was  $r = .164$  with  $p = .069$ . For text-T students ( $n = 128$ ),  $r = .278$  and  $p = .001$ . With a statistically significant correlation among text-T students, but not with text-R students, these data suggested that prior knowledge may have played a different role in the two text readings. To ascertain more information about the role prior knowledge played with text-T students, correlations were determined for each subgroup, those assigned to rereading and those assigned to elaborative interrogation.

For text-T students assigned to rereading ( $n = 64$ ), prior knowledge test score was positively correlated with gain score, where  $r = .34$ , and  $p = .0058$ . However, for text-T students assigned to elaborative interrogation ( $n = 64$ ), this correlation was not significant, with  $r = .24$ ,  $p = .056$ . For the elaborative interrogation group, prior knowledge may have played a role in another fashion, specifically by mediating learning. For those assigned to use the elaborative interrogation strategy, prior knowledge test score was positively correlated with the number of adequate why-question answers. In turn, the number of adequate why-question answers was positively correlated with gain score (see Table 16). This may suggest that high-prior-knowledge students wrote better why-question answers, thus activating their prior knowledge and leading to better comprehension, as evidenced by their higher gain scores.

Table 16

*Correlations for Text-T Students Assigned to Elaborative Interrogation*

	1	2	3
1. Prior Knowledge Test Score	—	.24	.45**
2. Gain Score		—	.34**
3. Adequate Why-Question Answers			—

\*\* Correlation is significant at the 0.01 level, two-tailed.

*Prior Knowledge Test Item Analysis*

The prior knowledge test was analyzed item by item for student performance (see Table 17). All 18 items were included in the analysis, although items 1 and 3 were omitted from the prior knowledge test score because their answers were displayed on periodic tables in two of the classrooms where the experiment was conducted. Item responses ranged from a high of 93% of participants correct (on item 9) to a low of 19% of participants (on item 18). On four of the items, the most commonly given answer was a wrong answer.

*Impact of Different Paths to College level Chemistry*

Understanding students' preparation for college level chemistry in terms of previous academic work in chemistry is important for understanding their prior knowledge levels. First-semester general chemistry students are often a heterogeneous population in terms of their academic backgrounds. Some completed high school chemistry; others did not. Some had comprehensive high school curricula; others did not. Some achieved high academic marks in high school

Table 17

*Prior Knowledge Test Item Analysis*

Item	Correct answer	Students with correct answer	Most common answer	Item	Correct answer	Students with correct answer	Most common answer
1 <sup>a</sup>	D	95%	D	10 <sup>b</sup>	C	24%	B
2	B	79%	B	11	B	42%	B
3 <sup>a</sup>	A	75%	A	12	C	70%	C
4	D	77%	D	13	A	67%	A
5	C	63%	C	14 <sup>b</sup>	D	39%	B
6	A	62%	A	15 <sup>b</sup>	B	19%	D
7	B	79%	B	16	A	68%	A
8	C	80%	C	17	A	67%	A
9	D	93%	D	18 <sup>b</sup>	B	19%	D

<sup>a</sup> These items were omitted from the analysis and not included in participants' scores.

<sup>b</sup> The most common answer for these items was a wrong answer.

chemistry; others did not. Some took high school chemistry within several years before entering college general chemistry; others did not.

The college level chemistry course in which the students were enrolled, CH 101 (Chemistry 101), has prerequisites of high school chemistry or CH 100 (Chemistry 100), which is a one-semester, three-credit introductory chemistry course offered at the college where the research was conducted. CH 100 is designed to cover basic chemistry topics in order to prepare students for CH 101. Students who did not

complete high school chemistry are required to take CH 100 before CH 101. Other students may be encouraged or may opt to take CH 100, especially those who took high school chemistry more than five years before intending to enroll in CH 101.

The students in this study took one of four preparation paths to CH 101: (a) high school chemistry only ( $n = 149$ ); (b) CH 100 only ( $n = 25$ ); (c) both high school chemistry and CH 100 ( $n = 65$ ); or (d) neither high school chemistry nor CH 100 ( $n = 8$ ). The prior knowledge test score results for these four paths are shown in Table 18. These scores were found to be significantly different,  $F(4, 246) = 4.1, p = .003$ .

Viewing the paths slightly differently, as might be relevant to college chemistry faculty, there were 90 students who had completed CH 100 (found by  $65 + 25$ ) and 157 students who had not completed CH 100 ( $149 + 8$ ). The 90 students who completed CH 100 had a significantly higher mean prior knowledge test score than the 157 students who did not complete CH 100. Specifically, the CH-100 completers'

Table 18

*Prior Knowledge Test Scores by Path to General Chemistry*

Path to general chemistry	$n$	Mean prior knowledge test score (of possible 16)
HS Chemistry only	149	9.09
CH 100 only	25	10.24
Both HS Chemistry and CH 100	65	10.15
Neither HS Chemistry nor CH 100	8	7.00

*Note.* HS = High School, CH 100 = Chemistry 100

mean score was 10.18 ( $SD = 2.84$ ) compared to a mean of 8.98 ( $SD = 2.63$ ) for noncompleters. In practical terms for the 16-item test, the equivalent percentage scores were 64% for the CH 100 completers and 56% for the noncompleters. In a classroom situation, such a difference could equate to a full letter grade difference.

### *Gender Differences in Prior Knowledge Levels*

Much attention has been given to gender differences in science and mathematics in the educational research literature (e.g., Eccles, 1997). In this study, it was found that there was a statistically significant difference in the prior knowledge test mean score for males ( $n = 102$ ,  $M = 9.89$ ,  $SD = 2.83$ ) and that of females ( $n = 149$ ,  $M = 9.06$ ,  $SD = 2.68$ ), where  $F(1, 250) = 5.58$ ,  $p = .019$ . In terms of percentage test scores, males averaged 62% on the prior knowledge test, while females averaged 57%. These data indicate that males entered the treatment with a slight advantage concerning the background knowledge needed to learn about Lewis structures. However, when broken down by country of origin, it was found that for U.S. students, there were no differences in prior knowledge between males and females. There was, in fact, a difference between males' and females' prior knowledge levels in the international student sample. The international males' mean prior knowledge test score was 9.91 ( $SD = 2.92$ ) while the females' was 8.66 ( $SD = 2.33$ ). In terms of percentages, these statistically significantly different scores among international participants were a mean of 62% for males and 54% for females.

This difference between the genders becomes more pronounced in the median split, which was applied to categorize participants into high and low prior knowledge levels. Using the median prior knowledge test score of 9.50, students with a prior

knowledge test score of 10 and above were classified as having high prior knowledge, while those with a score of 9 or below were classified as having low prior knowledge. This resulted in 126 students classified as high and 126 classified as low. However, a test for homogeneity indicated that the females and males were not the same in terms of their prior knowledge,  $\chi^2(1, N = 251) = 9.18, p = .002$  (note that one participant did not report gender). Among those classified as having high prior knowledge, 63 were female ( $f_e = 75$ , based on 59% of the sample being female), and 63 were male ( $f_e = 51$ , based on 41% of the sample being male). Among the low prior knowledge group, 86 were female ( $f_e = 75$ ) and 39 were male ( $f_e = 51$ ). Furthermore, among all males ( $n = 102$ ), 62% were placed in the high prior knowledge group and 38% were in the low category. Among all the females ( $n = 149$ ), 42% were in the high prior knowledge group and 58% were in the low group.

It is important to note that males and females were distributed among the four treatments in a homogenous fashion. In other words, almost half of the females (49%) read text R and the others (51%) read text T. About half were assigned the rereading strategy (52%) and the remainder (48%) was assigned the elaborative interrogation strategy. This even division was also true of the males, among whom about half (49%) read text R, and the others (51%) read text T. About half (48%) were assigned rereading, and the remainder (52%) used elaborative interrogation.

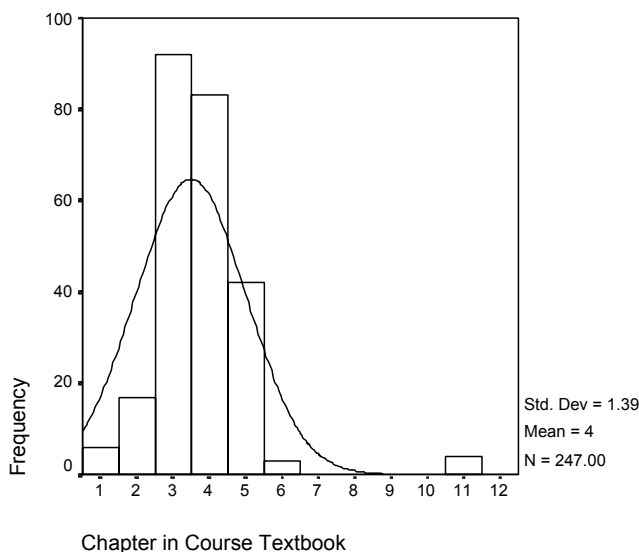
#### *Last Chapter Studied*

In addition to prior knowledge acquired in previous science chemistry courses such as high school chemistry and CH 100, the course textbook is another important source of prior knowledge relating to Lewis structures. Participants were asked on a



survey to indicate, to the best of their recollection, the last chapter they had studied in their chemistry textbook. To help them recall the contents of the chapters, the chapter titles were included with chapter numbers 1 to 12 on the form. These chapters were presented because they represented the chapters included by most faculty on their syllabi for the course. Of the 252 participants, 247 provided a response to this question, with most answers ranging from Chapter 2 to Chapter 5 (see Figure 18).

These data are informative because the textbook instruction concerning the drawing of Lewis structures appears in the middle of Chapter 8. Prior knowledge components, in the form of 27 technical terms and related concepts, for the Chapter 8 section on Lewis structures are found in Chapters 1, 2, 6, and 7, with several terms coming at the beginning of Chapter 8 (see the list of terms in Table 5, p. 99). Of the four chapters with prior knowledge material (Chapters 1, 2, 6, and 7), nearly all of the



*Figure 18.* Participants' self-reporting of the last chapter studied at the time of the treatment.

students (98%) reported that they had completed Chapter 2 or beyond. This means that, at a minimum, all students probably would have encountered 12 of the 27 (i.e., 44%) technical terms in their textbook reading. Their prior knowledge relating to the remaining 15 technical terms would, therefore, be based on their previous academic science and chemistry experiences.

It should be pointed out that while general chemistry textbooks seem to present chemistry information in a logical order, the chapters of most general chemistry textbooks do not necessarily build on all the preceding chapters. For instance, Chapters 3, 4, and 5 in the required textbook for this course would virtually have no bearing on understanding Lewis structures in Chapter 8. Chapters 3, 4, and 5 address, respectively, topics of stoichiometry (i.e., mass and molecular calculations related to chemical reactions); aqueous reactions (i.e., reactions that occur in water); and thermochemistry (i.e., the energy aspects of chemical reactions). Understanding these topics is not necessary when learning about Lewis structures.

It is interesting to note that this question on the student survey form concerning the last chapter read in the textbook evoked more feedback and comments to the researcher than any other question. Although not counted or tracked, verbal comments (perhaps about a dozen) made to the researcher indicated that some participants believed that (a) they did not have enough money to buy the book or felt it was too expensive, (b) they did not have enough time to read the book, or (c) they considered studying the class notes more important than reading the book. One participant (a 19-year-old international female) asked for reassurance from the

researcher that the course instructor would not see the survey form since she had only read as far as Chapter 1. Two other participants wrote comments on the survey form:

“Who has \$ to buy the book?” — 23-year-old U.S. female

“Comment: ADD students learn better hands on or w/ a good lecture teacher (interesting charismatic).” — 19-year-old U.S. female

The self-reporting of last chapter studied does not provide any information relating to the quality or quantity of studying and reading, but it can be viewed as an indicator of student progress in the course.

### *Students' Self-awareness*

Being aware of one's own academic strengths and weaknesses is a form of a monitoring learning strategy (see Table 1, p. 32). The student survey instrument used in this experiment contained a section asking participants to rate themselves regarding their knowledge of various topics in chemistry on a Likert scale. When students' self-ratings on chemical bonding were compared with their actual prior knowledge test scores, it was found that there was a significant level of agreement (see Table 19).

Table 19

#### *Students' Self-ratings on Chemical Bonding Mirror Prior Knowledge Test Scores*

Self-rating for		Mean prior knowledge test score
knowledge of bonding	<i>n</i>	(with percentage test score)
Low	91	8.60 (54%)
Medium	123	9.74 (61%)
High	25	11.16 (70%)

Analysis of the prior knowledge test score means showed a significant increase as students' self-ratings increased, where  $F(3,242) = 7.12, p = .0001$ . Of the full sample ( $N = 252$ ), seven participants did not give themselves a rating. Seven other participants reported that they had no knowledge of chemical bonding, but their mean prior knowledge test score was higher than those who said they had low knowledge. The pattern of self knowledge held true among those who reported that their knowledge of chemical bonding was low, medium, or high.

These self-ratings were somewhat unexpected results in that simply asking college students about their background knowledge in a science content area would yield generally accurate results. Such an approach, if the only method to measure prior knowledge, is not recommended (Shapiro, 2004).

### Brady et Al. Trend in Students' Lewis Structures

The trend of Lewis structure difficulty as reported by Brady et al. (1990) and confirmed in a descriptive replication experiment (above), emerged again in the text-strategy investigation performed to compare assigned strategies while reading text. The purpose of the replication experiment had been to validate the Brady group's list and to use the list in composing the pretest and posttest for the text-strategy research. The pre- and posttests were identical and contained 15 formulas in increasing theoretical order of difficulty (see Table 20). In other words, number 1 was the easiest and number 15 was the most difficult.

In this section, the methods used to evaluate Lewis structures are explained as well as the resulting Brady et al. (1990) trends.

Table 20

*Formulas Used on Pretest, Posttest, and in Text R for Lewis Structure Drawing*

Easy-to-learn		Average-to-learn		Difficult-to-learn	
Reference	Formula	Reference	Formula	Reference	Formula
1	HF	6	ClF <sub>3</sub>	11	CO <sub>2</sub>
2	PF <sub>6</sub> <sup>-</sup>	7	N <sub>2</sub>	12	BrF <sub>4</sub> <sup>-</sup>
3	CH <sub>4</sub>	8	NO <sub>2</sub> <sup>+</sup>	13	I <sub>3</sub> <sup>-</sup>
4	AlCl <sub>4</sub> <sup>-</sup>	9	SO <sub>3</sub> <sup>2-</sup>	14	NO <sub>2</sub> F
5	PCl <sub>3</sub>	10	HOI	15	NO

*Note.* Figures provided later in this Chapter refer to these formulas by these reference numbers.

### *Evaluation of Lewis Structures*

Two independent raters assisted the researcher in evaluating the Lewis structures based on a rubric developed by the researcher. The steps in the evaluation process were explained in detail in Chapter Three. With 252 students and 15 structures drawn on each pretest and 15 on each posttest, there were potentially 7,560 structures to evaluate: 3,780 on the pretests and 3,780 on the posttests. Of this number of potential structures, there were 992 blanks on the pretests (i.e., 26% of all pretest items) but only 188 blanks on the posttests (i.e., 5% of all posttest items). Not counting blanks, then, 6,380 Lewis structures were evaluated.

For purposes of discussion, a correct structure was defined as one that received five points from the rater. An incorrect structure was defined as one that received four points or fewer.

The pre- and posttest results for the sample are shown in Figure 19. This figure shows the percentage of students who gave correct answers on each test, the pretest and posttest, and it demonstrates descriptively that learning did indeed take place during the treatment. The percentage of students giving correct structures on the posttest was always greater, and usually much greater, than the percentage drawing correct structures on the pretest. Note that the Lewis structure numbers appearing on the x-axis correspond to the reference numbers for formulas shown in Table 20. For instance, number 1 refers to HF, number 2 refers to  $\text{PF}_6^-$ , etc.’

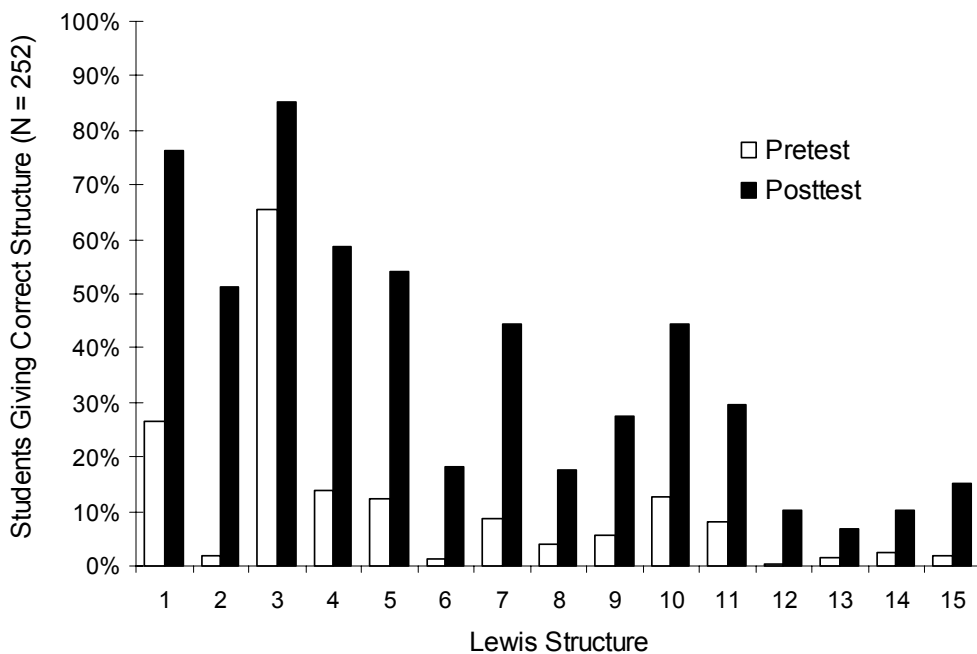


Figure 19. Correct Lewis structures drawn on the pretest and posttest.

Several observations emerge from analysis of Figure 19. First, a very large number of students knew how to draw the structure of methane,  $\text{CH}_4$  (structure number 3), on the pretest. The number of students giving a correct answer, 165, represented 65% of all students. No other item was answered correctly at even half this rate on the pretest. This result is not likely to surprise most chemistry faculty since  $\text{CH}_4$  is one of the simplest molecules to draw and often one of the first learned by students in chemistry courses. Following the reading, 215 individuals drew  $\text{CH}_4$  correctly, which represented an additional 50 students. To understand the definition of the dependent variable, gain score, (i.e., the number of Lewis structures learned), it should be pointed out that drawing a structure correctly on the pretest and on the posttest did not result in any credit toward the gain score. In this example of  $\text{CH}_4$ , only the 50 students who learned to draw the Lewis structure after the treatment received a point toward their gain score. Analysis of the difference between the pretest (white bar) and posttest (black bar) in Figure 19 indicates the percentage of students who learned to draw the structure as a result of reading about Lewis structures in this experiment.

Structure number 2,  $\text{PF}_6^-$ , was the most learned structure of all, going from less than 2% of students correct on the pretest to 51% correct on the posttest. This is one of the structures classified as easy-to-learn by Brady et al. (1990). The overall results shown in Figure 19 generally reflect the Brady et al. hypothesis of difficulty levels associated with drawing Lewis structures. Structure numbers 1 to 5 are those considered easy-to-learn after instruction in Lewis structures, 6 to 10 average-to-learn, and 11 to 15 difficult-to-learn, according to Brady et al. The trend of the

percentages of structures correctly drawn follows this pattern fairly closely in Figure 19. These pretest-posttest data were analyzed for each text treatment group.

Students assigned to read text R ( $n = 124$ ) had pre- and posttest results in essentially the same pattern as the overall sample results. For example, methane,  $\text{CH}_4$ , was drawn correctly by the highest percentage on the pretest and  $\text{PF}_6^-$  ranked as the most-learned structure with only three students correct on the pretest and 72 correct on the posttest.

From an overall perspective, the 124 text-R readers had a net improvement of 518 learned Lewis structures as a result of the treatment. They had 234 correct structures on the pretest and 752 correct on the posttest. In total, 551 structures were learned, but 33 were unlearned among these students, leaving the cumulative gain score of 518 for the group. Judged against the potential gain score ( $124 \text{ students} \times 15 \text{ structures/student} = 1,860 \text{ total structures}$ ; less 234 correct on the pretest results in 1,626 potential to-be-learned structures for text-R readers), this group learned 32% of everything it could have learned.

The pattern of pretest and posttest performance by the students assigned to text T ( $n = 128$ ) was similar to the pattern observed for the overall sample as well as the pattern observed for text-R readers. Similar to the text-R students' results,  $\text{CH}_4$  was answered correctly more frequently than any other structure on the pretest. For text-T readers, structure number 5,  $\text{PCl}_3$ , was the most learned structure. It may be no coincidence that this was one of only two tested structures that appeared within the body of text T.



The cumulative net learning for the 128 readers of text T was 447 Lewis structures. They had 186 structures correct on the pretest and 633 correct on the posttest. In all, 487 structures were learned, but 40 were unlearned, resulting in the cumulative gain score of 447 for the group. When compared with the potential gain score (determined by  $128 \text{ students} \times 15 \text{ structures/student} = 1,920 \text{ total structures}$ ; less 186 correct on the pretest gives 1,734 potential to-be-learned structures for text-T students), this group learned 26% of everything it could have learned.

### *Measuring Learning of Lewis Structures*

Each student's score on each pretest item was compared with the corresponding item on the student's posttest and a resultant change designator was assigned for each case. The main change of interest was learned structures. In other words, structures judged incorrect on the pretest, but correct on the posttest. In all, there were five possible results in each pretest-posttest item comparison:

1. *learned*, as indicated by incorrect on the pretest, but correct on the posttest;
2. *unlearned*, that is, correct on the pretest, but incorrect on the posttest;
3. *already known*, which was assigned when a student drew a correct structure on both the pre- and posttests;
4. *not-learned*, meaning the student drew an incorrect structure on both the pre- and posttests; and
5. *not attempted*, indicating the student did not attempt to draw the structure on either the pre- or posttests. (Note that if a student left a blank on the pretest but attempted an answer on the posttest, or vice versa, the resulting pretest-posttest item relationship was assigned to one of the above categories as

appropriate. Only the case of both a blank on the pretest and a blank the posttest was designated as *not attempted*).

Table 21 lists the percentage of students ( $N = 252$ ) whose pretest-posttest performance falls into each of the five pretest-posttest item relationships. The percentage of students who learned a structure after the treatment (i.e., incorrect on the pretest, but correct on the posttest) ranged from a high of 52% on Lewis structure number 1 (HF) to a low of 6% on structure number 13 ( $I_3^-$ ). In general, the percentage learned decreased as the theoretical difficulty of the structures increased. Structures 1 to 5 were rated as easy-to-learn after instruction in the Brady et al. (1990) research, 6 to 10 were rated as average-to-learn, and 11 to 15 were classified as difficult-to-learn. Learning took place in 1,038 cases, or 27%, of pretest-posttest item relationships.

The category of “already known” applied to those cases in which the student knew how to draw a correct structure on the pretest and drew the same correct structure on the posttest. There were 344 instances of this, or 9% of all the 3,780 pretest-posttest structure combinations. The structure falling into this category most often was structure 3,  $CH_4$ , for which 59% of students drew the correct structure before and after the treatment. This also accounts for the lower learning rate for  $CH_4$  in the sample. The extent of already known structures generally decreased going from the easy-to-learn category to the average-to-learn to the difficult-to-learn.

The cases in which students drew an incorrect structure both before and after the treatment were classified as “not-learned.” In other words, both the pretest and posttest answer for the structures were wrong. This category actually accounted for most of the pretest-posttest item combinations with 2,261 occurrences of the

Table 21

*Pretest-Posttest Matched-Item Outcomes for Sample (N = 252)*

Lewis structure	Learned	Unlearned	Already known	Not learned	Not attempted
Easy-to-learn category					
1 – HF	52%	2%	25%	21%	1%
2 – PF <sub>6</sub> <sup>-</sup>	50%	0%	2%	47%	2%
3 – CH <sub>4</sub>	26%	6%	59%	8%	1%
4 – AlCl <sub>4</sub> <sup>-</sup>	48%	3%	11%	37%	2%
5 – PCl <sub>3</sub>	44%	3%	10%	42%	1%
Average-to-learn category					
6 – ClF <sub>3</sub>	17%	0%	1%	79%	2%
7 – N <sub>2</sub>	37%	1%	7%	53%	2%
8 – NO <sub>2</sub> <sup>+</sup>	15%	1%	3%	79%	2%
9 – SO <sub>3</sub> <sup>2-</sup>	23%	1%	4%	69%	2%
10 – HOI	35%	4%	9%	50%	2%
Difficult-to-learn category					
11 – CO <sub>2</sub>	24%	2%	6%	66%	2%
12 – BrF <sub>4</sub> <sup>-</sup>	10%	0%	0%	87%	2%
13 – I <sub>3</sub> <sup>-</sup>	6%	1%	0%	90%	2%
14 – NO <sub>2</sub> F	8%	2%	1%	87%	2%
15 – NO	15%	2%	0%	81%	2%

*Note.* Percentages for a structure may add to 99%, 100%, or 101%, due to methods of rounding.

cumulative 3,780 possible combinations (i.e., 60% overall). This is an important category to consider in more detail, especially since it represented the majority of cases.

Assignment of the not-learned designation was based on both the pre- and posttest scores being less than five points. Such a classification standard, then, was an all-or-nothing grade designation. However, since all structures were graded on a five-point scale using a standard rubric, it was possible to review the structures for evidence of partial learning. The points on the posttest were compared to points on the pretest earned by each student ( $N = 252$ ) in the 2,261 instances of not-learned structures. On the pretest, the sample earned 1,120 cumulative points on these 2,261 items; on the posttest, the sample earned 2,323 cumulative points, an increase of 1,203 points. In other words, after the treatment, the sample earned more than twice as many points on the not-learned structures compared to before the treatment. Apparently, students made progress in their learning of drawing Lewis structures. The amount of partial learning, measured in points on the five-point grading scale, was generally one point per structure (see Table 22). There were only occasional exceptions to this pattern of one point per structure (e.g., three students averaged greater than a two-point increase on their not-learned structures). This pattern of partial learning was found to be equal across texts and strategies used.

Very few students left items blank on both the pretest and the posttest. The cumulative number was only 64 instances in the sample (less than 2% of all pretest-posttest combinations). The highest occurrence for any one structure was only 6 students.

Table 22

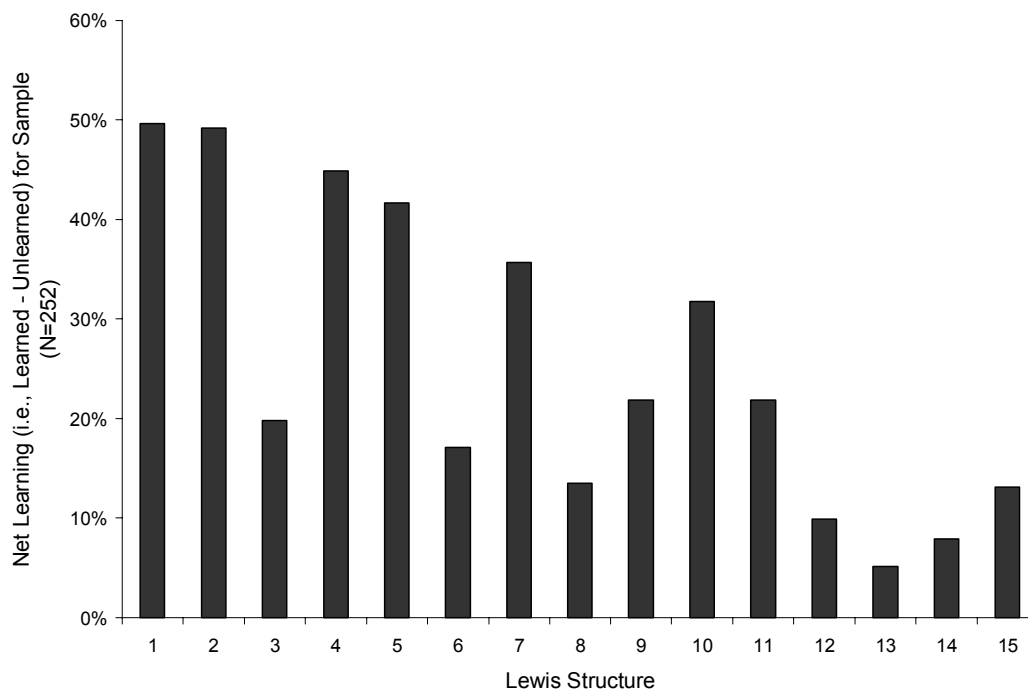
*Partial Learning in the Sample*

		Students exhibiting		Mean points gained
		partial learning	Structures partially	per partially learned
	<i>n</i>	(% of <i>n</i> )	learned	structure
Text R				
EI	61	59 (94%)	256	0.9
RR	63	58 (92%)	253	1.0
Text T				
EI	64	64 (100%)	306	1.0
RR	64	61 (97%)	388	1.1

*Note.* EI = Elaborative interrogation, RR = Rereading

In summary, 252 students participated in a reading treatment with the goal of learning to draw 15 Lewis structures. Students were tested before the treatment and after resulting in 3,780 pretest-posttest matched-item combinations to inspect and compare. Analysis of the structure combinations showed that 27% were learned, 60% were not learned (although partial learning occurred), 9% were already known, 2% were unlearned, and 2% were not attempted.

The trend of gain scores for structures 1 to 15 mirrored the Brady et al. (1990) trend of Lewis structure difficulty (see Figure 20). The degree of structure difficulty



*Figure 20.* Lewis structure gains (i.e., learned structures minus unlearned structures) for the sample.

increases and the rate of learning generally decreases, moving from left to right in Figure 20. This is especially noted in the low rate of learned structures for numbers 12 to 14 ( $\text{BrF}_4^-$ ,  $\text{I}_3^-$ , and  $\text{NO}_2\text{F}$ , respectively).

The learning results for the 15 structures used in this investigation were analyzed further in terms of their difficulty level. The results of this analysis follow below and provide additional descriptive evidence that the Brady et al. (1990) list of structures is a reliable resource for predicting college students' facility in learning to draw Lewis structures.

#### *Easy-to-learn Structures*

Students in all four treatment groups achieved their highest learning rates for the Lewis structures in the easy-to-learn category (structures numbered 1 to 5, HF,

$\text{PF}_6^-$ ,  $\text{CH}_4$ ,  $\text{AlCl}_4^-$ , and  $\text{PCl}_3$ , respectively). Learned structures (i.e., those that were wrong on the pretest but correct on the posttest) for structure number 1, HF, ranged from 48% for the text-T students assigned to elaborative interrogation, to a high of 56% for text-R students assigned to rereading. For structure number 2,  $\text{PF}_6^-$ , the range was 42 to 62%, with text-T students assigned to elaborative interrogation at the low end and text-R students assigned to rereading at the high end. Learning for structure 3,  $\text{CH}_4$ , appeared much lower, however, because a majority of students already knew the Lewis structure for this formula before the experiment. Nevertheless, learning was still observed for some students on this structure.

Figure 21 shows the percentage of students who learned to draw the five easy-to-learn Lewis structures during the experiment. In three cases, structures 1, 2, and 4, the highest amount of learning was achieved by the text-R students assigned to rereading. Text-R students assigned to elaborative interrogation were highest on structure 3, and text-T students assigned to rereading were highest on structure 5. Many students already knew structures 1, 3, 4, and 5, with 25%, 59%, 11%, and 10%, respectively, drawing these correct on both the pretest and the posttest. Only four students (2%) knew structure 2 before the treatment. For structures 1 to 5, the percentages of not-learned structures were 21%, 47%, 8%, 37%, and 43%, respectively. For these five easy-to-learn Lewis structures, the unlearned structures and the structures not attempted were very low (less than 2% each). As was demonstrated earlier, partial learning did occur among the instances classified as not-learned.

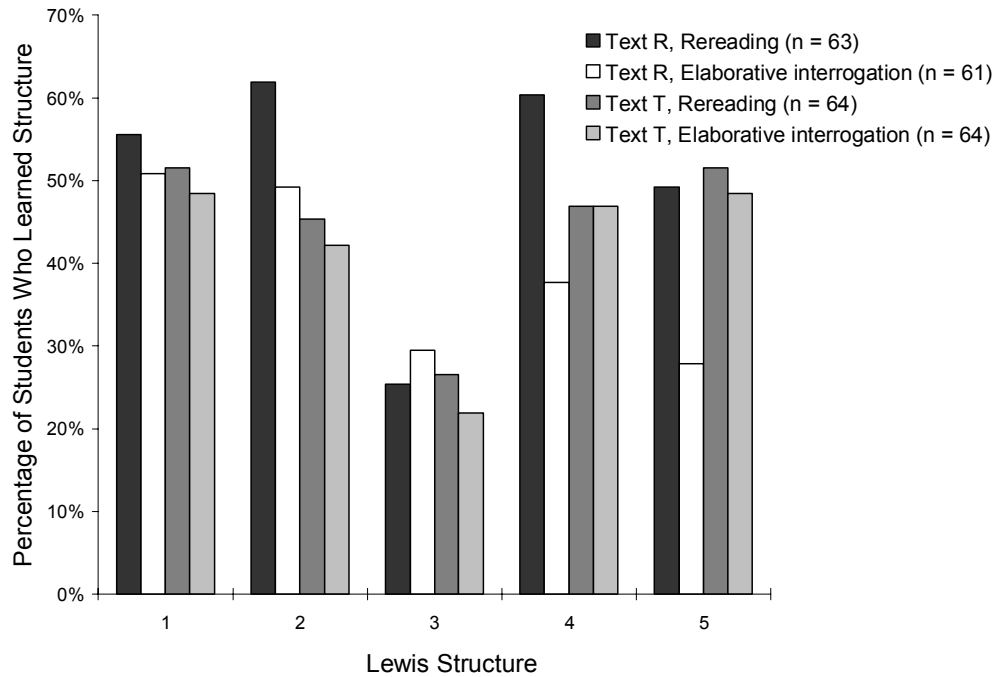


Figure 21. The easy-to-learn Lewis structures learned by each treatment group.

A 4(treatment)  $\times$  5(learning result) contingency table for each structure was submitted to a goodness-of-fit analysis to compare the observed cell frequencies with the expected in order to detect any statistically significant differences among the results. This contingency table is shown in Table 23 for structure number 1 (HF) results.

The analysis showed that there were no statistically significant differences among any of the treatments for the distribution of pretest-posttest item pair evaluations, with  $\chi^2(12, N = 252) = 12.9, p = .38$ . In other words, the observed frequencies in the cells were close to what would be expected for the sample and no significant differences were found. The other four easy-to-learn structures were



Table 23

*4 × 5 Contingency Table for HF Structure Results*

		Learned	Unlearned	Already known	Not learned	Not attempted
Text R						
EI		31	1	20	9	0
RR		35	1	16	11	0
Text T						
EI		31	0	16	16	1
RR		33	3	10	17	1

*Note.* EI = Elaborative interrogation, RR = Rereading

examined in the same manner, and no significant differences were found in any case. For structures 2 to 4, the  $p$  values from the  $\chi^2$  analyses were .20, .49, .19, and .068, respectively. This suggested that learning was not significantly different across texts and treatments groups.

#### *Average-to-learn Structures*

The five pretest and posttest structures classified by Brady et al. (1990) as average-to-learn were  $\text{ClF}_3$ ,  $\text{N}_2$ ,  $\text{NO}_2^+$ ,  $\text{SO}_3^{2-}$ , and HOI. True to the Brady trend, the number of learned structures was lower here compared to the easy structures. The range of learned structures for the overall sample for formulas 6 to 10 was 15% to 37% (cf. 8% to 47% for structures 1 to 5, and 21% to 47% if  $\text{CH}_4$  is ignored). Figure 22 shows the percentages of learned structures for all four treatment groups.

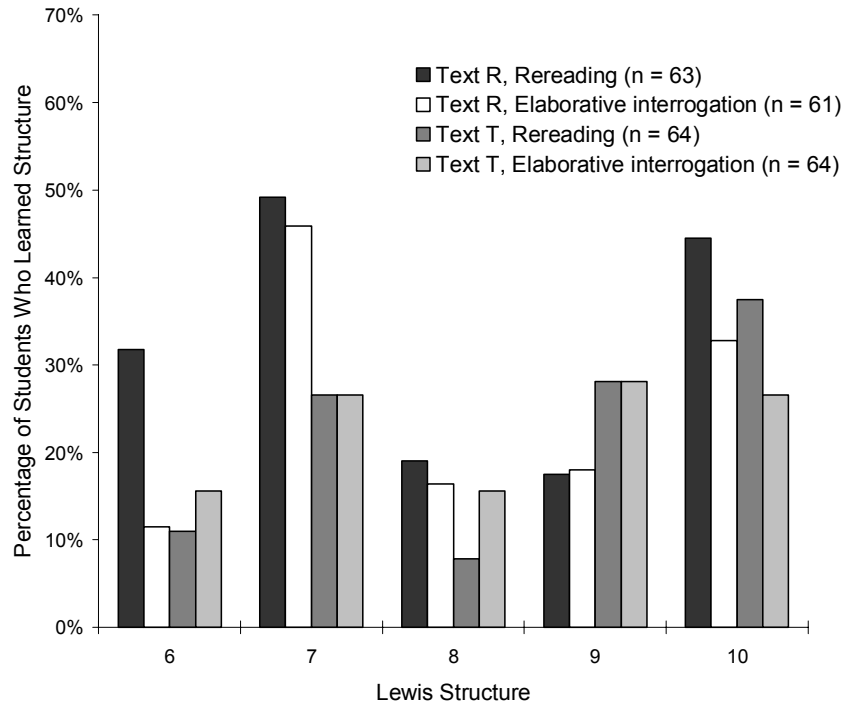


Figure 22. The average-to-learn Lewis structures learned by each treatment group.

Compared to the easy-to-learn structures, there was a much lower amount of already known relationships for structure numbers 6 to 10, where 1%, 7%, 3%, 4%, and 9% of students, respectively, drew correct Lewis structures on both the pre- and posttests. The rates of unlearning or no attempts were consistently low as they were for the students' results for the easy structures. The rate of not-learning for the average-to-learn Lewis structures, however, was higher than it was for the easy-to-learn structures, ranging from 53% not-learned for structure number 7 to 79% not-learned for structure number 6.

Among the average-to-learn structures, the text-R students assigned to rereading had the highest amount of learning in four out of five cases, namely,

structures 6, 7, 8, and 10. For structure 9,  $\text{SO}_3^{2-}$ , text-T students assigned both to rereading and to elaborative interrogation were highest and did equally well.

In the  $\chi^2$  analyses of these five structures, using 4(treatment)  $\times$  5(learning result) contingency tables, significantly different frequencies were found for structures 6 and 7, although not for 8, 9, or 10. In the case of structure 6,  $\text{ClF}_3$ , the text-R students assigned to rereading stood above the others (see Figure 22). This difference was significant, with  $\chi^2(12, N = 252) = 22.34, p = .031$ . The standardized residual for this cell was 2.71, indicating that the number of students learning  $\text{ClF}_3$  reading text R and assigned to the rereading strategy was the cause for rejecting the goodness-of-fit hypothesis.

Similar results were found for structure 7,  $\text{N}_2$ , where readers of text R, regardless of strategy, learned significantly more than readers of text T. For this structure and its 4  $\times$  5 contingency table,  $\chi^2(12, N = 252) = 27.04, p = .008$ . None of the standardized residuals had an absolute value greater than 2. However, the highest residuals were found for the frequencies of learned and not-learned structures for readers of both texts using the rereading strategy. For text R, 31 students assigned to rereading learned to draw the Lewis structure for  $\text{N}_2$ . This was greater than expected ( $f_e = 23.25$ ). Twenty-four text-R students assigned to rereading did not learn to draw  $\text{N}_2$ ; this was lower than the expected ( $f_e = 33.50$ ). For text-T students assigned to rereading, 17 students learned the structure ( $f_e = 23.62$ ) and more than expected did not learn it ( $f = 44, f_e = 34.03$ ).

### Difficult-to-learn Structures

The five final structures on the tests, numbered 11 to 15 ( $\text{CO}_2$ ,  $\text{BrF}_4^-$ ,  $\text{I}_3^-$ ,  $\text{NO}_2\text{F}$ , and  $\text{NO}$ ), lived up to their designation of difficult-to-learn. Figure 23 shows the amount of learning that occurred for each of these structures by each treatment group. A telling comparison is that the highest percentage of learning for the difficult-to-learn structures is approximately the same as the lowest level of learning for the easy-to-learn structures (cf. Figure 21, p.176).

For all five difficult-to-learn structures, the text-R students assigned to rereading learned more than students in any other treatment. There are two standouts for low learning gains, namely text-R students assigned to elaborative interrogation for structure 12 and text-T students assigned to rereading for structure 13. However, in no cases were any significant differences found by  $\chi^2$  analysis of the 4(treatment)  $\times$

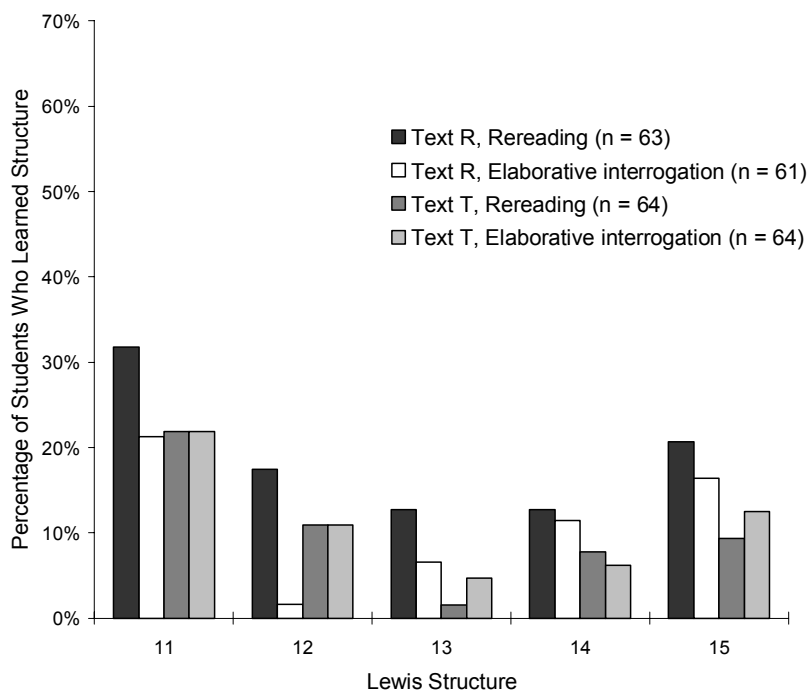


Figure 23. The difficult-to-learn Lewis structures learned by each treatment group.

5(learning result) contingency tables for the structures. The  $p$  values in these analyses of structures 11 to 15 were .17, .17, .19, .45 and .33, respectively. This suggests that the amount of learning was not significantly different across texts and strategies.

### Role of Why-questions in Learning

The elaborative interrogation strategy is hypothesized to stimulate a user's cognitive processing in order to integrate new information with what is already known about a topic. In the current research, it was found that rereading, a rehearsal strategy, was statistically more potent than elaborative interrogation in reading a contrived factual-based text. However, in the case of more authentic text, whether answering why-questions provided any benefit to students was undetermined.

Researchers of elaborative interrogation have studied whether answering a why-question about a particular fact correctly leads to answering the related recall test question correctly. In the current research, the quality of each why-question answer was rated. However, since the why-questions were not associated with individual facts tested by recall, as has been the case in much of the research literature, a one-why-question with one-recall-test-item correlation was not made.

Two independent raters assisted the researcher in scoring the why-question responses. Each response was given one of four evaluations: adequate, inadequate, nonexplanatory, or blank. These ratings were defined in detail in Chapter Three.

#### *Text R Why-question Responses*

One hundred twenty-four participants received text R as their treatment text. Approximately half of these ( $n = 61$ ) were assigned to use the elaborative

interrogation strategy while reading the text. At the end of each paragraph, the reader was instructed to write an answer the why-question on the right side of the page.

First, from a global perspective, there were 915 why-questions to be answered by the 124 text-R students (i.e.,  $124 \text{ students} \times 15 \text{ questions/student} = 915 \text{ total questions}$ ). Of the 915 why-question responses, 103 (11%) were rated as adequate, 522 (57%) as inadequate, 150 (16%) as nonexplanatory, and 140 (15%) were left blank. In other words, 68% (or about two-thirds) of the responses involved the use of chemistry terms and concepts in students' attempts to answer the questions, whether the actual written answer was adequate or inadequate. The majority was ranked as inadequate. The other third of the responses were either nonexplanatory or blank.

When analyzed by individual question, the ratings varied from item to item. For example, for question 1, 21% of students provided an adequate answer while only 2% of students gave an adequate answer for question 2. Only 3% of answers were blank for question 1, but 26% of question-12 answers were blank. Figure 24 provides detailed information about the responses to the 15 why-questions in text R. Since the 15 Lewis structures were provided in increasing order of difficulty in text R, it may not be surprising that the questions with the greatest proportion of adequate answers tended to be at the beginning of the reading (viz., questions 1, 3, 4, 5, and 7), while the questions with the highest amount of nonexplanatory and blank answers came near the end of the reading, specifically questions 12 to 15. Another explanation might be student fatigue; however, it will be shown below that text-T student why-question responses did not follow a trend of declining answer quality. This suggests that fatigue was not a factor.

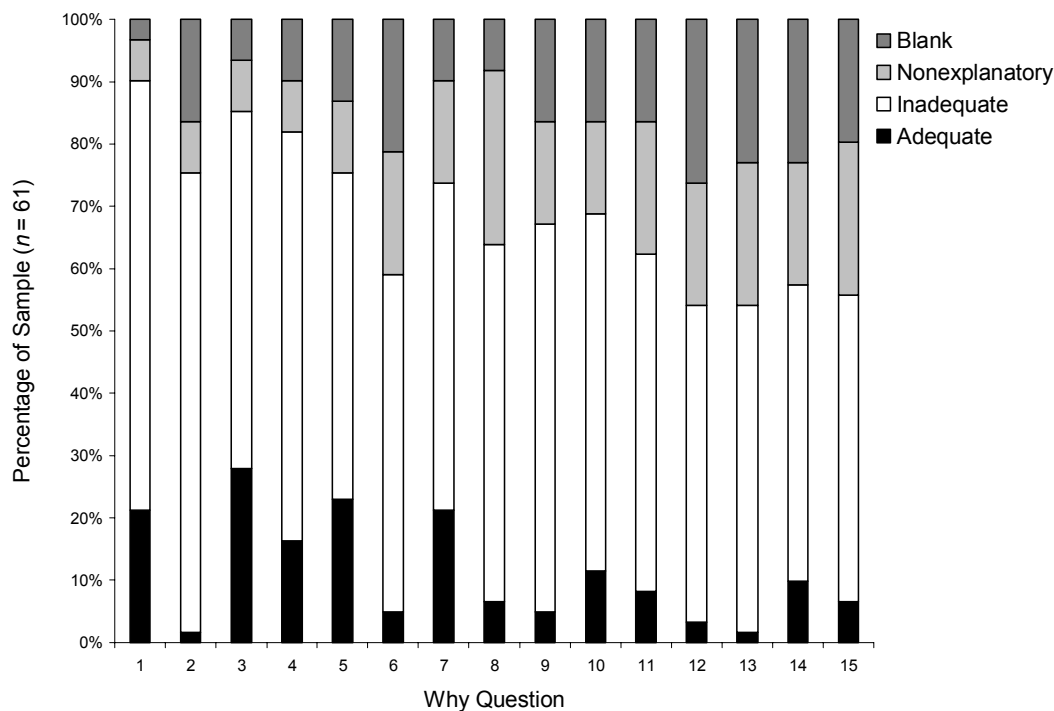


Figure 24. Distribution of why-question response ratings for text R.

The mean number of adequate answers for text-R readers was 1.69 (out of 15). The mean number of inadequate answers was 8.56, nonexplanatory 2.46, and blank 2.30. The number of why-question answers according to these ratings was fairly consistent across demographic subgroups (see Table 24), with only several cases of significant differences.

The mean number of nonexplanatory why-question answers was statistically significantly less for international students ( $M = 1.27$ ,  $SD = 2.96$ ) as compared to U.S. students ( $M = 3.61$ ,  $SD = 4.57$ ),  $F(1, 59) = 5.63$ ,  $p = .021$ . In other words, international students gave fewer answers with statements unrelated to chemistry (e.g., “It doesn’t make sense”) or with single words or terms lacking an explanation. A difference in the number of nonexplanatory answers was also observed in the

Table 24

*Mean Numbers of Why-question Answers for Text R by Rating across Subgroups of Students*

	<i>n</i>	Adequate	Inadequate	Nonexplanatory	Blank
All	61	1.69	8.56	2.46	2.30
Gender					
Female	33	1.64	8.12	2.39	2.85
Male	27	1.81	8.89	2.63	1.67
Country of origin					
U.S.	31	1.71	7.42	3.61 <sup>c</sup>	2.26
International	30	1.67	9.73	1.27 <sup>d</sup>	2.33
Age Group					
Traditional	31	1.61	10.06 <sup>a</sup>	1.94	1.39
Returning	30	1.77	7.00 <sup>b</sup>	3.00	3.23
CH 101 Preparation					
HS Chemistry	34	1.12	9.03	2.76 <sup>e</sup>	2.09
CH 100	8	2.75	8.50	2.88 <sup>e</sup>	0.88
Both	17	2.41	8.24	0.71 <sup>f</sup>	3.65

*Note.* Superscripts in the same column and in the same subcategory that do not share the same letter superscript are significantly different at the  $\alpha = .05$  level.



preparation for CH 101 subgroups. Students who had completed both high school chemistry and CH 100 gave fewer nonexplanatory answers compared to both those who took high school chemistry only and those who took CH 100 only. The differences in this case were found to have  $F(3, 57) = 4.55, p = .006$ .

Another statistically significant difference in means was found for inadequate answers between traditional students (i.e., those of age 18 to 21) and returning students (i.e., those of age 22 and above). Returning students gave fewer inadequate answers ( $M = 7.00, SD = 4.97$ ) compared to traditional students ( $M = 10.06, SD = 4.21$ ), where  $F(1, 59) = 6.77, p = .012$ .

### *Text T Why-question Responses*

Of the 128 students assigned to text T, the textbook excerpt, half ( $n = 64$ ) were assigned to use the elaborative interrogation strategy and received text with 15 why-questions to answer in writing. The why-questions were posed throughout the text, immediately after sentences judged by the researcher to be nexus points of new information with background knowledge related to the topic. The 15 sentences were underlined and an instruction to answer the question was embedded in the text. Space was provided for the written answers on the right side of the page. In all 15 cases, the same question was asked, namely, “Why does this make sense?”

From the overall perspective, there were 960 why-questions to be answered among the 128 text-T readers (i.e.,  $128 \text{ students} \times 15 \text{ questions/student} = 960$  total why-question answers). Among these 960 answers, 240 (25%) were rated as adequate, 421 (44%) as inadequate, 115 (12%) as nonexplanatory, and 184 (19%) were blank. The percentage of adequate why-question answers was noticeably greater

for text-T readers (25%) compared to text-R readers (11%). This may be due, in part, to the more authentic nature of text T.

As was the case with text-R why-question responses, when analyzed by individual question, the ratings varied from item to item. For example, for question 10 in text T, 42% of students provided an adequate answer while only 8% of students gave an adequate answer for question 11. Only 9% of answers were blank for question 3, but 38% of question-12 answers were blank. Figure 25 provides detailed information about the responses to the 15 why-questions in text T.

The mean number of adequate answers for text-T readers was 3.75 (out of 15). The mean number of inadequate answers was 6.58, nonexplanatory 1.80, and blank 2.88. The number of why-question answers according to these ratings was fairly consistent across demographic subgroups (see Table 25), except for U.S. and international students as well as one difference for traditional versus returning students. The U.S. and international students had statistically significant differences on the number of adequate answers and inadequate answers, with U.S. students having statistically significantly more in both categories,  $F(1, 62) = 6.99, p = .01$  for adequate responses and  $F(1, 62) = 6.34, p = .014$  for inadequate. International students, on the other hand, left statistically significantly more answer spaces blank in comparison with U.S. students,  $F(1, 62) = 20.77, p = 2.5 \times 10^{-5}$ . Having fewer adequate answers and more blanks would seem to support less learning of Lewis structures for international students using the elaborative interrogation strategy with text T. To the contrary, there was no statistically significant difference in mean gain

score between U.S. ( $n = 36, M = 2.75, SD = 2.89$ ) and international students ( $n = 28, M = 4.18, SD = 3.40$ ), where  $F(1, 62) = 2.87, p = .095$ .

For returning students who had significantly more blanks than traditional students, there was again no impact on the gain score. There was no significant difference in mean gain scores for readers of text T who used elaborative interrogation between traditional ( $n = 36, M = 3.14, SD = 3.51$ ) and returning students ( $n = 27, M = 3.81, SD = 3.27$ ), with  $F(1, 61) = .61, p = .44$ .

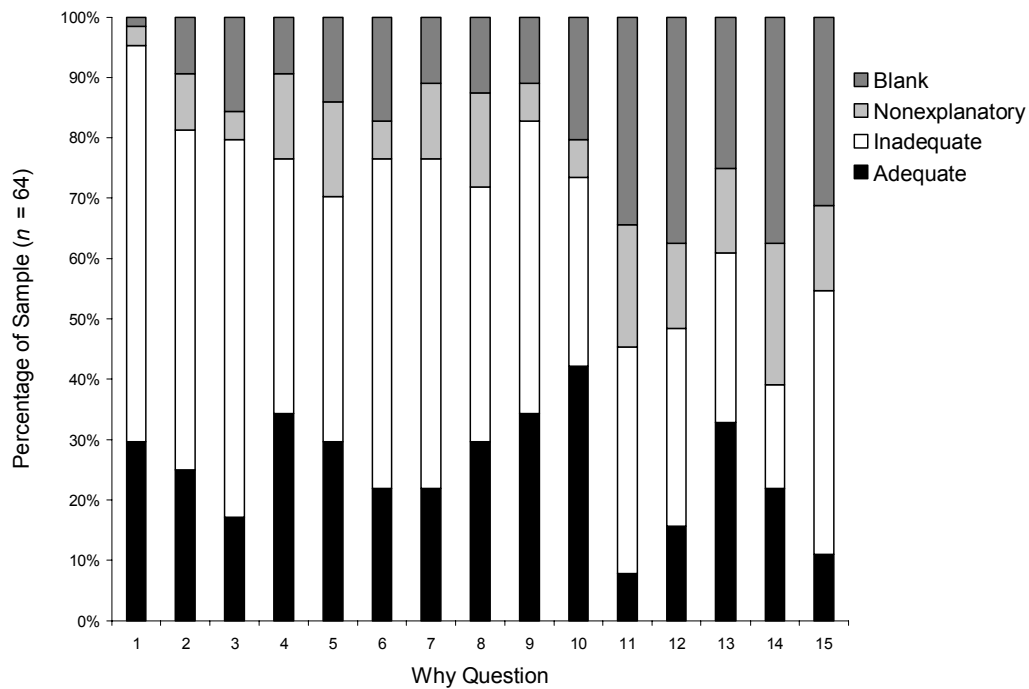


Figure 25. Distribution of why-question response ratings for text T.

Table 25

*Mean Numbers of Why-question Answers for Text T by Rating across Subgroups of Students*

	<i>n</i>	Adequate	Inadequate	Nonexplanatory	Blank
All	64	3.75	6.58	1.80	2.88
Gender					
Female	38	3.47	6.34	1.97	3.21
Male	26	4.15	6.92	1.54	2.38
Country of origin					
U.S.	36	4.58 <sup>a</sup>	7.42 <sup>c</sup>	1.83	1.17 <sup>e</sup>
International	28	2.68 <sup>b</sup>	5.50 <sup>d</sup>	1.75	5.07 <sup>f</sup>
Age Group					
Traditional	36	4.36	7.08	1.58	1.97 <sup>g</sup>
Returning	27	3.07	5.74	2.00	4.19 <sup>h</sup>
CH 101 Preparation					
HS Chemistry	41	3.51	6.66	2.02	2.81
CH 100	5	4.20	5.80	0.40	4.60
Both	14	4.93	6.43	1.71	1.93

*Note.* Superscripts in the same column and in the same subcategory that do not share the same letter superscript are significantly different at the  $\alpha = .05$  level.

## CHAPTER 5: DISCUSSION AND IMPLICATIONS

### Synopsis of This Investigation

The purpose of this research was to investigate the use of comprehension strategies by college chemistry students when they study about an important topic, the construction of Lewis structures. Such structures are figure representations of molecules, which typically use letters, lines, and dots. The letters or letter pairs, symbols understood by chemists, represent atomic nuclei. Lines and dots are used to represent electrons. Being able to draw correct Lewis structures is important because so much of chemistry is devoted to molecular structure (Hurst, 2002). Chemistry students draw and interpret Lewis structures throughout general chemistry and advanced classes such as organic chemistry (e.g., Kuo et al., 2004).

Constructing Lewis structures is known to be a difficult skill for chemistry students to learn (Ahmad & Omar, 1992; Carroll, 1986). Brady et al. (1990) investigated how chemistry students learn to construct Lewis structures, and identified the distinct chemistry knowledge and necessary skills. Based on an investigation involving college students' attempts to draw Lewis structures, Brady et al. classified each of 50 structures as easy-to-learn, average-to-learn, or difficult-to-learn. According to the Brady et al. definitions, 22% of the structures they investigated were easy for students to learn within a delimited population, 46% were average, and 32% were difficult.

College general chemistry students learn about Lewis structures by attending classes and by studying from their textbooks. The latter of these activities was the focus of the current research.

Understanding text about Lewis structures requires having a certain amount of prior knowledge about relevant chemistry topics. Such prior knowledge was delimited and defined in this study by analyzing a textbook authors' use of technical terms in the passage concerning Lewis structure instruction (T. L. Brown et al., 2003). This particular textbook was the one required in the chemistry course at the institution where the research was conducted, and is similar to other college general chemistry textbooks used at different institutions (see Chapter Two for comparison with other textbooks such as Ebbing & Gammon, 2002, and Kotz & Treichel, 2003).

A number of studies have reported learning gains for college students who used the strategy known as elaborative interrogation when learning facts (e.g., Pressley et al., 1987; Woloshyn et al., 1990; Woloshyn et al., 1994; Smith, 2003). In the current investigation of learning how to construct Lewis structures by reading text, knowledge of facts was required in addition to the application of those facts in a procedure. The current research was launched in an effort to determine whether the elaborative interrogation strategy would also be effective in learning a procedure. Such an application of elaborative interrogation has not been reported.

Previous investigations of elaborative interrogation have focused primarily on fact-learning as measured by recall tests such as free-recall, cued-recall, or associative-matching recall (e.g., Pressley et al., 1988; Wood et al., 1990; Woloshyn et al., 1992; Willoughby et al., 1994, Ozgungor, 2002). Most of the earliest cases involved clinical settings with students who read contrived text not associated with a course requirement. In other words, the participants were generally research

volunteers, typically enrolled in psychology courses. A great deal about elaborative interrogation was learned from those studies.

In the past five years, several researchers have investigated the utility of elaborative interrogation in authentic settings with authentic text materials (e.g., Ems-Wilson, 2000; Hill, 1999; Smith, 2003). By that, it is meant that these studies used course reading material with students enrolled in those courses. For instance, Ems-Wilson used chemistry reading and computer-animation materials with undergraduate chemistry students. Hill used online immunology course materials with medical school students. Smith used biology reading materials with undergraduate biology students. These efforts marked a transition in the literature from clinical research to authentic settings.

The design of the current research project was intended to imitate previously reported studies in some ways, but also to go beyond those studies as well. The “factual-based text R” was composed by the researcher to build a bridge from previously reported successful applications of elaborative interrogation to a new topic, Lewis structures. Since elaborative interrogation is known to be an effective strategy for college students learning facts, the researcher composed text R with factual information about 15 specific Lewis structures.

The next connection in the design was then intended to branch the investigation of elaborative interrogation into a new realm, specifically into textual instruction about a procedure. The “procedural-based text T” excerpt contained imperative sentences as part of the instruction about the procedure chemists follow to construct Lewis structures. This is important to note since previously reported texts in

the literature have contained only declarative sentences expressing facts. This procedural text was unique. Only six actual Lewis structures appeared in the text, which was devoted to explaining and elucidating the process. Of these six, only two appeared on the pre- and posttests. This compares with the 15 structures in text R, all of which appeared on the tests.

Comprehension testing in the current research was also different from most of what has been previously reported. Most investigations have utilized free-recall, cued-recall, or associative matching, (e.g., McDaniel & Donnelly, 1996; O'Reilly et al., 1998; Pressley et al., 1988; Willoughby et al., 1994), and occasionally short answer questions (e.g., Ozgungor, 2002; Seifert, 1993). Somewhat different among previous reports was that of Ems-Wilson (2000), who used a test requiring students to apply chemistry principles and evaluate molecules. In the current research, a more authentic test format was implemented, namely an application test that required students to draw Lewis structures. Students were given a formula and space on the test to draw the structure. Based on the preponderance of literature reporting the superiority of elaborative interrogation compared with rereading, it was presumed that students assigned to elaborative interrogation would perform better on the tests.

The researcher composed text R, a prior knowledge test, and the pre- and posttests. Their content was developed by analysis of text T and the course textbook in such a way as to mirror the textbook authors' content and technical terminology. Text R contained approximately the same number of total words as text T, and had about the same frequency of the technical terms as used in text T. The prior knowledge test contained questions about the requisite chemistry topics to study



Lewis structures. In other words, after the technical terms and their frequencies in the Lewis structure instruction were determined, they were located within the textbook's previous chapters, and then the prior knowledge test was built to reflect those terms, which were included on the prior knowledge test in the same proportion as their distribution within the textbook. The pre- and posttests were identical and contained 15 formulas with space for students to draw in the Lewis structure for each. These 15 structures were the same as those in text R. They were selected for inclusion on the tests because of their presumed levels of difficulty for college students as reported by Brady et al. (1990). Specifically, the tests were composed to contain a balanced mix of easy, average, and difficult structures. Before composing the tests, the Brady et al. procedure was replicated with a separate group of second-semester general chemistry students who had already studied Lewis structures; they received no additional instruction before the replication testing. This replication provided verification of the Brady et al. findings and substantiated the content of the tests as containing questions that college students should be able to learn from instruction.

In this investigation, ten research questions were addressed. In the following section, the findings of the investigation and their related questions and hypotheses are discussed. After that, these findings are compared with previously reported literature. Then, after several post hoc observations, the final section contains recommendations for further research.

### Findings of This Investigation

The findings of this investigation fall into four categories: (a) results from the Brady et al. replication, (b) results from the study of students who read factual text

about 15 specific Lewis structures, (c) results from the study of students who read the textbook passage about the procedure for constructing Lewis structures, and (d) results from the overall text-strategy investigation. These are each addressed separately in the following sections. By reviewing the individual text results before the overall text-strategy results, the order of research questions here following Question 1 is Questions 5 to 7, then Questions 8 to 10, followed by Questions 2 to 4.

### *The Brady et Al. Replication: Research Question 1*

The first research question addressed the validity of the Brady et al. (1990) Lewis structure difficulty index. Specifically, the question asked:

How do students' scores on a Lewis structure test compare with previously reported results when level of instruction, nature of tests, and grading standards are comparable?

In order to investigate this question, the Brady et al. experiment was replicated using students at a similar point in the general chemistry curriculum. Of the 50 structures used by Brady et al. (1990), 10 were chosen for the replication experiment. The descriptive results of the replication experiment provided support for the notion that the list of structures reported by Brady et al. was generally arranged in increasing order of difficulty, where HF, hydrogen fluoride, and PCl<sub>3</sub>, phosphorus trichloride, were reported as the easiest structures to construct (i.e., 100% of students drew them on the first attempt in Brady et al.) and NO, nitrogen monoxide, was reported as the most difficult to construct (i.e., no student drew it correctly on the first attempt in Brady et al.).

This replication was important for several reasons. First, it supported the idea that college students should be able to draw certain Lewis structures following instruction. Second, it provided content validation for the items selected for the pre- and posttests. These specific Lewis structures also formed the basis of the content presented in text R.

In addition to supporting the Lewis structure difficulty level in the replication experiment, the trend of Lewis structure difficulty was also later reflected in the text-strategy investigation. Students' learning was highest for the easy-to-learn structures, then decreased throughout the average-to-learn structures, and was lowest for the difficult-to-learn structures. This result added support for the Brady et al. (1990) list of structures being an important guide in Lewis structure instruction.

#### *Factual Text Results: Research Questions 5 to 7*

In the strategy-prior knowledge investigation involving text R, three research questions were posed in a 2(strategy)  $\times$  2(prior knowledge level) factorial pretest-posttest design. The dependent variable was the gain score based on the number of Lewis structures learned during the treatment. The research questions and their associated hypotheses were as follows:

##### Question 5 and Hypothesis

Question: How does the elaborative interrogation strategy differ from the rereading strategy for college chemistry students who study the drawing of Lewis structures by reading factual text?

Hypothesis: There is no difference between mean gain scores on tests about Lewis structures for college students assigned to use the elaborative

interrogation strategy and those assigned to use the rereading strategy when reading a factual text.

#### Question 6 and Hypothesis

Question: How do students with high prior knowledge differ from students with low prior knowledge when studying the drawing of Lewis structures by reading factual text?

Hypothesis: There is no difference between mean gain scores on tests about Lewis structures for college students with low prior knowledge and those with high prior knowledge when reading a factual text.

#### Question 7 and Hypothesis

Question: How do scores on Lewis structure tests vary when different strategies are used by students with different levels of prior knowledge when reading factual text?

Hypothesis: There is no interaction between assigned strategy and prior knowledge level for mean gain scores on tests about Lewis structures for college students reading factual text.

Text R was a text authored by the researcher to describe 15 specific Lewis structures using declarative sentences in a factual format. This is unlike the typical instruction about Lewis structures in college chemistry textbooks, where a procedure for determining structures is usually described with imperative statements to explain the process. The researcher-authored format was intended to provide a reading about Lewis structures that would be more parallel to reading materials reported in the elaborative interrogation research literature. Since elaborative interrogation is known

to be an effective strategy for learning facts, it was surmised that students assigned to this strategy would show a learning benefit when compared to students who were assigned to rereading.

Experimental results showed that text R was an effective format for learning the Lewis structure topic. In addressing research Question 5 in a two-tailed ANOVA, it was found that students assigned to the rereading strategy performed statistically significantly better after the treatment with text R than students assigned to the elaborative interrogation strategy. In other words, students assigned to rereading had significantly higher gain scores on their tests. Thus, the null hypothesis for research Question 5 was rejected.

It may be important to note that students were told the criterion task in the current experiment, thus creating an intentional learning condition. This was done because it is known that studying improves in this condition (T. H. Anderson & Armbruster, 1984) and because such an intentional learning environment more closely simulates realistic college and secondary school studying situations. This issue of intentional learning as compared to incidental learning will be explored in more detail later in this Chapter.

Prior knowledge did not play a statistically significant role for students learning from text R. The results of a two-tailed ANOVA supported the conclusion to research Question 6 that there was no statistically significant difference in learning between the college students with high prior knowledge and those with low prior knowledge when studying the drawing of Lewis structures by reading factual text. Therefore, the null hypothesis for research Question 6 was not rejected.

For research Question 7, the results of a two-tailed ANOVA supported the conclusion that there was no statistically significant interaction when different strategies were used with college students of differing prior knowledge levels while studying the drawing of Lewis structures by reading factual text. Therefore, the null hypothesis for research Question 7 was not rejected.

### *Procedural Text Results: Research Questions 8 to 10*

The three research questions related to text T were probably the most interesting for college general chemistry faculty and students courses since the text was taken from an authentic textbook and used by students actually enrolled in a general chemistry course. In this strategy-prior knowledge investigation, the research questions were posed in a 2(strategy)  $\times$  2(prior knowledge level) factorial pretest-posttest design, where the dependent variable was the gain score based on the number of Lewis structures learned during the treatment. The research questions and associated hypotheses were as follows:

#### Question 8 and Hypothesis

Question: How does the elaborative interrogation strategy differ from the rereading strategy for college chemistry students who study the drawing of Lewis structures by reading their textbook?

Hypothesis: There is no difference between mean gain scores on tests about Lewis structures for college students assigned to use the elaborative interrogation strategy and those assigned to use the rereading strategy when reading a course textbook.

#### Question 9 and Hypothesis

Question: How do students with high prior knowledge differ from students with low prior knowledge when studying the drawing of Lewis structures by reading their textbook?

Hypothesis: There is no difference between mean gain scores on tests about Lewis structures for college students with low prior knowledge and those with high prior knowledge when reading a course textbook.

#### Question 10 and Hypothesis

Question: How do scores on Lewis structure tests vary when different strategies are used by students with different levels of prior knowledge when reading their textbook?

Hypothesis: There is no interaction between assigned strategy and prior knowledge level for mean gain scores on tests about Lewis structures for college students reading a course textbook.

Research Question 8 was at the heart of the investigation since it focused on the authentic textbook procedural-format reading about Lewis structures. Because elaborative interrogation had literature-based strength with factual prose, it was thought that there was good reason to believe that this strength would translate to another type of academic text, namely authentic, technical, science text such as Lewis structure instruction. However, the two-tailed ANOVA supported the conclusion for research Question 8 that there was no statistically significant difference between the two strategies for students reading authentic chemistry text. Thus, the null hypothesis for Question 8 was not rejected.

In addressing research Question 9, the two-tailed ANOVA results supported the conclusion that prior knowledge was an important factor in learning Lewis structures from text T. Students with higher prior knowledge learned significantly more from text T than students with lower prior knowledge. Therefore, the null hypothesis for research Question 9 was rejected.

The role of prior knowledge has been shown to be a critical factor in the effectiveness of learning and using learning strategies (Dochy et al., 1999; Caverly et al., 2000). Students who have successfully completed appropriate courses before college level general chemistry, who appeared to have read and studied their textbooks, and who learned important prerequisite concepts did well when learning about Lewis structures from text T. If prior knowledge was weak, students who read the very same text appeared to be not ready to benefit from the text passage.

Finally, in addressing research Question 10, the two-tailed ANOVA results supported the conclusion that there was no statistically significant interaction when different strategies were used by college students of differing prior knowledge levels when studying the construction of Lewis structures by reading their textbook. The null hypothesis for research Question 10 was not rejected.

#### *Text-Strategy Investigation Results: Research Questions 2 to 4*

The major investigation of this research focused on nine research questions. The statistical treatment of these questions was performed in three sets of ANOVAs. Two sets have been reported above, each addressing research questions related to the individual texts, students' assigned strategies, and their prior knowledge levels.



The data reported in this section involve the entire sample ( $N = 252$ ) and three research questions addressed in a  $2(\text{text}) \times 2(\text{strategy})$  factorial pretest-posttest design. The dependent variable was the gain score defined as the number of Lewis structures students learned during the treatment. The research questions and associated hypotheses were:

#### Question 2 and Hypothesis

Question: How does the elaborative interrogation strategy differ from the rereading strategy for college chemistry students who study the drawing of Lewis structures?

Hypothesis: There is no difference between mean gain scores on tests about Lewis structures for college students assigned to use the elaborative interrogation strategy and those assigned to use the rereading strategy.

#### Question 3 and Hypothesis

Question: How does factual text differ from procedural text for college chemistry students who study the drawing of Lewis structures?

Hypothesis: There is no difference between mean gain scores on tests about Lewis structures for college students assigned to read about Lewis structures from a factual text and those assigned to read about Lewis structures from a procedural text.

#### Question 4 and Hypothesis

Question: How do scores on Lewis structure tests vary when different strategies are used (viz., elaborative interrogation and rereading) for different reading formats (viz., factual text and procedural text)?

Hypothesis: There is no interaction between assigned type of text and assigned strategy for mean gain scores on tests about Lewis structures.

In addressing Question 2, the two-tailed ANOVA results supported the conclusion that students assigned to the rereading strategy learned to draw statistically significantly more Lewis structures than students assigned to the elaborative interrogation strategy (regardless of which text they used). This is based on the main effect for strategy found in the ANOVA. The null hypothesis for research Question 2 was thus rejected.

Students did gain knowledge about drawing Lewis structures during the treatment; this was documented in detail in Chapter Four. However, overall, students would possibly need more study time or effort to master all the Lewis structures on the tests in this investigation. The learning gains were modest for both the rereading students and the elaborative-interrogation students. What they learned amounted to approximately one third and one fourth of the given 15 structures, respectively.

The two-tailed ANOVA supported the conclusion for research Question 3 that there was no statistically significant difference between the reading of factual text and procedural text for college students learning to construct Lewis structures. In other words, there was no apparent difference in learning this topic from either text. Therefore, the null hypothesis for research Question 3 was not rejected.

Finally, for research Question 4, the two-tailed ANOVA results gave support for no statistically significant interaction when different types of texts were read using different strategies and the null hypothesis was not rejected.

## Comparison of Findings with Previous Research

### *Research Trends in Authentic Settings*

Researchers involved in the study of elaborative interrogation have recognized the importance of transitioning investigations from clinical into authentic settings (e.g., Woloshyn et al., 1990). In recent years, researchers have made this transition and have reported the use of more authentic text in more authentic situations (e.g., Dornisch, 2003; Ems-Wilson, 2000; Hill, 1999; Ozgungor, 2002; Smith, 2003). In fact, during the development of this body of research from clinical to authentic settings, a number of key research factors have evolved, as shown in Table 26. Several trends in this transition are worthy of note.

First, in the recent investigations, there has tended to be less training or practice with the assigned strategies prior to the intervention. Virtually all of the previously reported clinical studies included use of the strategy in a practice session as well as feedback to students about their performance before the experimental treatment commenced (e.g., O'Reilly et al., 1998; Pressley et al., 1987; Willoughby et al., 1994; Woloshyn et al., 1990). Only rarely was training or practice not reported (e.g., Seifert, 1993). Among the recent work in more authentic settings, only one case reported training students before implementing the strategy (Ems-Wilson, 2000).

Another trend in the recent literature is the use of silent rereading instead of oral rereading for comparison with elaborative interrogation. As was the case with nearly all of the previously reported clinical studies, rereading has been included as one of several strategies or as the only other strategy for comparison with elaborative interrogation. In much of the previously reported literature, students read then reread

Table 26

*Evolution of Research Factors from Clinical to Authentic Settings*

Research factor	Typical characteristics	
	Clinical setting	Authentic setting
Participating students	Volunteers	Course registrants
Implementation	Individual students	Groups of students
Learning condition	Incidental	Intentional
Text	Contrived	Authentic
Strategy training	More	Less
Reading method	Aloud	Silent
Time control	Researcher	Student
Learning target	Facts	Procedure
Test question level	Knowledge	Application
Prior knowledge	Researcher judgment	Direct measure

orally (e.g., O'Reilly et al., 1998; Pressley et al., 1988; Willoughby et al., 1994; Woloshyn et al, 1990; Woloshyn et al., 1992; Woloshyn et al., 1994). While some of the previously reported literature did employ silent rereading (e.g., McDaniel & Donnelly, 1996; Seifert, 1993), all of the recent reports in more authentic settings have utilized silent rereading (viz., Dornisch, 2003; Ems-Wilson, 2000; Hill, 1999; Ozgungor, 2002; Smith, 2003). This may be an important modification in the investigation models since students who read silently comprehend material more rapidly than other students who read the same text orally (McCallum et al., 2004).

A third trend concerns the control of time on the learning task. In the majority of previously reported elaborative interrogation clinical literature, the time of students' exposure to information was strictly controlled. In the earliest work, the control was often exercised in a sentence-by-sentence fashion. In other words, each sentence was displayed for a fixed period of time. Readers could not look ahead to subsequent sentences and they could not look back to previous sentences when they had finished reading; their attention was focused solely on one sentence at a time (e.g., Pressley et al., 1987; Pressley et al., 1988; Willoughby et al., 1994). While there were several previously reported studies that allowed students to read at a personally preferred rate (e.g., McDaniel & Donnelly, 1996), the recent research studies in authentic settings report no such time constraints or exposure limits (Dornisch, 2003; Ems-Wilson, 2000; Hill, 1999; Oztungor, 2002; Smith, 2003). Such student-determined reading rates provide for more realistic study behaviors, but they also introduce a potential new influence on the results of strategy implementation.

A fourth trend emerging in the research in the more authentic settings is the use of possibly better measures of prior knowledge. Much of the previously reported literature appears to have relied on researcher judgment about students' prior knowledge (e.g., Pressley et al., 1988; Woloshyn et al., 1992; Wood et al., 1990). In some cases, a sample demographically similar to the one in a strategy investigation was independently measured before the intervention for familiarity with the subject matter (e.g., Willoughby et al., 1993; Woloshyn et al., 1994). In other cases, students were asked to rate their level of knowledge on a Likert scale (e.g., O'Reilly, 1998). In none of these cases was the participating students' prior knowledge of the reading's

domain directly measured. It has been argued that direct measurement with formats such as “multiple choice, open ended, completion, recognition, and matching questions tend to measure prior knowledge with greater accuracy” than those employing researcher judgments or surveys (Shapiro, 2004, p. 161). Recent research reports (Ems-Wilson, 2000; Ozgungor, 2002; Smith, 2003), including the current research, have employed such recommended measures. While the judgments reported in the previous literature were likely well-founded (e.g., in Woloshyn et al., 1992, it is probable that Canadian college students had more prior knowledge about Canada than they did about Germany), the shift to better and direct prior knowledge measurements may also have an impact on the conclusions researchers in authentic settings are able to make.

These trends in the transition from clinical to more authentic settings are important to bear in mind as the findings in the current research are compared to findings in previously reported literature.

In the following sections, the findings of the current research will be compared to previously reported research. The specific areas addressed are: (a) the ease or difficulty of learning to construct Lewis structures, (b) the utility of using elaborative interrogation for learning from text, (c) the utility of elaborative interrogation as a beneficial strategy for readers with high prior knowledge, (d) incidental versus intentional learning conditions, and (e) the role of rereading as a placebo control.

## *Drawing Lewis Structures*

The Brady et al. (1990) investigation identified the skills that are used by college students when constructing Lewis structures. Brady and associates used 50 different structures in their experiment. Ten of those structures were used for the replication experiment in the current investigation. The descriptive results of the replication experiment supported the order of structures on the Brady group's list. In other words, structures easy for the original Brady et al. students to draw also proved easy for the replication student sample; structures difficult for the original students to draw proved difficult for the students in the replication as well.

This pattern related to degree of difficulty emerged again in the text-strategy experiment, where 15 Lewis structures (not the same list as used in the replication experiment) were used on the pre- and posttests. After the Brady et al. (1990) list had been validated, it was used as the source of the formulas for the tests. Specifically, five easy-to-learn structures, five average-to-learn structures, and five difficult-to-learn structures were chosen.

The findings in the current research were consonant with those previously reported concerning Lewis structure difficulty levels. These results add support to the Brady et al. (1990) list as a tool in the classroom and in research.

## *Using Elaborative Interrogation to Learn*

The researcher-authored text, text R, was developed to serve as a bridge from previously reported literature concerning elaborative interrogation to the new domain of constructing Lewis structures. Numerous experiments in the literature report success for college students learning facts from text while assigned to use elaborative

interrogation (e.g., Pressley et al., 1987; Woloshyn et al., 1990; Woloshyn et al., 1994; Smith, 2003). Therefore, text R was composed with factual statements about Lewis structures. The result in the current experiment of students assigned to the rereading strategy with text R having a statistically significantly higher mean gain score was not expected. Previous investigations consistently reported that when learning facts, students assigned to elaborative interrogation outperformed those assigned to rereading on recall tests.

While text R was intended generally to mimic previously reported texts about such topics as animals or Canadian provinces, it did have one difference in that it also contained figures, specifically figures of the Lewis structures that were discussed in the text. The use of images with text in elaborative interrogation research has been reported (Willoughby et al., 1994, Experiment One). In that case, the images were pictures of the animals associated with the text. Students were tested about the animal facts using cued recall. In the Willoughby et al. results, students assigned to elaborative interrogation did better than students assigned to rereading. The animal pictures seemed to provide a boost to students when answering questions about unfamiliar animals. Students who read text R in the current research may have experienced a similar boost from having a “picture” of their learning target presented with the text. Of course, no evidence was collected to verify this explanation.

A difference in the current work was that students were not directly tested on their knowledge of the facts presented in the text; they were tested on the figures that they saw accompanying the text. The predominant measures in previous literature were cued-recall, free recall, associative matching (e.g., McDaniel & Donnelly, 1996;



O'Reilly et al., 1998; Pressley et al., 1988; Willoughby et al., 1994), and occasionally short answer questions (e.g., Ozgungor, 2002; Seifert, 1993). In the current research, the test required students to draw Lewis structures for given formulas. It could be argued that the students were tested about the textual facts indirectly, since the text described the Lewis structure. Nevertheless, they knew in advance that they would be tested on drawing Lewis structures. This information was provided to create an intentional learning condition, which is typical of college studying (T. H. Anderson & Armbruster, 1984). The advance information about the test may have also caused readers to view and think about the figures in ways that would help them be remembered for the test. Of course, it is not possible to know this with certainty.

Another explanation of this unexpected gain score result is that those who were assigned to use elaborative interrogation with text R may have exerted more cognitive effort with the text, and thus, less attention to the Lewis structure figures. The why-questions may have caused them to spend their time thinking about the content of the text. The intention of asking the questions was to assist readers in connecting new information with previously known information. Those assigned to rereading, however, were able to look at their papers for the entire length of the intervention. In addition to looking at the words about the Lewis structures twice, they were also able to look at the Lewis structure figures twice, as well. This may have provided an advantage in remembering the figures.

### *Using Elaborative Interrogation When Prior Knowledge Is High*

Previously published research about the use of elaborative interrogation reported that there was an advantage to students who had higher levels of prior

knowledge about the subject matter they were reading (e.g., Woloshyn et al., 1992; Woloshyn, Wood, & Willoughby, 1994). In the use of text R, there was no difference in gain score performance for readers with high or low prior knowledge. In the case of the more authentic passage from the textbook, text T, prior knowledge appeared to be the main factor affecting gain score differences. There was a statistically significant difference between the gain scores of students with high prior knowledge and those with low prior knowledge. However, whether assigning elaborative interrogation or assigning rereading was more beneficial was undetermined. When assigned to students using text T, neither strategy appeared to be more effective as there was no statistically significant difference between the mean gain scores of the two groups.

Experiments in previously reported elaborative interrogation literature may have controlled for prior knowledge differences among students by random assignment to treatment groups; however, individuals' prior knowledge was rarely measured directly by methods now recommended (Shapiro, 2004). In several previously reported studies, the effect of strategy use by students with different levels of prior knowledge was investigated (Willoughby et al., 1993; Willoughby et al., 1994; Woloshyn et al., 1992). In each case, a memory benefit was found for high prior knowledge students compared to low prior knowledge students. However, in none of those cases was the participating students' prior knowledge measured directly. Those particular studies found that students assigned to elaborative interrogation remembered more than students assigned to rereading. Without direct measurement of prior knowledge, the role this variable played in the outcomes was

not reported, although Woloshyn et al. (1992) presented a cogent case for the importance of the assigned strategy compared to the role of students' prior knowledge levels in learning new factual information.

With more sensitive determination of prior knowledge in this and several recent research reports in authentic settings (Ems-Wilson, 2000; Ozgungor, 2002; Smith, 2003), the role of prior knowledge level in the application of an assigned strategy may become clearer.

A potentially interesting aspect of this investigation was the accuracy of a Likert scale survey to measure prior knowledge. Shapiro (2004) advised against such an instrument as the measure of prior knowledge. In the current research, two methods of measuring prior knowledge were employed: a direct measure in the form of a multiple-choice test and an indirect measure in the form of Likert scale survey questions. Although such surveys have been discouraged in favor of direct measures (Shapiro), it was found that students' self-ratings were statistically significant in the same way as their multiple-choice prior knowledge test scores. In other words, those who rated themselves as having low prior knowledge did indeed have statistically significantly lower prior knowledge compared to those who rated themselves as having medium or high prior knowledge. In contrast to Shapiro, this result may give some support to the use of Likert scale surveys in assessing college students' prior knowledge.

### *Incidental versus Intentional Learning Conditions*

Student expectations about tests can affect the attention and effort they apply when studying (T. H. Anderson & Armbruster, 1984). When students believe they

will have a test (i.e., an intentional learning condition), they may apply more cognitive effort to understanding material, no matter what comprehension strategy they may employ. When students believe they will not be tested (i.e., an incidental learning condition), they may read with attention and effort applied differently.

In the current research, the experimental condition was intentional learning. Students were told that there would be a test following their reading and that the test was about Lewis structures. Specifically, they were told the following.

The quiz contains 15 formulas. You will be asked to draw the Lewis structure for each formula.

Both incidental and intentional learning conditions are reported in the literature of elaborative interrogation investigations. Early in the literature, the use of incidental learning conditions was endorsed over intentional conditions because it was believed that the use of the incidental condition “promotes the processing intended by the experimenter, minimizing subjects’ use of strategies that they might believe would better accomplish a learning goal” (Pressley et al., 1988, p. 269). This is probably true concerning implementation of assigned strategies, but it does not accurately reflect realistic learning situations, as was also acknowledged in the early elaborative interrogation literature (e.g., Pressley et al., 1987).

In several research reports, experiments were designed precisely to compare incidental and intentional learning conditions when different comprehension strategies were assigned to readers (viz., Pressley et al., 1987, Experiments One, Two and Three; Woloshyn et al., 1990, Experiment Two). In each case, students assigned to use elaborative interrogation recalled more than students assigned to use rereading.

In Pressley et al. (1987), all the differences were statistically significant, whether in the incidental or intentional condition. However, descriptively, the differences were much more pronounced in the incidental condition. Using the reported sample means of Pressley's Experiment One, a calculated descriptive difference shows that students assigned to elaborative interrogation learned 333% more than students assigned to rereading in the incidental condition. In the intentional condition, the learning difference was one tenth of that size, specifically 32%. The results of Experiments Two and Three were similar (viz., 274% difference in the incidental condition compared to 35% in the intentional condition).

Woloshyn et al. (1990) used three different measures to compare recall in the condition comparison, namely free recall, fact recall, and associative matching. In the incidental condition on all tests, students assigned to elaborative interrogation recalled significantly more than students assigned to rereading. However, this was not the case in the intentional condition, where there was no significant difference in two of the three testing formats, free recall and fact recall. Only in the Woloshyn et al.'s associative matching test, was there a significant difference between scores of students assigned to elaborative interrogation and those assigned to rereading.

Perhaps due to the influence of Pressley et al. (1988), much clinical-based elaborative interrogation research has been conducted in an incidental condition (e.g., Martin & Pressley, 1991; Woloshyn et al., 1992). Others have reported the use of intentional conditions (e.g., McDaniel & Donnelly, 1996; Willoughby et al., 1994; Wood et al., 1992). In some reports, the particular condition is not reported (e.g., Seifert, 1993; Wood et al., 1993). In the absence of a specification, it is likely that the

condition was intentional, that is, students were told about the test in the experimental instruction.

Among the previously reported studies using intentional conditions, some indicated a recall advantage for students assigned to elaborative interrogation compared to those assigned to rereading (e.g., Pressley et al., 1998; Woloshyn et al., 1994; Wood et al., 1992). But there were also cases in which such an advantage was not found (e.g., Woloshyn et al., 1990, as described above), or in which there were certain qualifications to the results. For example, in two related studies it was reported that college students assigned to elaborative interrogation remembered more animal facts than students assigned to rereading, unless the tests were about unfamiliar animals, in which case the results from elaborative interrogation and rereading were not significantly different (Willoughby et al., 1993; Willoughby et al., 1994). In another example involving elementary students, there was a difference on recall tests about animal facts for students assigned to elaborative interrogation and rereading, if the students were identified as high- or average-achieving, but not if the students were identified as low-achieving (Wood et al., 1993).

Among the more recent authentic research reports, there is more similarity to the results in the current research. While two cases have reported a benefit for students assigned to elaborative interrogation over those assigned to rereading (Ozgungor, 2002; Smith, 2003), three have found no advantage for elaborative interrogation over rereading or other strategies (Dornisch, 2003; Ems-Wilson, 2000; Hill, 1999).

## *The Role of Rereading*

In the current research and much of the previously reported literature, the rereading strategy served as a placebo control for comparison with elaborative interrogation. In most reported cases, students assigned to elaborative interrogation have achieved significantly higher recall scores on tests than students assigned to rereading (e.g., Pressley et al., 1988; Woloshyn et al., 1992; Woloshyn et al., 1990). However, in this and several other recently reported investigations in authentic settings, no difference was found between assigning elaborative interrogation and assigning rereading to adult students (Dornisch, 2003; Ems-Wilson, 2000; Hill, 1999).

It is possible that rereading may not be as latent a comprehension strategy as presupposed in much of the elaborative interrogation literature. The combination of (a) employing silent reading, (b) instructing students to read twice, and (c) announcing the postreading test may create conditions for students to experience the maximum benefits from rereading. Such potential benefits of using rereading, then, appeared to rival the benefits of using elaborative interrogation in the current and the other recent similarly designed investigations (Dornisch, 2003; Hill, 1999). These three factors and their effects will be examined next.

Rereading instructions in the previously reported literature have not always been consistently designed from one researcher to another. One common combination has been (a) employing oral reading, (b) instructing students to read repeatedly until time had expired, and (c) not announcing a postreading test (e.g., Pressley et al., 1988; Woloshyn et al., 1992; Woloshyn et al., 1990). It might be argued that such a

combination minimizes the benefits from rereading. This may be so for three reasons. First, it has been reported recently (McCallum et al., 2004) that when students read silently they comprehend more quickly than if they read orally. McCallum et al. reported that students reading silently completed a text in 76% of the time, on average, that it took for students reading the text orally. There was no difference in mean scores between these two groups on a postreading comprehension test. Thus, in elaborative interrogation research, there may be a larger learning benefit to students who reread silently, as in the current study, compared to students who reread orally.

The second reason involves the number of times students assigned to rereading actually read the text. In the current study, students were instructed to read the text twice. Specifically, the instructions were as follows:

Read the material TWICE. (Read everything once, then re-read everything OR read each paragraph twice before going on to the next.)

Whether students actually did this or not cannot be confirmed. However, the researcher's observations of students suggested the students understood the directions and complied. According to Amlund et al. (1986), reading text two times provides a greater benefit, especially for recalling main ideas, than reading text only one time or reading text three times, although students tended to recall more details after a third reading. In some of the previously reported literature, students were encouraged to continue reading multiple times until time for the text passage ran out (e.g., Pressley et al., 1988; Woloshyn et al., 1992; Woloshyn et al., 1990). Typical instructions to students in these cases were as follows.



“Your task is to keep reading each sentence aloud at a rate that allows you to understand each fact as true. You are to keep reading each sentence at that rate for the entire time that it is presented” (Woloshyn et al., 1992, p. 117).

How many times students read the sentences was not always reported, but in one case, it was stated as 2.3 times on average (Woloshyn et al., 1990). Therefore, investigations such as the current research which stipulate that students should read two times probably provide a setting for more benefit than experiments where rereading three times, or even more, was possible.

And finally, the third reason for a possible difference concerns the intentional learning condition in the current research. Students read more carefully when they know they will be tested (Millis & King, 2001).

Another aspect of the use of rereading in more authentic settings involves the amount of time on task. In the current research, students assigned to use elaborative interrogation required significantly more time to complete their reading and question-answering compared to those who were assigned rereading. For students assigned to use elaborative interrogation,  $M = 25$  minutes; for students assigned to rereading,  $M = 19$  minutes. It is important to note that there was no correlation between time on task and learning gains. In other words, in the current investigation, there was no evidence that additional time resulted in additional learning. These time values were, coincidentally, nearly identical to those reported by Ozgungor (2002), who had, also coincidentally, a text of nearly the same length as the texts in the current research. Ozgungor’s students assigned to elaborative interrogation used significantly more time ( $M = 27$  minutes) than those assigned to rereading ( $M = 16$  minutes). The results

from the current research and Ozgungor's research suggest that elaborative interrogation may just be a more time-consuming strategy than rereading.

### Post Hoc Observations

The nature of the research sample and the size of subgroups afforded the opportunity to examine several key factors in more depth. These examinations were not envisioned in the original research design. Nevertheless, the data were available and the issues were deemed important or relevant enough to warrant the additional investigation.

At least three important post hoc topics emerged from this investigation: (a) possible gender differences, (b) possible differences in U.S. and international students, and (c) the importance of the preparation path to general chemistry. Each of these will be addressed in this section.

#### *Attention to Gender Differences*

Much discussion and research has occurred around the issue of gender differences in math and science education (e.g., Eccles, 1997). In secondary schools and higher education, higher level math and science classes are often populated with more males than females. An inspection of the rosters of leading chemists indicates that the field has been, and generally is, dominated by males. Indeed, there have been only a handful of women Nobel Prize winners in chemistry: Marie Curie in 1911, Irene Joliot-Curie in 1935, Dorothy Crowfoot Hodgkin in 1964, and Jean-Marie Lehn in 1987.

Gender differences in this investigation surfaced in the area of prior knowledge. Since the level of prior knowledge is an important key to learning more

chemistry, it may be important to understand these differences. It was good news that there was no difference in prior knowledge levels between U.S. males and females. This may add to the evidence that U.S. schools have made some efforts to attend to the progress of both boys and girls in the sciences. There was evidence of a difference, however, among the international males and females. The males had significantly more prior knowledge than the females. The sample of international students in this study was not homogeneous and no one country had a majority of students. Nevertheless, it is important for educators to be aware of possible prior knowledge differences between males and females among international students. Women college students from abroad who are studying in the U.S. should be encouraged to take advantage of special tutoring services, for instance. This study supported the idea that females who do have higher prior knowledge about Lewis structures learned just as much as males with higher prior knowledge. The important point for educators here is to ensure that precollege science classes instill the knowledge important for success in college level science courses such as general chemistry. This may be accomplished by a careful articulation of secondary chemistry curricula and college level curricula.

#### *Attention to Differences in International Students*

There was some evidence to suggest that the international sample was learning in different ways than the U.S. students. For instance, while the rereading strategy was a statistically significant factor for U.S. students in research Questions 2 to 4, this was not found for international students. The better strategy was undetermined; in other words, neither strategy worked better for these students. In the

case of research Questions 5 to 7 involving learning from text R, the rereading strategy was found to be a significant main effect for U.S. students. Again, this was not the case for international students, for whom prior knowledge was the significant main effect. International students shared the same main effect of prior knowledge with U.S. students in the research addressing Questions 8 to 10 and the authentic textbook.

Differences such as these highlighted the possibility that U.S. and international students, at least in this specific context of a college level general chemistry topic, perhaps learn in different ways. Understanding this phenomenon, if it exists, may provide support for development of learning strategy instruction helpful to students of international origins.

### *The Path to General Chemistry*

There are several academic paths that students can take in preparation for college level general chemistry. These include some combination of high school chemistry and a college preparatory course such as CH 100 (Chemistry 100), which is offered at the college where this research was conducted. Similar courses exist at other colleges and universities. Specifically, there were four paths to general chemistry, CH 101 (Chemistry 101) for students in the current investigation: (a) high school chemistry only, (b) CH 100 only, (c) both high school chemistry and CH 100, and (d) neither high school chemistry nor CH 100. The prerequisite for the general chemistry course at the college where the research was conducted is either high school chemistry or CH 100. Students who have not completed high school chemistry generally take CH 100 before enrolling in CH 101. Some students who have

completed high school chemistry opt to take CH 100 as a review before CH 101. Students who have not taken high school chemistry can seek special departmental permission to enroll directly in CH 101 without taking CH 100. This permission is not commonly granted as evidenced by the handful of such students in this sample.

The prior knowledge levels of these four groups as measured in this investigation were significantly different from one another. Students who had completed CH 100, either as their only course or in addition to high school chemistry, had higher prior knowledge levels. In fact, those who had completed only CH 100 had the highest prior knowledge level about chemistry topics related to Lewis structures. This result supports the importance of the role of CH 100 as a powerful preparation path for general chemistry. Advisors, faculty, and students can potentially benefit from this information. It may give hope to students who have not completed high school chemistry. Completing CH 100 potentially builds a solid foundation and provides the background knowledge to succeed in learning college level chemistry topics such as Lewis structures.

### Recommendations for Further Research

This investigation showed how two strategies, rereading and elaborative interrogation, can provide assistance to students in their learning under restricted learning conditions. The following recommendations for further research are made both to refine and to extend this line of research. Specifically, the recommendations focus on eight areas: (a) operationalizing the term “elaborative interrogation” consistently in the research literature, (b) providing explicit training and practice in strategy use, (c) comparing incidental and intentional conditions, (d) exploring

rereading in more depth by itself as well as in comparison with other strategies, (e) investigating more explicit elaborative question formats, (f) exploring the role of learning from figures associated with text, (g) investigating long-term impacts of strategy use, and (h) informing future clinical investigations. Each will be addressed in the next sections.

### *Operationalizing “Elaborative Interrogation”*

The term “elaborative interrogation” has appeared in the research literature for about 15 years, starting with Pressley et al. (1988). The earliest models of this strategy all involved researchers posing why-questions to students who provided oral answers to the questions. Such questions were not answerable by looking back at text; the answers had to originate from students’ prior knowledge and experiences about the topic. In later models, students wrote their answers on paper. In general, the elaborative interrogation strategy can be described as having three steps: (a) student reads text, (b) why-question is posed, and (c) student answers question. The goal of the strategy is to assist students in connecting new information to prior knowledge, thus increasing comprehension.

Variations on this elaborative interrogation process have been reported in the literature. Some of the variations may lead to confusion among consumers of the research literature and have an impact on the body of knowledge. For example, some studies have omitted the step of posing the why-question. In both Gaultney (1998) and Hill (1999), students were instructed to ask themselves why-questions throughout the reading. While this is perhaps an ideal to strive for (i.e., self-regulated strategy use), it is questionable as to whether students who are inexperienced in the strategy

can apply it on their own effectively. It is possible that they might benefit more from first using the strategy in a structured format.

In addition, in at least one case, there is no available evidence that students were required to answer the why-question (Gaultney, 1998). Answering or attempting to answer a question seems to be a pivotal part of the elaborative interrogation strategy.

In another case, Ozgungor (2002) reported the use of elaborative interrogation, but it appears that some questions posed during the reading were not strictly elaborative in nature. Examination of the experimental text and questions suggests that many of the questions probably could be answered by looking back at the text. The questioning in this case appeared to be aimed at *organizing* the material (i.e., building relationships among the new ideas), not necessarily *elaborating* (i.e., connecting new ideas with prior knowledge).

This variety in the use of the term, elaborative interrogation, suggests that a definitive operationalization of the term is needed in the literature. Researchers, journal editors, and reviewers need to take care in distinguishing adjunct questioning techniques (e.g., Hamaker, 1986) and preserve the term, elaborative interrogation, for questioning methodologies intended to stimulate readers' use of prior knowledge.

### *Instructing and Practicing Strategies*

The current investigation was designed for implementation in an authentic classroom setting and was intended to be as realistic as possible. Because students were randomly assigned to strategies within the same room, the instruction concerning each strategy was limited to a general description. In the case of

rereading, instructions are somewhat self-explanatory. However, in the case of elaborative interrogation, the asking of why-questions may have been a novel activity for students and the brief strategy instruction, as implemented in this investigation, did not allow an opportunity for student practice and researcher feedback, as has been previously reported (e.g., O'Reilly et al., 1998; Pressley et al., 1987; Willoughby et al., 1994; Woloshyn et al., 1992; Wood et al., 1990).

Most students in the current study seemed to understand the nature of the elaborative interrogation strategy, even if the level of adequate answers was low (especially with text R). Apparently, just a few students did not understand the strategy as evidenced by several functional noncontent-based answers to why-questions. For instance, when asked “why does this make sense,” one student wrote that the author had written the material clearly. Such answers were rare, but reflect a possible need for more explanation about or training in the strategy. The number of adequate answers may indeed increase with more thorough strategy instruction and practice before implementation. However, it should be noted that strategy instruction and practice alone is not always a determiner of success, as was shown in Ems-Wilson (2000), who also employed elaborative interrogation in the investigation of a college chemistry topic in an authentic setting.

### *Comparing Incidental and Intentional Learning Conditions*

The purely clinical investigations of elaborative interrogation in college settings have utilized volunteer students, usually from psychology courses, who read contrived text about a topic not related to their academic program, who were not told that they would be tested, but who were, in fact, were tested. As research shifts to



authentic settings, all of these facets change. In other words, in authentic investigations, the students are enrolled in a course related to their academic program, they read more authentic text about a topic related to their course, and they are told that they will be tested. While the results from clinical tests provide insights to hypothesize how strategies might provide cognitive benefits, the resilience of strategies is tested in authentic settings.

A preference for investigating learning strategies under incidental learning conditions appeared early in this line of literature (Pressley et al., 1988). An argument was made that the incidental paradigm produced the purest application of the assigned strategy. Elaborative interrogation was later confirmed to provide more benefit for recall tests in comparison with rereading under such incidental conditions (Woloshyn et al., 1990).

Whether in clinical or authentic settings, this issue of learning condition is really a matter of the nature of student expectations and how those expectations affect their reading tasks and strategy use. If students expect to be tested, that is, to be held accountable for what they are reading, it is likely that they will exert more cognitive effort while studying (T. H. Anderson & Armbruster, 1984; Caverly, et al., 2000). In a clinical situation, whether there will be a test or not is an open question; either possibility may seem reasonable to participants. In an authentic setting, however, it is more difficult to suspend the belief that course material will appear on a test.

Nevertheless, it may be interesting to conduct further research into comparing incidental and intentional learning conditions with more authentic text, as was used in the current research. The previously reported investigations that compared incidental

and intentional conditions used contrived text in the comparisons, namely the so-called man sentences (Pressley et al., 1987) and facts about Canadian universities (Woloshyn et al., 1990). Replicating such experimental procedures while using an authentic text (e.g., the procedural text T taken from T. L. Brown et al., 2003) should help to clarify whether this conditional distinction has an impact across all types of text.

It may be more interesting to compare learning gains in different types of intentional conditions while attempting to vary student expectations about the comprehension tests. This approach may help to shed some light on which strategies work best in which situations. A point of comparison might be factual tests versus inferential tests. In other words, tests that contain questions based directly on information explicitly stated in the reading (i.e., a “factual” test), and tests that contain questions requiring the student to make inferences based on the reading. Students could then be instructed to prepare for one type of test, but then the researcher could equally distribute both types of tests among the student sample. In this way, for instance, some students instructed that they would receive a factual test would indeed receive one, but other students instructed that they would receive a factual test would instead receive an inferential test. Conversely, some students instructed that they would receive an inferential test would receive one, but others instructed that they would receive an inferential test would instead receive a factual test. Results from this type of research could provide support for students having multiple strategies to choose from, and perhaps adjusting their choices based on particular learning demands.

## *Exploring Rereading with Authentic Text*

Researchers studying and comparing comprehension strategies have at their disposal “sparse literature on strategic rereading” (Millis & King, 2001, p. 44). As a result, not much is understood about what specifically occurs during rereading. Nevertheless, rereading is commonly used as a placebo control for comparison with other strategies (T. H. Anderson & Armbruster, 1984).

It is known that college students are likely to engage in rereading spontaneously (Wade et al., 1990) and that they know more after the second reading than they do after the first (Barnett & Seefeldt, 1989; Millis & King, 2001). How they know more after reprocessing the text is not completely understood. Millis and King hypothesized that during the rereading of text, readers first verify what they saw and know from the first reading and then have the option to elaborate. In other words, readers may build their comprehension with “inferences generated from world knowledge” (Millis & King, p. 45). There is scant evidence to support such a hypothesis, but this suggests that students who read and then reread a text might be capable of elaboration during the second reading. Whether students actually do or not is an open question.

Several areas of rereading research may be of potential interest for further pursuit. First, looking at rereading under incidental and intentional conditions may prove interesting. In the previously reported elaborative interrogation literature, rereading was typically less potent to students for fostering a benefit on recall tests. In those cases, the text was contrived. It may be possible that in authentic settings where the text is more authentic (e.g., the current research; Ems-Wilson, 2000; Ward, 1999),

students are more interested in the text since it relates to their academic program. And, in being more interested, they apply more cognitive effort to reading and maximize the utility of rereading. An investigation comparing memory gains by using incidental and intentional conditions may shed some light on this question.

Two other factors should also be examined in an effort to understand the power and limitations of rereading as a learning strategy. The first is the source of the time and rate control, namely the researcher or the student. Both of these methods appear in the elaborative interrogation literature and may have different impacts on the learning benefits attributed to the strategy. In more authentic settings, it is more likely that students will be allowed to control their own rate of reading. This more closely approximates real life, but it may also introduce a confounding factor of time differences among rereading students as well as among students using different strategies.

Another factor involves the manner in which the reading-rereading is conducted: orally or silently. Again, both of these have appeared in the elaborative interrogation literature. There is recent evidence to support a difference in the rate of readers' comprehension under these two different methods. Readers assigned to oral reading learn as much as readers assigned to silent reading, but silent readers learn it more quickly (McCallum et al., 2004). Therefore, with both of these reading methods being reported in elaborative interrogation literature, some of the differences in recall test measures may be attributable to this difference.

Additional research that compares oral and silent rereading may provide a better understanding of the nature of rereading. Conducting such research with

authentic text in authentic settings may yield different results from research in clinical settings with contrived text. Students may reread more strategically when reading text about an academic subject compared to reading about man sentences, university facts, or animals.

### *Investigating Alternate Question Wording*

The elaborative interrogation strategy was intended as a questioning method to encourage learners to make connections between new information and the prior knowledge they already have about that topic (Pressley et al., 1988). In generating an answer to the question, “why,” in theory, students reflect about the topic domain and engage in thinking that incorporates new information into their existing schema (Pressley et al., 1988). Whether this is really what students are thinking about when they answer a why-question is really not known nor has it been thoroughly investigated. That answering why-questions is helpful is generally inferred from students’ performances on recall tests. However, in a case where researchers examined and evaluated students’ answers to why-questions for the presence of any prior knowledge, very little evidence was found that such prior knowledge was indeed activated (McDaniel & Donnelly, 1996).

Except for early work comparing question wording to reach this cognitive connection goal (Martin & Pressley, 1991), there has been very little, if any, exploration of alternative question types. Most of the elaborative interrogation literature has reported use of the why-question as a standard method of implementation. Several investigations have included different question types. For example, Ems-Wilson (2000) organized college chemistry students into groups and

instructed them in self-directed elaborative interrogation methods utilizing question prompts recommended by King (1992). Among the 19 prompts in King are three that are similar to questions used in elaborative interrogation research, namely, (a) “Explain why...,” (b) “Why is ... important?,” and (c) “How does ... effect ...?” (King, p. 113).

In another break from the strict why-question format, Ozgungor (2002) asked college students to answer 14 questions during a reading, where four questions were what-questions, eight were how-questions, and only two were why-questions.

O’Reilly et al. (1998) approached their investigation as a comparison of three strategies, namely rereading, elaborative interrogation, and a so-called “self-explanation” strategy. In the case of elaborative interrogation, their students were asked “Why does it make sense that...?” (O’Reilly et al., p. 439). The self-explanation students, on the other hand, were asked “Explain what the sentence means to you. That is, what new information does the sentence provide you? And how does it relate to what you already know?” (O’Reilly et al., p. 439). The self-explanation students did significantly better on recall tests compared to both the elaborative interrogation and the rereading students in this case. This may not be surprising since the self-explanation prompt is really a triple prompt (i.e., the one sentence and two questions may stimulate three thoughts in response) compared to the single prompt in the elaborative interrogation strategy and no prompt in the rereading strategy.

A potential line of further research, therefore, is to explore alternative questions in the attempt to assist students in making connections between new

material and prior knowledge. Although that is the goal in asking “why,” it is implicit; it is masked to the reader. An explicit, unmasked question that makes the goal of the question clear may produce better learning gains. Instead of asking a question such as “Why does this make sense?” and assuming students will make the cognitive jump to consider what they already know to answer, an alternative question, in a modified O’Reilly et al. (1998) approach, might be phrased as “Why does this make sense based on what you already know about ...?” Such a question makes specific reference to prior knowledge and may better guide students in their attempts to answer. It may be time for an investigation such as Martin and Pressley (1991) to focus solely on asking different questions and comparing comprehension gains as well as the use of prior knowledge in the answers to questions as in McDaniel and Donnelly (1996).

### *Exploring the Mechanism of Learning Figures*

As the to-be-learned targets in this investigation, Lewis structures are a type of figure or image. The combined use of text and images in strategy investigations is only rarely reported (e.g., Willoughby et al., 1994), but it may be especially valuable to pursue in the context of topics like chemistry, where textbook topics frequently involve the combination of text and figures. The unique aspect of this, compared to other investigations of figures or diagrams with science text, (e.g., Harp & Mayer, 1997; Hegarty, Carpenter, & Just, 1991) is that the figure itself is the learning target.

Although all students in the current investigation read text concerning Lewis structures, either facts about them or a procedure about constructing them, students were not directly tested about the content of the text. The most important outcome in

a chemistry class is the ability to draw the structures. It may be an interesting investigation to include a treatment in which students learn from figures only. An example of such an investigation might be to use text R as developed in this research, and prepare three distinct materials for students: (a) only textual descriptions of Lewis structures, (b) only figures of Lewis structures, and (c) both text and figures. Such a research comparison might be helpful in understanding the role of learning from text and learning from figures in a college level science domain.

### *Investigating Long-term Impacts*

This current research shed some light on how college students can perhaps use comprehension strategies when reading about Lewis structures. Students were tested immediately after reading. This reduced any influence of factors such as outside-of-class study time, diffusion, or research-sample mortality. However, the long-term impacts of strategy-use are important in college level courses. In real college situations, students must demonstrate their knowledge on criterion tasks, which typically are administered at a time longer removed from when they complete their reading. Adding a delayed posttest to an investigation such as the current design could also measure the long-term efficacy of comprehension strategies. In such designs, there is potential for more confounding influences; careful design and documentation would be required in order to understand and interpret the results.

### *Informing Clinical Investigations*

Previously reported literature conducted in clinical settings has provided evidence in support of the elaborative interrogation hypothesis. In such settings, the typical elaborative interrogation research involved volunteers from psychology



courses reading contrived text aloud, individually, while unaware of a potential test, which was a recall test containing knowledge-level questions.

However, as research efforts have moved into more authentic situations (as described by the factors in Table 26, p. 204), the elaborative interrogation effect has not manifested itself with the same intensity, if at all (e.g., Dornish, 2003; Ems-Wilson, 2000; Hill, 1999). The results from such studies raise interesting issues that may be clarified by returning to clinical situations for additional clarification. All of the factors cited above among these suggestions for further research could be conducted in both classroom and clinical settings.

Within the clinical setting, for instance, it may help to clarify potential benefit of elaborative interrogation in college science classrooms by conducting experimentation, similar to that reported, with science-course volunteers. Numerous other factors could be manipulated, one at a time, in a series of clinical experiments. Key questions that might be addressed include: (a) does the use of an authentic textbook have an effect on the strategy benefit; (b) are there differences caused by having students read silently; (c) are there difference in performance when students read at their own personal pace; and (d) does use of the strategy prove effective for answering higher-level test questions such as application- or analysis-type questions.

Clinical research informed by the results of classroom research can help to clarify important aspects of using comprehension strategies in realistic college classroom settings. These clarifications may, in turn, refine classroom research efforts as well.

## Summary

College science students learn important topics by reading their textbooks. The construction of Lewis structures is an important topic in chemistry (e.g., Hurst, 2002) and it is known to be difficult for students to learn (Ahmad & Omar, 1992; Carroll, 1986). Science textbooks are known to contain dense technical prose, which can be difficult for college students to read (Holliday et al., 1994; Millis et al., 1998; Simpson & Nist, 2002). Therefore, comprehension strategies are important to consider for increasing student achievement in science courses. Elaboration strategies, which are intended to assist in the integration of new information with prior knowledge, are especially relevant to consider in classes such as chemistry, where the learning of new topics is so often dependent on having a working knowledge of already learned information. The strategy known as elaborative interrogation was investigated in this research in order to determine its potential for use by college chemistry students. In addition, the strategy of rereading was also investigated.

The body of evidence about elaborative interrogation showed that students who possess a certain minimum amount of prior knowledge in a topic area generally experience a benefit on recall test measures after answering why-questions during the reading of new information (e.g., Pressley, 1987; Pressley, 1988; Willoughby et al., 1994; Woloshyn et al., 1992; Wood et al., 1990). Evidence for rereading indicated that students who employ the method learn more concepts and information during their second reading (e.g., Millis & King, 2001).

In the current investigation involving elaborative interrogation and rereading, whether one strategy was more effective than the other was undetermined in the case of reading from an authentic textbook. However, prior knowledge was determined to be a statistically significant factor when learning from authentic text, regardless of which strategy was assigned. This finding provides support for importance of learning chemistry in a sequential manner, building a firm foundation of the basics before moving onto more sophisticated topics.

Learning about learning is an important, but often overlooked, aspect of education (e.g., Mayer, 1996; Pressley, 2002). Students who are able to select, initiate, and utilize effective learning strategies increase their potential to comprehend and use new information. Research that explores student use of strategies will continue to develop educators' understanding of such strategies and inform efforts to help students be better students.

# APPENDICES

## Appendix I: Consent Form

**PROJECT TITLE:** The Use of Elaborative Interrogation with Factual and Procedural Text about Lewis Structures in an Authentic College Science Learning Environment.

**AGE:** I state that I am 18 years of age or older and wish to participate in a research program conducted by Stephen Cain of the Graduate School, University of Maryland, College Park, College of Education, Department of Curriculum and Instruction.

**PURPOSE:** I understand that I am participating in a study that is examining different study strategies used by college students with the purpose of determining whether one is more effective than another.

**PROCEDURES:** I understand that the procedure involves reading text followed by taking a test. Some participants will read the text two times; some students will read the text once and answer questions while reading.

**BENEFITS:** I understand that the experiment is not designed to help me personally, but that the investigator hopes to learn more about learning strategies that will help college students comprehend information in their textbooks better.

**RISKS TO PARTICIPANTS:** I understand that risks to me are minimal. I will be carrying out activities similar to normal college class activities, namely reading and writing. The likelihood of harm or discomfort is not any greater than what might be encountered in ordinary daily life or in regular class activities.

**CONFIDENTIALITY:** I understand that all test scores obtained during this study will be used to interpret the effectiveness of the learning materials studied in the research. I understand that the test scores will have no impact on my class grade. My name will not appear on any of the materials that are included in the study. Instead, this study will use a coded number system. My name will appear only on this consent form. All materials related to this study will be shredded at the conclusion of the research, no later than December 31, 2010.

**Principal Investigator & Faculty Advisor**

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Stephen D. Cain  
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If you have questions about your rights as a research subject or wish to report a research-related injury, please contact: Institutional Review Board Office, University of Maryland, College Park, Maryland, 20742; (e-mail) [irb@deans.umd.edu](mailto:irb@deans.umd.edu); (telephone) 301-405-4212 The reason for this request is to be consistent with the Rights and Injuries Questions section of the Informed Consent Checklist, provided by the DHHS Office of Human Research Protections at <http://ohrp.osophs.dhhs.gov/humansubjects/assurance/consentckls.htm>.

I have read the information above about this research project, I understand the consent form, and have had an opportunity to ask questions about my consent.

---

PRINT Your Name	Your Signature	Date
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## Appendix II: Replication Test

**Directions:** Draw the Lewis structure for each of the following. Recall that a pair of electrons can be shown as two dots or one solid line. Be sure that your final answer is drawn in the “final answer” box. If you are aware of multiple resonance structures for any formula, any one resonance structure is an acceptable answer.

1. HF

*My final answer:*

6.  $\text{BrF}_4^-$

*My final answer:*

2.  $\text{CH}_4$

*My final answer:*

7.  $\text{OSF}_2$

*My final answer:*

3.  $\text{PCl}_4^+$

*My final answer:*

8.  $\text{I}_3^-$

*My final answer:*

4.  $\text{N}_2$

*My final answer:*

9.  $\text{FNO}_2$

*My final answer:*

5.  $\text{CO}_3^{2-}$

*My final answer:*

10. NO

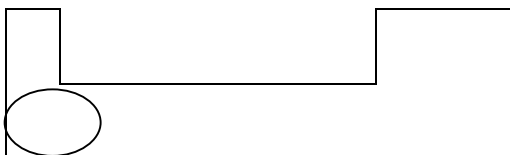
*My final answer:*

### Appendix III: Prior Knowledge Test

**INSTRUCTIONS:** Choose the best answer for each question. There is only one correct answer for each. Write your answers on the answer sheet provided. If you are unsure about a question, make your best guess or skip it.

1. Which element symbol is matched with its correct name?
  - A. Ca, carbon
  - B. I, iron
  - C. Po, phosphorus
  - D. Cl, chlorine
  
2. A sample of an element does not conduct electricity. Individual atoms of this element tend to gain electrons during chemical reactions. This element is most likely:
  - A. a metal
  - B. a nonmetal
  - C. a metalloid (also called “semimetal”)

3. Elements in the circled part of this periodic table are:



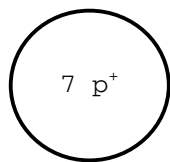
- A. metals
  - B. nonmetals
  - C. metalloids (also called “semimetals”)
- 
4. Which of the following binary compounds is most likely ionic?
    - A.  $\text{N}_2\text{O}$
    - B.  $\text{CO}$
    - C.  $\text{SO}_3$
    - D.  $\text{CaCl}_2$

5. Which elements are known as the “halogen family”?

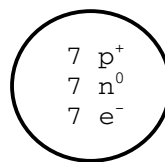
	1A	2A		3A	4A	5A	6A	7A	8A
1	H								He
2	Li	Be		B	C	N	O	F	Ne
3	Na	Mg		Al	Si	P	S	Cl	Ar
4	K	Ca						Br	Kr
5	Rb	Sr						I	Xe
6	Cs	Ba						At	Rn

- A. Period 1  
 B. Period 2  
 C. Group 7A  
 D. Group 8A
6. If atom **X** and atom **Y** form a compound when atom **X** gives 2 electrons to **Y**, then:
- A. **XY** forms by ionic bonding  
 B. **XY** contains 2 covalent bonds  
 C. **XY** is a polyatomic ion  
 D. **XY** is a diatomic molecule
7. If the symbol N stands for an atom of the most common isotope of nitrogen, which of the following schematic drawings best represents N? ( $p^+$  = proton,  $n^0$  = neutron,  $e^-$  = electron)

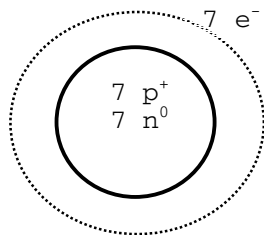
A.



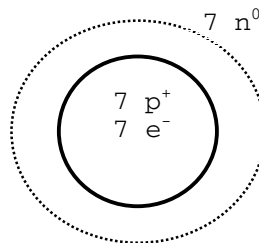
C.



B.

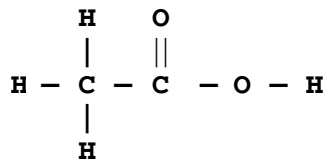


D.



8. Compared to neutrons, electrons:
- have greater mass and move at faster speeds
  - have greater mass and move at slower speeds
  - have less mass and move at faster speeds
  - have less mass and move at slower speeds
9. How many atoms of oxygen are in the formula,  $\text{Mg}(\text{NO}_3)_2$ ?
- 2
  - 3
  - 5
  - 6

10. Choose the false statement about this molecule:



- The empirical formula of the molecule is  $\text{CH}_2\text{O}$ .
  - Sixteen (16) electrons participate in the molecule's bonds.
  - The molecule contains a hydroxide ion ( $\text{OH}^-$ ).
  - The  $\text{C}=\text{O}$  double bond has different properties than the  $\text{C}-\text{O}$  single bond.
11. Where is a rubidium atom's valence ("outer shell") electron located? (Assume ground state.)
- Rb•**
- 1s orbital
  - 5s orbital
  - 5p orbital
  - 5d orbital
12. Which statement best describes the valence electrons of elements O and S?
- O has more valence electrons than S
  - O has fewer valence electrons than S
  - O has the same number of valence electrons as S



13. Which of the following has the same number of valence electrons as  ${}_{15}\text{P}$ ?
- ${}_{7}\text{N}$
  - ${}_{16}\text{S}$
  - ${}_{18}\text{Ar}$
  - ${}_{30}\text{Zn}$

14. The electron configuration  $[\text{Ne}]3s^23p^1$  represents an atom of:
- B
  - Ne
  - Na
  - Al

15. Which element shown on this periodic table has the largest neutral atom? (In other words, which has the longest atomic radius?)

	1A								8A	
2	Li									Ne
3										
4										
5	Rb									Xe

- Li
  - Rb
  - Ne
  - Xe
16. An atom with a strong ability to attract bonding electrons toward its nucleus is said to have:
- high electronegativity
  - low electronegativity
  - high ionic character
  - low ionic character

17. In obeying the Octet Rule, an atom of fluorine (F) is most likely to:
- A. gain 1 electron
  - B. lose 1 electron
  - C. gain 7 electrons
  - D. lose 7 electrons

18. Choose the true statement about this symbol for sulfur.

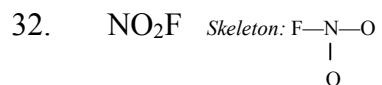
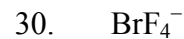
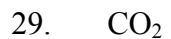
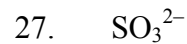


- A. This is an atom with a total of 6 electrons.
- B. The unpaired dots represent electrons in p orbitals.
- C. It is a sulfur atom with 4 valence electrons.
- D. This symbol has a charge of 2-.

## Appendix IV: Pretest

*Note.* The pretest was given as one document with the prior knowledge test. Therefore, the numbering begins here at 19.

**INSTRUCTIONS:** Draw the Lewis structure for each of the following on the answer sheet provided. If you are unsure about a structure, make your best guess or skip it.



## Appendix V: Student Survey

① Where were you born? \_\_\_\_\_  
*City/Town State/Province Country*

② How old are you? \_\_\_\_\_ years

③ What is your gender?     *Female*         *Male*

④ Did you complete high school chemistry?

*Yes*     *No*

**IF YES**, please answer questions a-c. **IF NO**, skip to #⑤

- a) How many years ago did you take the class? \_\_\_\_\_  
b) In what country did you take the class? \_\_\_\_\_  
c) Was your high school in an *urban* (city),  
*rural* (farm area), or *suburban* location? \_\_\_\_\_

⑤ Have you completed an introductory chemistry course *in college*, before this course?

*Yes*     *No*

**IF YES**, please answer questions a-c. **IF NO**, skip to #⑥

- a) How many years ago did you take the class? \_\_\_\_\_  
b) Did you take it at this college or another? \_\_\_\_\_  
c) What grade did you earn? \_\_\_\_\_

- ⑥ Following is an alphabetical list of some major chemistry topics you may have studied in school or encountered in your daily life. *Circle* the rating you would give yourself for your knowledge of each topic, where 3 is high, 2 is medium, 1 is low. Use 0 if you feel you have no knowledge of the topic.

CHEMISTRY TOPIC	YOUR RATING			
	High	Medium	Low	None
Acids and bases	3	2	1	0
Atomic theory	3	2	1	0
Chemical bonding	3	2	1	0
Chemical equilibrium	3	2	1	0
Chemical reactions	3	2	1	0
Energy changes in reactions	3	2	1	0
Moles	3	2	1	0
Stoichiometry	3	2	1	0
Your overall knowledge of chemistry	3	2	1	0

- ⑦ To the best of your recollection, what was the last chapter you studied in your CH 101 textbook, *Chemistry: The Central Science*, 9<sup>th</sup> edition? *Circle* your answer.

Ch <b>1</b> Introduction: Matter and Measurement	Ch <b>2</b> Atoms, Molecules, and Ions	Ch <b>3</b> Stoichiometry: Calculations with Chemical Formulas and Equations
Ch <b>4</b> Aqueous Reactions and Solution Stoichiometry	Ch <b>5</b> Thermochemistry	Ch <b>6</b> Electronic Structure of Atoms
Ch <b>7</b> Periodic Properties of the Elements	Ch <b>8</b> Basic Concepts of Chemical Bonding	Ch <b>9</b> Molecular Geometry and Bonding Theories
Ch <b>10</b> Gases	Ch <b>11</b> Intermolecular Forces, Liquids and Solids	Ch <b>12</b> Modern Materials

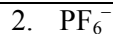
## Appendix VI: Posttest

**INSTRUCTIONS:** Draw the Lewis structure for each of the following in the space provided. If you are unsure about a structure, make your best guess or skip it.

A periodic table is attached for your reference.



*My final answer:*



*My final answer:*



*My final answer:*



*My final answer:*



*My final answer:*



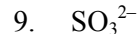
*My final answer:*



*My final answer:*



*My final answer:*



*My final answer:*



*My final answer:*



*My final answer:*



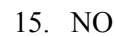
*My final answer:*



*My final answer:*



*My final answer:*



*My final answer:*



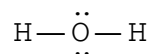
## Appendix VIII: Text Cover Sheet

*Note.* This instructional cover sheet was attached to all text treatments.

Everyone in the room has been given a handout that contains a reading about drawing molecular structures, sometimes called Lewis structures. Chemistry professors consider this a critical subject, for both general chemistry and organic chemistry courses. In fact, in several weeks you have an entire lab devoted to molecular modeling and need to understand molecular structures in order to understand many other important ideas presented later in the course. In case you are unfamiliar with Lewis structures, consider this example.

### EXAMPLE

The Lewis structure of water, H<sub>2</sub>O, is shown below. Each line represents a single bond made of two electrons and each pair of dots (shown as : or ··) represents an unshared pair of electrons.



Read the text while following the special instructions, which are printed at the top of each page as a reminder.

- Some students will be instructed to read the material twice, that is reread the material a second time.
- Some students will be instructed to read the material only once, while writing their answers to study questions that appear in the right margin.

There are excellent reasons to believe that both methods really help students learn difficult science topics like molecular structures. I really don't know which method will work best for each of you. That is one of the things we are trying to figure out.

Be sure to follow the instructions that apply to you.

While you are reading, keep in mind that you will have a quiz at the end of the reading covering the presented material. The quiz contains 15 formulas. You will be asked to draw the Lewis structure for each formula. For your reference and help while you read, a periodic table is included on the last page of this handout. You will also have a periodic table while you are taking the quiz.

What you learn during this exercise surely will be helpful to you in the coming weeks of CH 101.



## Appendix IX: Text R–Rereading Treatment

### YOUR INSTRUCTIONS:

Read the material TWICE.

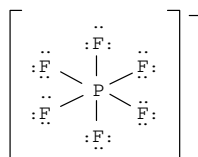
(Read everything once, then re-read everything OR read each paragraph twice before going on to the next.)

NOTE: An important guideline to follow in drawing Lewis structures is called the *octet rule* which states that atoms tend to gain, lose, or share electrons until they are surrounded by eight valence electrons.

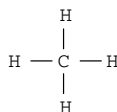
1. Hydrogen fluoride, HF, is composed of a hydrogen atom and a fluorine atom. In the Lewis structure, the two atoms are connected by a single bond and the fluorine has three unshared pairs of electrons. Being a particle with no net charge and having all electrons in pairs, HF is classified as a molecule. In Lewis structures, a hydrogen atom forms only one covalent bond and has no unshared pairs of electrons. The Lewis structure of HF is drawn as:



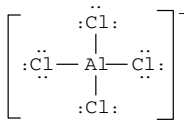
2. The phosphorus hexafluoride ion,  $\text{PF}_6^-$ , contains one phosphorus atom and six fluorine atoms. In the Lewis structure, the central phosphorus has a single bond to each fluorine, each of which has three unshared pairs of electrons. Being a particle with a net charge of 1–,  $\text{PF}_6^-$  is classified as a polyatomic anion and the 1– charge (or simply “–”) is written to the upper right side of brackets drawn around the structure. Like other period 3 elements with d orbitals available for bonding, phosphorus can exceed an octet in structures such as this. The Lewis structure of  $\text{PF}_6^-$  is drawn as:



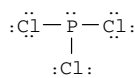
3. Methane,  $\text{CH}_4$ , consists of one carbon atom and four hydrogen atoms. In the Lewis structure, four hydrogens are connected by single bonds to the central carbon. Being a particle with no net charge and having all electrons in pairs,  $\text{CH}_4$  is classified as a molecule. The four valence electrons on carbon (an element in group 4A) are shared, one at a time, with the one valence electron from each hydrogen (an element in group 1A). The Lewis structure of  $\text{CH}_4$  is drawn as:



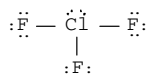
4. The aluminum chloride ion,  $\text{AlCl}_4^-$ , is composed of one aluminum and four chlorine atoms. In the Lewis structure, the central aluminum has a single bond to each chlorine, each of which has three unshared pairs of electrons. Being a particle with a net charge of 1–,  $\text{AlCl}_4^-$  is classified as a polyatomic anion and the 1– charge is written to the upper right side of brackets drawn around the structure. This is the first structure of this exercise in which all atoms exactly obey the octet rule. The Lewis structure of  $\text{AlCl}_4^-$  is drawn as:



5. Phosphorus trichloride,  $\text{PCl}_3$ , contains one phosphorus atom and three chlorine atoms. In the Lewis structure, a central phosphorus is bonded to three chlorine atoms, each of which has three unshared pairs of electrons. Being a particle with no net charge and having all electrons in pairs,  $\text{PCl}_3$  is classified as a molecule. Nitrogen, another element in group 5A on the periodic table, also forms a similar molecule with chlorine,  $\text{NCl}_3$ . The Lewis structure of  $\text{PCl}_3$  is drawn as:



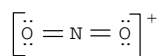
6. Chlorine trifluoride,  $\text{ClF}_3$ , consists of a chlorine atom and three fluorine atoms. In the Lewis structure, each fluorine is joined by a single bond to the chlorine, which has two unshared pairs of electrons. Each fluorine atom has three unshared pairs. Being a particle with no net charge and having all electrons in pairs,  $\text{ClF}_3$  is classified as a molecule. Like other period 3 elements with d orbitals available for bonding, chlorine is capable of exceeding an octet in certain instances. The Lewis structure of  $\text{ClF}_3$  is drawn as:



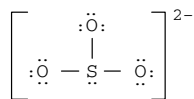
7. Dinitrogen,  $\text{N}_2$ , commonly called just “nitrogen,” consists of two nitrogen atoms. In the Lewis structure, the two nitrogen atoms are held together by a triple bond. Each nitrogen atom has one unshared pair of electrons. Being a particle with no net charge and having all electrons in pairs,  $\text{N}_2$  is classified as a molecule. The triple bond in  $\text{N}_2$  is signified by three parallel lines. The Lewis structure of  $\text{N}_2$  is drawn as:



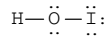
8. The nitrogen dioxide ion,  $\text{NO}_2^+$ , contains a nitrogen atom and two oxygen atoms. In the Lewis structure, each oxygen is joined to the central nitrogen by a double bond. Both oxygen atoms have two unshared pairs of electrons. Being a particle with a net charge of  $1+$ ,  $\text{NO}_2^+$  is classified as a polyatomic cation and the  $1+$  charge (or simply “+”) is written to the upper right side of brackets drawn around the structure. This is one of the few polyatomic cations encountered in chemistry and should not be confused with a similar formula,  $\text{NO}_2^-$ , which is an anion called nitrite. The Lewis structure of  $\text{NO}_2^+$  is drawn as:



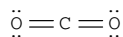
9. Sulfite ion,  $\text{SO}_3^{2-}$ , consists of one sulfur atom and three oxygen atoms. In the Lewis structure, the central sulfur is bonded to three oxygen atoms by single bonds. The sulfur atom has one unshared pair of electrons and each oxygen atom has three unshared pairs. Being a particle with a net charge of  $2-$ ,  $\text{SO}_3^{2-}$  is classified as a polyatomic anion and the  $2-$  charge is written to the upper right side of brackets drawn around the structure. Sulfur and oxygen combine to form several different compounds and polyatomic ions including  $\text{SO}_2$ ,  $\text{SO}_3$ ,  $\text{SO}_3^{2-}$ ,  $\text{SO}_4^{2-}$ , and  $\text{S}_2\text{O}_3^{2-}$ . The Lewis structure of  $\text{SO}_3^{2-}$  is drawn as:



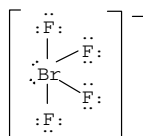
10. Hydrogen hypoiodite,  $\text{HOI}$ , contains a hydrogen atom, an oxygen atom, and an iodine atom. In the Lewis structure, the atoms are held together by single bonds, in the order of hydrogen, oxygen, and then iodine. The oxygen has two unshared pairs of electrons while the iodine has three. Being a particle with no net charge and having all electrons in pairs,  $\text{HOI}$  is classified as a molecule. The oxygen and iodine obey the octet rule with eight electrons, but hydrogen always observes the rule with only two. The Lewis structure of  $\text{HOI}$  is drawn as:



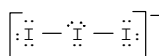
11. Carbon dioxide,  $\text{CO}_2$ , is made of one carbon and two oxygen atoms. In the Lewis structure, the central carbon is bonded to two oxygen atoms by a double bond to each. The oxygen atoms each have two unshared pairs of electrons. Being a particle with no net charge and having all electrons in pairs,  $\text{CO}_2$  is classified as a molecule. Sulfur and selenium, elements in group 6A, the oxygen family, also bond with carbon in a similar fashion to form  $\text{CS}_2$  and  $\text{CSe}_2$ , respectively. The Lewis structure of  $\text{CO}_2$  is drawn as:



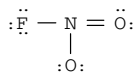
12. The bromine tetrafluoride ion,  $\text{BrF}_4^-$ , contains a bromine atom and four fluorine atoms. In the Lewis structure, the central bromine, with two unshared pairs of electrons, has a single bond to each fluorine, each of which has three unshared pairs of electrons. Being a particle with a net charge of  $1^-$ ,  $\text{BrF}_4^-$  is classified as a polyatomic anion and the  $1^-$  charge is written to the upper right side of brackets drawn around the structure. Having four bonds and two unshared pairs of electrons in this ion, the large bromine atom exceeds an octet. The Lewis structure of  $\text{BrF}_4^-$  is drawn as:



13. The triiodide ion,  $\text{I}_3^-$ , consists of three iodine atoms. In the Lewis structure, the three atoms are arranged in a row, with single bonds connecting them and three unshared pairs of electrons on each. Being a particle with a net charge of  $1^-$ ,  $\text{I}_3^-$  is classified as a polyatomic anion and the  $1^-$  charge is written to the upper right side of brackets drawn around the structure. Like other large period 5 elements with d orbitals available for bonding, iodine is capable of exceeding an octet. The Lewis structure of  $\text{I}_3^-$  is drawn as:



14. Nitryl fluoride,  $\text{NO}_2\text{F}$ , contains one fluorine atom, one nitrogen atom, and two oxygen atoms. In the Lewis structure, the central nitrogen is bonded to the fluorine with a single bond, to one oxygen with a single bond, and to the other oxygen with a double bond. The fluorine has three unshared pairs of electrons. The singly-bonded oxygen also has three unshared pairs, and the doubly-bonded oxygen has two unshared pairs. Being a particle with no net charge and having all electrons in pairs,  $\text{NO}_2\text{F}$  is classified as a molecule. Chlorine, like fluorine of group 7A, forms a similar molecule with nitrogen and oxygen,  $\text{NO}_2\text{Cl}$ . The Lewis structure of  $\text{NO}_2\text{F}$  is drawn as:



15. Nitrogen monoxide,  $\text{NO}$ , contains one nitrogen atom and one oxygen atom. In the Lewis structure of  $\text{NO}$ , also known as "nitric oxide," the two atoms are connected by a double bond. The oxygen atom has two unshared pairs of electrons and the nitrogen atom has one unshared pair in addition to *one single electron*. Being a particle with no net charge and having an *odd* number of electrons,  $\text{NO}$  is classified as a *radical*. Having a single unshared electron is unusual, but this occurs in a small number of structures. The Lewis structure of  $\text{NO}$  is drawn as:



## Appendix X: Text R–Elaborative Interrogation Treatment

### YOUR INSTRUCTIONS :

Read each paragraph ONCE. Answer the questions in the right margin when directed.

(Continue answers on back if necessary.)

NOTE: An important guideline to follow in drawing Lewis structures is called the *octet rule* which states that atoms tend to gain, lose, or share electrons until they are surrounded by eight valence electrons.

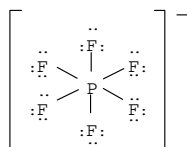
1. Why does this structure make sense?

1. Hydrogen fluoride, HF, is composed of a hydrogen atom and a fluorine atom. In the Lewis structure, the two atoms are connected by a single bond and the fluorine has three unshared pairs of electrons. Being a particle with no net charge and having all electrons in pairs, HF is classified as a molecule. In Lewis structures, a hydrogen atom forms only one covalent bond and has no unshared pairs of electrons. The Lewis structure of HF is drawn as:



**GO TO QUESTION 1 →**

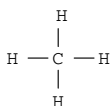
2. The phosphorus hexafluoride ion,  $\text{PF}_6^-$ , contains one phosphorus atom and six fluorine atoms. In the Lewis structure, the central phosphorus has a single bond to each fluorine, each of which has three unshared pairs of electrons. Being a particle with a net charge of 1-,  $\text{PF}_6^-$  is classified as a polyatomic anion and the 1- charge (or simply “-”) is written to the upper right side of brackets drawn around the structure. Like other period 3 elements with d orbitals available for bonding, phosphorus can exceed an octet in structures such as this. The Lewis structure of  $\text{PF}_6^-$  is drawn as:



**GO TO QUESTION 2 →**

2. Why does this structure make sense?

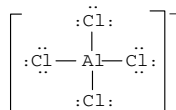
3. Methane,  $\text{CH}_4$ , consists of one carbon atom and four hydrogen atoms. In the Lewis structure, four hydrogens are connected by single bonds to the central carbon. Being a particle with no net charge and having all electrons in pairs,  $\text{CH}_4$  is classified as a molecule. The four valence electrons on carbon (an element in group 4A) are shared, one at a time, with the one valence electron from each hydrogen (an element in group 1A). The Lewis structure of  $\text{CH}_4$  is drawn as:



**GO TO QUESTION 3 →**

3. Why does this structure make sense?

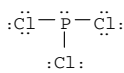
4. The aluminum chloride ion,  $\text{AlCl}_4^-$ , is composed of one aluminum and four chlorine atoms. In the Lewis structure, the central aluminum has a single bond to each chlorine, each of which has three unshared pairs of electrons. Being a particle with a net charge of 1-,  $\text{AlCl}_4^-$  is classified as a polyatomic anion and the 1- charge is written to the upper right side of brackets drawn around the structure. This is the first structure of this exercise in which all atoms exactly obey the octet rule. The Lewis structure of  $\text{AlCl}_4^-$  is drawn as:



**GO TO QUESTION 4 →**

4. Why does this structure make sense?

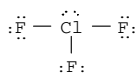
5. Phosphorus trichloride,  $\text{PCl}_3$ , contains one phosphorus atom and three chlorine atoms. In the Lewis structure, a central phosphorus is bonded to three chlorine atoms, each of which has three unshared pairs of electrons. Being a particle with no net charge and having all electrons in pairs,  $\text{PCl}_3$  is classified as a molecule. Nitrogen, another element in group 5A on the periodic table, also forms a similar molecule with chlorine,  $\text{NCl}_3$ . The Lewis structure of  $\text{PCl}_3$  is drawn as:



**GO TO QUESTION 5 →**

**5. Why does this structure make sense?**

6. Chlorine trifluoride,  $\text{ClF}_3$ , consists of a chlorine atom and three fluorine atoms. In the Lewis structure, each fluorine is joined by a single bond to the chlorine, which has two unshared pairs of electrons. Each fluorine atom has three unshared pairs. Being a particle with no net charge and having all electrons in pairs,  $\text{ClF}_3$  is classified as a molecule. Like other period 3 elements with d orbitals available for bonding, chlorine is capable of exceeding an octet in certain instances. The Lewis structure of  $\text{ClF}_3$  is drawn as:



**GO TO QUESTION 6 →**

**6. Why does this structure make sense?**

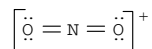
7. Dinitrogen,  $\text{N}_2$ , commonly called just “nitrogen,” consists of two nitrogen atoms. In the Lewis structure, the two nitrogen atoms are held together by a triple bond. Each nitrogen atom has one unshared pair of electrons. Being a particle with no net charge and having all electrons in pairs,  $\text{N}_2$  is classified as a molecule. The triple bond in  $\text{N}_2$  is signified by three parallel lines. The Lewis structure of  $\text{N}_2$  is drawn as:



**GO TO QUESTION 7 →**

**7. Why does this structure make sense?**

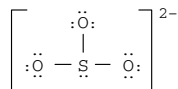
8. The nitrogen dioxide ion,  $\text{NO}_2^+$ , contains a nitrogen atom and two oxygen atoms. In the Lewis structure, each oxygen is joined to the central nitrogen by a double bond. Both oxygen atoms have two unshared pairs of electrons. Being a particle with a net charge of 1+,  $\text{NO}_2^+$  is classified as a polyatomic cation and the 1+ charge (or simply “+”) is written to the upper right side of brackets drawn around the structure. This is one of the few polyatomic cations encountered in chemistry and should not be confused with a similar formula,  $\text{NO}_2^-$ , which is an anion called nitrite. The Lewis structure of  $\text{NO}_2^+$  is drawn as:



**GO TO QUESTION 8 →**

**8. Why does this structure make sense?**

9. Sulfite ion,  $\text{SO}_3^{2-}$ , consists of one sulfur atom and three oxygen atoms. In the Lewis structure, the central sulfur is bonded to three oxygen atoms by single bonds. The sulfur atom has one unshared pair of electrons and each oxygen atom has three unshared pairs. Being a particle with a net charge of  $2-$ ,  $\text{SO}_3^{2-}$  is classified as a polyatomic anion and the  $2-$  charge is written to the upper right side of brackets drawn around the structure. Sulfur and oxygen combine to form several different compounds and polyatomic ions including  $\text{SO}_2$ ,  $\text{SO}_3$ ,  $\text{SO}_3^{2-}$ ,  $\text{SO}_4^{2-}$ , and  $\text{S}_2\text{O}_3^{2-}$ . The Lewis structure of  $\text{SO}_3^{2-}$  is drawn as:



**GO TO QUESTION 9 →**

**9. Why does this structure make sense?**

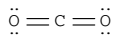
10. Hydrogen hypoiodite, HOI, contains a hydrogen atom, an oxygen atom, and an iodine atom. In the Lewis structure, the atoms are held together by single bonds, in the order of hydrogen, oxygen, and then iodine. The oxygen has two unshared pairs of electrons while the iodine has three. Being a particle with no net charge and having all electrons in pairs, HOI is classified as a molecule. The oxygen and iodine obey the octet rule with eight electrons, but hydrogen always observes the rule with only two. The Lewis structure of HOI is drawn as:



**GO TO QUESTION 10 →**

**10. Why does this structure make sense?**

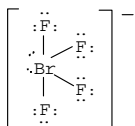
11. Carbon dioxide,  $\text{CO}_2$ , is made of one carbon and two oxygen atoms. In the Lewis structure, the central carbon is bonded to two oxygen atoms by a double bond to each. The oxygen atoms each have two unshared pairs of electrons. Being a particle with no net charge and having all electrons in pairs,  $\text{CO}_2$  is classified as a molecule. Sulfur and selenium, elements in group 6A, the oxygen family, also bond with carbon in a similar fashion to form  $\text{CS}_2$  and  $\text{CSe}_2$ , respectively. The Lewis structure of  $\text{CO}_2$  is drawn as:



**GO TO QUESTION 11 →**

**11. Why does this structure make sense?**

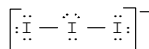
12. The bromine tetrafluoride ion,  $\text{BrF}_4^-$ , contains a bromine atom and four fluorine atoms. In the Lewis structure, the central bromine, with two unshared pairs of electrons, has a single bond to each fluorine, each of which has three unshared pairs of electrons. Being a particle with a net charge of  $1-$ ,  $\text{BrF}_4^-$  is classified as a polyatomic anion and the  $1-$  charge is written to the upper right side of brackets drawn around the structure. Having four bonds and two unshared pairs of electrons in this ion, the large bromine atom exceeds an octet. The Lewis structure of  $\text{BrF}_4^-$  is drawn as:



**GO TO QUESTION 12 →**

**12. Why does this structure make sense?**

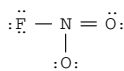
13. The triiodide ion,  $I_3^-$ , consists of three iodine atoms. In the Lewis structure, the three atoms are arranged in a row, with single bonds connecting them and three unshared pairs of electrons on each. Being a particle with a net charge of  $1-$ ,  $I_3^-$  is classified as a polyatomic anion and the  $1-$  charge is written to the upper right side of brackets drawn around the structure. Like other large period 5 elements with  $d$  orbitals available for bonding, iodine is capable of exceeding an octet. The Lewis structure of  $I_3^-$  is drawn as:



**GO TO QUESTION 13 →**

**13. Why does this structure make sense?**

14. Nitryl fluoride,  $NO_2F$ , contains one fluorine atom, one nitrogen atom, and two oxygen atoms. In the Lewis structure, the central nitrogen is bonded to the fluorine with a single bond, to one oxygen with a single bond, and to the other oxygen with a double bond. The fluorine has three unshared pairs of electrons. The singly-bonded oxygen also has three unshared pairs, and the doubly-bonded oxygen has two unshared pairs. Being a particle with no net charge and having all electrons in pairs,  $NO_2F$  is classified as a molecule. Chlorine, like fluorine of group 7A, forms a similar molecule with nitrogen and oxygen,  $NO_2Cl$ . The Lewis structure of  $NO_2F$  is drawn as:



**GO TO QUESTION 14 →**

**14. Why does this structure make sense?**

15. Nitrogen monoxide,  $NO$ , contains one nitrogen atom and one oxygen atom. In the Lewis structure of  $NO$ , also known as "nitric oxide," the two atoms are connected by a double bond. The oxygen atom has two unshared pairs of electrons and the nitrogen atom has one unshared pair in addition to *one single electron*. Being a particle with no net charge and having an *odd* number of electrons,  $NO$  is classified as a *radical*. Having a single unshared electron is unusual, but this occurs in a small number of structures. The Lewis structure of  $NO$  is drawn as:



**GO TO QUESTION 15 →**

**15. Why does this structure make sense?**

## Appendix XI: Text T–Rereading Treatment

*Note.* BROWN, THEODORE E.; LEMAY, H. EUGENE; BURSTEN, BRUCE E.; BURDGE, JULIA R., CHEMISTRY: THE CENTRAL SCIENCE, 9TH EDITION, © 2003. Reprinted by permission of Pearson Education, Inc., Upper Saddle River, NJ.

### YOUR INSTRUCTIONS:

Read the material TWICE.

(Read everything once, then re-read everything OR read each paragraph twice before going on to the next.)

#### DRAWING LEWIS STRUCTURES

Lewis structures can help us understand the bonding in many compounds and are frequently used when discussing the properties of molecules. Drawing Lewis structures is an important skill that you should practice. To do so, you should follow a regular procedure. First we'll outline the procedure, and then we'll go through several examples.

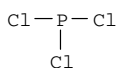
1. *Sum the valence electrons from all atoms.* Use the periodic table as necessary to help you determine the number of valence electrons in each atom. For an anion, add an electron for each negative charge. For a cation, subtract an electron for each positive charge. Don't worry about keeping track of which electrons come from which atoms. Only the total number is important.
2. *Write the symbols for the atoms to show which atoms are attached to which, and connect them with a single bond* (a dash, representing two electrons). Chemical formulas are often written in the order in which the atoms are connected in the molecule or ion, as in HCN. When a central atom has a group of other atoms bonded to it, the central atom is usually written first, as in  $\text{CO}_3^{2-}$  and  $\text{SF}_4$ . It also helps to remember that the central atom is generally less electronegative than the atoms surrounding it. In other cases, you may need more information before you can draw the Lewis structure.
3. *Complete the octets of the atoms bonded to the central atom.* Remember, however, that hydrogen can have only two electrons. (NOTE: An important guideline to follow in drawing Lewis structures is called the *octet rule* which states that atoms tend to gain, lose, or share electrons until they are surrounded by eight valence electrons.)
4. *Place any leftover electrons on the central atom, even if doing so results in more than an octet.*
5. *If there are not enough electrons to give the central atom an octet, try multiple bonds.* Use one or more of the unshared pairs of electrons on the atoms bonded to the central atom to form double or triple bonds.

#### SAMPLE EXERCISE 1

*Draw the Lewis structure for phosphorus trichloride,  $\text{PCl}_3$ .*

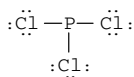
**Solution** First, we sum the valence electrons. Phosphorus (group 5A) has five valence electrons, and each chlorine (group 7A) has seven. The total number of valence-shell electrons is therefore:  $5 + (3 \times 7) = 26$ .

*Second,* we arrange the atoms to show which atom is connected to which, and we draw a single bond between them. There are various ways the atoms might be arranged. In binary (two-element) compounds, on the other hand, the first element listed in the chemical formula is generally surrounded by the remaining atoms. Thus, we begin with a skeleton structure that shows single bonds between phosphorus and each chlorine:

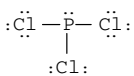


(It is not crucial to place the atoms in exactly this arrangement.)

*Third,* complete the octets on the atoms bonded to the central atom. Placing octets around each Cl atom accounts for 24 electrons.



*Fourth,* place the remaining two electrons on the central atom, completing the octet around that atom as well.



This structure gives each atom an octet, so we stop at this point. Remember that in achieving an octet, the bonding electrons are counted for both atoms.

#### SAMPLE EXERCISE 2

*Draw the Lewis structure for HCN.*

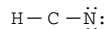
**Solution** Hydrogen has one valence-shell electron, carbon (group 4A) has four, and nitrogen (group 5A) has five. The total number of valence-shell electrons is therefore  $1 + 4 + 5 = 10$ . Again, there are various ways we might choose to arrange the atoms.



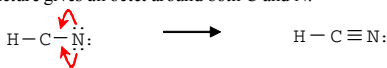
Because hydrogen can accommodate only one electron pair, it always has only one single bond associated with it in any compound. C—H—N, therefore, is an impossible arrangement. The remaining two possibilities are H—C—N and H—N—C. The first is the arrangement found experimentally. You might have guessed this to be the atomic arrangement because the formula is written with the atoms in this order. Thus we begin with a skeleton structure that shows single bonds between hydrogen, carbon, and nitrogen:



These two bonds account for four electrons. If we then place the remaining six electrons around N to give it an octet, we do not achieve an octet on C:



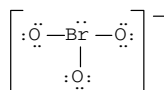
We therefore try a double bond between C and N, using an unshared pair of electrons that we had placed on N. Again, there are fewer than eight electrons on C, so we try a triple bond. This structure gives an octet around both C and N:



### SAMPLE EXERCISE 3

Draw the Lewis structure for the  $\text{BrO}_3^-$  ion.

**Solution** Bromine (group 7A) has seven valence electrons, and oxygen (group 6A) has six. An extra electron is added to account for the ion having a 1- charge. The total number of valence-shell electrons is therefore  $7 + (3 \times 6) + 1 = 26$ . After putting in the single bonds and distributing the unshared electron pairs, we have



For oxyanions— $\text{BrO}_3^-$ ,  $\text{SO}_4^{2-}$ ,  $\text{NO}_3^-$ ,  $\text{CO}_3^{2-}$ , and so forth—the oxygen atoms surround the central nonmetal atoms. Notice here and elsewhere that the Lewis structures of ions are written in brackets with the charge shown outside the bracket at the upper right.

### EXCEPTIONS TO THE OCTET RULE

The octet rule is so simple and useful in introducing the basic concepts of bonding that you might assume that it is always obeyed. It is limited in dealing with ionic compounds of the transition metals. The octet rule also fails in many situations involving covalent bonding. These exceptions to the octet rule are of several main types, including:

1. Molecules with an odd number of electrons
2. Molecules in which an atom has more than an octet

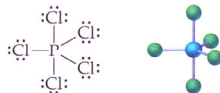
#### Odd Number of Electrons

In the vast majority of molecules, the number of electrons is even, and complete pairing of electrons occurs. In a few molecules, such as  $\text{ClO}_2$ ,  $\text{NO}$ , and  $\text{NO}_2$ , however, the number of electrons is odd. Complete pairing of these electrons is impossible, and an octet around each atom cannot be achieved. For example,  $\text{NO}$  contains  $5 + 6 = 11$  valence electrons.



#### More than an Octet

The largest class of exceptions consists of molecules or ions in which there are more than eight electrons in the valence shell of an atom. When we draw the Lewis structure for  $\text{PCl}_5$ , for example, we are forced to “expand” the valence shell and place 10 electrons around the central phosphorus atom.



Other examples of molecules and ions with “expanded” valence shells are  $\text{SF}_6$ ,  $\text{AsF}_6^-$ , and  $\text{ICl}_4^-$ . The corresponding molecules with a second-period atom, such as  $\text{NCl}_5$  and  $\text{OF}_6$ , do *not* exist. Let’s take a look at why expanded valence shells are observed only for elements in period 3 and beyond in the periodic table.

Elements of the second period have only the 2s and 2p valence orbitals available for bonding. Because these orbitals can hold a maximum of eight electrons, we never find more than an octet of electrons around elements from the second period. Elements from the third period and beyond, however, have *ns*, *np* and unfilled *nd* orbitals that can be used in bonding. For example, the orbital diagram for the valence shell of a phosphorus atom is as follows:



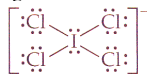
Although third-period elements such as phosphorus often satisfy the octet rule, as in  $\text{PCl}_3$ , they also often exceed an octet by seeming to use their empty *d* orbitals to accommodate additional electrons.

Size also plays an important role in determining whether an atom can accommodate more than eight electrons. The larger the central atom, the larger the number of atoms that can surround it. The occurrences of expanded valence shells therefore increase with increasing size of the central atom. The size of the surrounding atoms is also important. Expanded valence shells occur most often when the central atom is bonded to the smallest and most electronegative atoms, such as F, Cl, and O.

#### **SAMPLE EXERCISE 4**

*Draw the Lewis structure for  $\text{ICl}_4^-$ .*

**Solution** Iodine (group 7A) has 7 valence electrons; each chlorine (group 7A) also has 7; an extra electron is added to account for the 1- charge of the ion. Therefore, the total number of valence electrons is  $7 + 4(7) + 1 = 36$ . The I atom is the central atom in the ion. Putting 8 electrons around each Cl atom (including a pair of electrons between I and each Cl to represent the single bonds between these atoms) requires  $8 \times 4 = 32$  electrons. We are thus left with  $36 - 32 = 4$  electrons to be placed on the larger iodine:



Iodine has 12 electrons around it, exceeding the common octet of electrons.

## Appendix XII: Text T–Elaborative Interrogation Treatment

*Note.* BROWN, THEODORE E.; LEMAY, H. EUGENE; BURSTEN, BRUCE E.; BURDGE, JULIA R., CHEMISTRY: THE CENTRAL SCIENCE, 9TH EDITION, © 2003. Reprinted by permission of Pearson Education, Inc., Upper Saddle River, NJ.

### YOUR INSTRUCTIONS:

Read each paragraph ONCE. Answer the questions in the right margin when directed.

Each question refers to the previous underlined sentence. (Continue answers on back if necessary.)

<u>DRAWING LEWIS STRUCTURES</u>	
<p>Lewis structures can help us understand the bonding in many compounds and are frequently used when discussing the properties of molecules. Drawing Lewis structures is an important skill that you should practice. To do so, you should follow a regular procedure. First we'll outline the procedure, and then we'll go through several examples.</p>	<b>1. Why does this make sense?</b>
<p>1. <u>Sum the valence electrons from all atoms.</u> Use the <u>periodic table as necessary</u> to help you determine the number of valence electrons in each atom. <b>GO TO QUESTION 1 →</b> For an anion, add an electron for each negative charge. For a cation, subtract an electron for each positive charge. Don't worry about keeping track of which electrons come from which atoms. Only the total number is important.</p>	
<p>2. <u>Write the symbols for the atoms to show which atoms are attached to which, and connect them with a single bond</u> (a dash, representing two electrons). <b>GO TO QUESTION 2 →</b> Chemical formulas are often written in the order in which the atoms are connected in the molecule or ion, as in HCN. When a central atom has a group of other atoms bonded to it, the central atom is usually written first, as in <math>\text{CO}_3^{2-}</math> and <math>\text{SF}_4</math>. It also helps to remember that the central atom is generally less electronegative than the atoms surrounding it. In other cases, you may need more information before you can draw the Lewis structure.</p>	<b>2. Why does this make sense?</b>
<p>3. <u>Complete the octets of the atoms bonded to the central atom.</u> Remember, however, that <u>hydrogen can have only two electrons.</u> <b>GO TO QUESTION 3 →</b> (NOTE: An important guideline to follow in drawing Lewis structures is called the <i>octet rule</i> which states that atoms tend to gain, lose, or share electrons until they are surrounded by eight valence electrons.)</p>	
<p>4. <u>Place any leftover electrons on the central atom, even if doing so results in more than an octet.</u></p>	<b>3. Why does this make sense?</b>
<p>5. <u>If there are not enough electrons to give the central atom an octet, try multiple bonds.</u> Use one or more of the unshared pairs of electrons on the atoms bonded to the central atom to form double or triple bonds.</p>	

<p><b>SAMPLE EXERCISE 1</b> <i>Draw the Lewis structure for phosphorus trichloride, <math>\text{PCl}_3</math>.</i></p>	<b>4. Why does this make sense?</b>
<p><b>Solution</b> <i>First,</i> we sum the valence electrons. Phosphorus (group 5A) has five valence electrons, and each chlorine (group 7A) has seven. <b>GO TO QUESTION 4 →</b> The total number of valence-shell electrons is therefore: <math>5 + (3 \times 7) = 26</math>.</p>	
<p><i>Second,</i> we arrange the atoms to show which atom is connected to which, and we draw a single bond between them. <b>GO TO QUESTION 5 →</b> There are various ways the atoms might be arranged. In binary (two-element) compounds, on the other hand, the first element listed in the chemical formula is generally surrounded by the remaining atoms. Thus, we begin with a skeleton structure that shows single bonds between phosphorus and each chlorine</p>	
$\begin{array}{c} \text{Cl} - \text{P} - \text{Cl} \\   \\ \text{Cl} \end{array}$	<b>5. Why does this make sense?</b>
<p>(It is not crucial to place the atoms in exactly this arrangement.)</p>	
<p><i>Third,</i> complete the octets on the atoms bonded to the central atom. Placing octets around each Cl atom accounts for 24 electrons.</p>	
$\begin{array}{c} :\ddot{\text{Cl}} - \text{P} - \ddot{\text{Cl}}: \\   \\ :\ddot{\text{Cl}}: \end{array}$	
<p><i>Fourth,</i> place the remaining two electrons on the central atom, completing the octet around that atom as well.</p>	<b>6. Why does this make sense?</b>
$\begin{array}{c} :\ddot{\text{Cl}} - \ddot{\text{P}} - \ddot{\text{Cl}}: \\   \\ :\ddot{\text{Cl}}: \end{array}$	
<p>This structure gives each atom an octet, so we stop at this point. Remember that in achieving an octet, the bonding electrons are counted for both atoms. <b>GO TO QUESTION 6 →</b></p>	

### SAMPLE EXERCISE 2

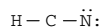
Draw the Lewis structure for HCN.

**Solution** Hydrogen has one valence-shell electron, carbon (group 4A) has four, and nitrogen (group 5A) has five. The total number of valence-shell electrons is therefore  $1 + 4 + 5 = 10$ . Again, there are various ways we might choose to arrange the atoms.

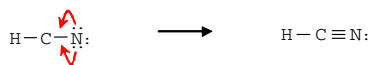
Because hydrogen can accommodate only one electron pair, it always has only one single bond associated with it in any compound. **GO TO QUESTION 7** → C—H—N, therefore, is an impossible arrangement. The remaining two possibilities are H—C—N and H—N—C. The first is the arrangement found experimentally. You might have guessed this to be the atomic arrangement because the formula is written with the atoms in this order. Thus we begin with a skeleton structure that shows single bonds between hydrogen, carbon, and nitrogen:



These two bonds account for four electrons. If we then place the remaining six electrons around N to give it an octet, we do not achieve an octet on C:



We therefore try a double bond between C and N, using an unshared pair of electrons that we had placed on N. Again, there are fewer than eight electrons on C, so we try a triple bond. This structure gives an octet around both C and N:



7. **Why does this make sense?**

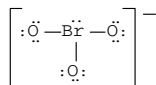
8. **Why does this make sense?**

### SAMPLE EXERCISE 3

Draw the Lewis structure for the  $\text{BrO}_3^-$  ion.

**Solution** Bromine (group 7A) has seven valence electrons, and oxygen (group 6A) has six. An extra electron is added to account for the ion having a 1- charge. **GO TO QUESTION 8** → The total number

of valence-shell electrons is therefore  $7 + (3 \times 6) + 1 = 26$ . After putting in the single bonds and distributing the unshared electron pairs, we have



For oxyanions— $\text{BrO}_3^-$ ,  $\text{SO}_4^{2-}$ ,  $\text{NO}_3^-$ ,  $\text{CO}_3^{2-}$ , and so forth—the oxygen atoms surround the central nonmetal atoms. Notice here and elsewhere that the Lewis structures of ions are written in brackets with the charge shown outside the bracket at the upper right. **GO TO QUESTION 9** →

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1. Molecules with an odd number of electrons
2. Molecules in which an atom has more than an octet

#### Odd Number of Electrons

In the vast majority of molecules, the number of electrons is even, and complete pairing of electrons occurs. In a few molecules, such as  $\text{ClO}_2$ ,  $\text{NO}$ , and  $\text{NO}_2$ , however, the number of electrons is odd. Complete pairing of these electrons is impossible, and an octet around each atom cannot be achieved.

**GO TO QUESTION 10** → For example,  $\text{NO}$  contains  $5 + 6 = 11$  valence electrons.

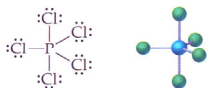


9. **Why does this make sense?**

10. **Why does this make sense?**

### More than an Octet

The largest class of exceptions consists of molecules or ions in which there are more than eight electrons in the valence shell of an atom. When we draw the Lewis structure for  $\text{PCl}_5$ , for example, we are forced to "expand" the valence shell and place 10 electrons around the central phosphorus atom.



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Elements of the second period have only the 2s and 2p valence orbitals available for bonding. **GO TO**

**QUESTION 11** → Because these orbitals can hold a maximum of eight electrons, we never find more than an octet of electrons around elements from the second period. Elements from the third period and beyond, however, have *ns*, *np* and unfilled *nd* orbitals that can be used in bonding. For example, the orbital diagram for the valence shell of a phosphorus atom is as follows:



Although third-period elements such as phosphorus often satisfy the octet rule, as in  $\text{PCl}_3$ , they also often exceed an octet by seeming to use their empty *d* orbitals to accommodate additional electrons. **GO TO**

**QUESTION 12** →

11. Why does this make sense?

12. Why does this make sense?

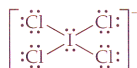
Size also plays an important role in determining whether an atom can accommodate more than eight electrons. The larger the central atom, the larger the number of atoms that can surround it. **GO TO**

**QUESTION 13** → The occurrences of expanded valence shells therefore increase with increasing size of the central atom. The size of the surrounding atoms is also important. Expanded valence shells occur most often when the central atom is bonded to the smallest and most electronegative atoms, such as F, Cl, and O. **GO TO QUESTION 14** →

### SAMPLE EXERCISE 4

Draw the Lewis structure for  $\text{ICl}_4^-$ .

**Solution** Iodine (group 7A) has 7 valence electrons; each chlorine (group 7A) also has 7; an extra electron is added to account for the 1- charge of the ion. Therefore, the total number of valence electrons is  $7 + 4(7) + 1 = 36$ . The I atom is the central atom in the ion. Putting 8 electrons around each Cl atom (including a pair of electrons between I and each Cl to represent the single bonds between these atoms) requires  $8 \times 4 = 32$  electrons. We are thus left with  $36 - 32 = 4$  electrons to be placed on the larger iodine:



Iodine has 12 electrons around it, exceeding the common octet of electrons. **GO TO QUESTION 15** →

13. Why does this make sense?

14. Why does this make sense?

15. Why does this make sense?

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