The Effect of Guided Inquiry on Student Misconceptions in Chemistry

by

Leslie D. McSparrin

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Leslie D. McSparrin

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Signature: Leslie D. McSparrin 7/22/05

Leslie D. McSparrin, Student — Date

Approvals: Stacey Lowery Bretz 7/22/05

Dr. Stacey Lowery Bretz, Thesis Advisor — Date

7/22/05

Dr. Allen Hunter, Committee Member — Date

Sherri Lovelace-Cameron 7/22/05

Dr. Sherri Lovelace-Cameron, Committee Member — Date

7/26/05

Dr. Peter J. Kasvinsky, Dean of Graduate Studies — Date

ABSTRACT

The research in this study was designed to answer the research question: *Does teaching chemistry by the method of guided inquiry correct student misconceptions?* Two chemistry concepts were the focus of the study. One concept studied was the production of light by atomic emissions (including characteristic properties of both waves and light). The other concept studied was acid/base theory. A two-tiered multiple-choice pretest was administered to participants before the start of each unit. Following each unit, the same two-tiered multiple-choice test was administered as a posttest. Sixty-four students from a semi-rural high school in Northwestern Pennsylvania participated in the study across three levels of chemistry: Advanced Placement Chemistry, Chemistry I, and Conceptual Chemistry. The mean score increased in the positive direction for participants in all three levels of chemistry by the time of the posttests. In addition, many students provided answers with written responses that indicated that certain previously documented misconceptions had been corrected. Also, most of the participants were able to successfully apply the scientific method to complete culminating authentic assessments during the study. These conclusions are substantiated by both quantitative statistical data and qualitative written response and interview data. Students in Chemistry I experienced the most substantial gains among the participants. The students in this study reported that they had gained more understanding from guided inquiry activities and preferred this form of science instruction in chemistry.

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Chapter 1:

Introduction and Statement of the Problem

Introduction:

The launch of the Sputnik rocket in the 1950s shook our nation to a realization that a revolution in math and science instruction was necessary. Almost 50 years later, American educators are once again shaken to realize that because students pale in comparison to peer students in other countries in basic algebra and physical science skills, another revolution is needed. In 1994, Boston College launched an international study of student skills in mathematics and science, called the Third International Mathematics and Science Study (TIMSS)[1] as a meaningful measurement of educational systems worldwide. A schematic of the conceptual framework of content-related educational experiences that were used for the design of measures and analyses for the TIMSS can be seen in Figure 1[2]. According to the TIMSS, U.S. children in fourth grade ranked very high in comparison to the other 50 nations that took part in the study. However, these same U.S. students slipped to average level achievement by eighth grade, and slumped to the lowest achievement by 12th grade! "The most 'startling finding' in the TIMSS study…is that those U.S. students who are considered to be the best and brightest in science – the top 2 or 3 percent – also sink to the bottom"[1]. It was also found that U.S. students had marked weaknesses in reasoning and problem solving. In addition, U.S. students were the poorest of all countries when asked to find rules for or generalize about a natural phenomenon[3]. Even though U.S. students scored better than the cross-nation mean, mean student scaled scores were significantly higher for students in other

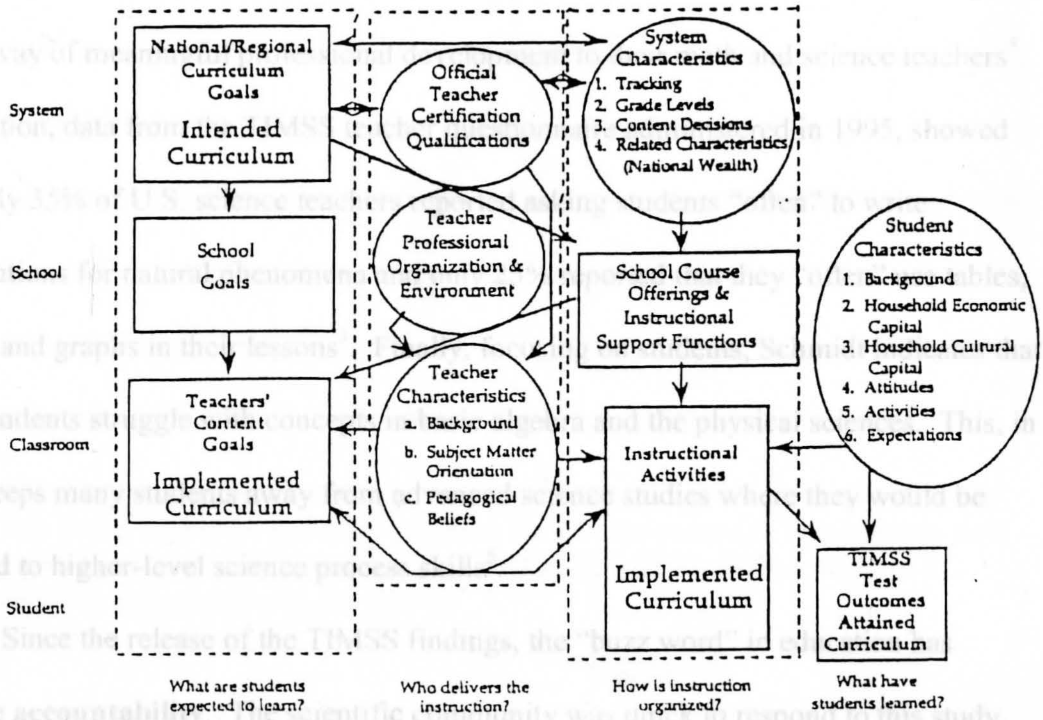


Figure 1: TIMMS Conceptual Framework[2]

countries. Encouragingly, however, there were only four to seven other countries that scored significantly higher than the U.S. across earth science, chemistry, and physics[4]. William Schmidt[5], a professor at Michigan State University, attributes this decline in math and science performance to three factors: curriculum, teachers, and students. Focusing on curriculum, Schmidt points out that science teachers spend much of their valuable class time each year revisiting topics already covered in previous years. Student retention of ideas seems to be very low from one year to the next. In addition to low retention of knowledge, most U.S. teens complete their two or three years of science requirements by taking only life and earth sciences, never seeing topics in chemistry and physics. Focusing on teachers, Schmidt indicates poor pre-service teacher training in the

physical sciences is a problem. He is quick to point out that most schools offer very little in the way of meaningful professional development to their math and science teachers[5]. In addition, data from the TIMSS teacher questionnaire administered in 1995, showed that only 35% of U.S. science teachers reported asking students "often" to write explanations for natural phenomena and only 25% reported that they "often" use tables, charts, and graphs in their lessons[3]. Finally, focusing on students, Schmidt indicates that most students struggle with concepts in basic algebra and the physical sciences. This, in turn, keeps many students away from advanced science studies where they would be exposed to higher-level science process skills[5].

Since the release of the TIMSS findings, the "buzz word" in education has become **accountability**. The scientific community was quick to respond to this study, producing a set of comprehensive national science guidelines in 1996 by the National Research Council known as the *National Science Education Standards (NSES)*[6]. The *NSES* clearly define to the scientific community what all K-12 students should know, understand, and be able to do in all aspects of science. In addition to the *NSES*, the *No Child Left Behind Act of 2001*[7] further assures that schools are operating to improve student achievement. In *NCLB*, two important tenets of educational reform exist: accountability for results, and an emphasis on doing what works based on scientific research. This act also seeks to improve teaching and learning by providing better information to teachers and principals, to ensure that teacher quality is a high priority, and to place more accountability on state and local agencies[7]. This, in turn, has led to both state and local standards for science and technology being developed nationwide. Analysis of many of these state and local standards, as well as the *NSES*, reveals that the emphasis in the classroom should be in developing inquiry skills among students to improve understanding of scientific concepts. More specifically, the new national curriculum calls for "inquiry as content"[6].

So, why do students score poorly on the science portion of the TIMSS and turn away from studies in the physical sciences? Sheila Tobias[8] addresses this question thoroughly in her book titled: *They're Not Dumb, They're Different: Stalking the Second Tier*. One student, "Michele", was quoted in Tobias' book as being alienated by:

> Too little time allotted to simply reading the text. This reinforces the message that doing problems is all that is called for. A course design that assumes that everyone in the class has already decided to be a physicist and wants to be *trained*, not *educated* in the subject.
>
> "Michele"[8]

Another student in Tobias' study, "Eric," indicated that science courses appear difficult to students because they are difficult to get a good grade in, time consuming and/or boring, dull, and simply not fun[8]. Tobias seemed to sum up the feelings of her "second tier" students by saying in her final speculations:

> They hungered – all of them – for information about *how* the various methods they were learning had come to be, *why* physicists and chemists understand nature the way they do, and *what* were the *connections* between what they were learning and the larger world.

Instead, the students in Tobias' study were exposed to the "tyranny of technique" – the drill of problem solving through algorithms and obtaining the <u>one</u> correct answer[8].

One response to Tobias' work has been to ask what is wrong with the "tyranny of technique"? Generations of students have been taught this way and succeeded in the physical sciences. A classic study by Nurrenbern and Pickering[9] demonstrated an important point in regard to this question. According to the authors of this study, "chemistry teachers have assumed implicitly that being able to solve problems is equivalent to understanding of molecular concepts." Their study, carried out with a heterogeneous group of college students, showed that about two-thirds of the students in the study did not understand one of the fundamental properties of gases – i.e.,that the gas occupies the entire volume of the container[9]. Sawrey[10] further demonstrated that even the best problem solvers had poor performance on conceptual questions in chemistry. Sawrey proposed that this phenomenon is a consequence of the "problem-solving campaign" or the "tyranny of technique" referred to by Tobias. Pickering[11], in a later study, supported Sawrey's ideas by arguing that students' difficulties with conceptual questions seem to revolve around the lack of exposure to conceptual type questions. He also proposed that an instructor/teacher could teach students to solve conceptual problems. Nakhleh and Mitchell[12] sum up these ideas well in their conclusion by stating:

> It does not seem that presenting an algorithm and demonstrating the myriad of problems that can be solved using that algorithm facilitate understanding of the underlying concept. Our teaching, therefore, must take on a much more concept-based framework…our current methods of teaching chemistry are, perhaps not teaching chemistry, but teaching how to get answers to algorithmic problems.

The Research Question:

As pointed out earlier, Schmidt[5] reported that a low percentage of teachers ask students to observe and write explanations for natural phenomena and to interpret tables, charts, and graphs. In response to this, the *NSES*[6], as well as state and local standards, are moving teachers away from didactic methods of teaching and more toward having students make observations of natural phenomena and reflecting on their observations. In addition, Sawrey[10] supposed that the poor conceptual understanding of chemical concepts held by students is a direct result of teaching chemistry to students by solving a myriad of practice problems and exposing them to the "tyranny of technique" referred to by Tobias. Nakhleh[12] further indicated that there simply needs to be a revolution in the method of teaching chemistry and developing a more concept-based framework for students.

A possible avenue for making this change is for the teacher to use guided inquiry as a teaching tool. Therefore, guided inquiry was the focus of this research as it affects students' conceptual understanding of chemistry. The short term and long term effects on student misconceptions as a result of teaching chemistry through guided inquiry were examined. The content focus was primarily on two units: production of light by atomic emissions (including characteristic properties of both waves and light) and acid/base chemistry. The research question that was examined in this study was: ***Does teaching chemistry by the method of guided inquiry correct student misconceptions?***

Chapter 2:

Literature Review

Misconceptions

As Nakhleh and Mitchell indicated[12], students must have an understanding of the underlying concept in order to solve a chemistry problem effectively. Difficulties often arise in this process when students' ideas about science are not congruent with the accepted ideas of the scientific community. These ideas that do not agree with the accepted theories are known as *student misconceptions* or *alternative conceptions*[13] as opposed to incorrect or invalid theories. A third term, with fewer implications in learning a chemical concept, is the *alternative framework*. Unlike a misconception, the alternative framework describes a mental construct created by the student to serve as an alternative to a scientific concept to clarify concepts or rationalize discrepancies[13]. Novak[14] prefers the use of the term alternate conceptions. He clearly outlines his rationale for using this term by saying, "Not only does it refer to experience-based explanations constructed by a learner to make a range of natural phenomena and objects intelligible, but also it confers intellectual respect on the learner who holds those ideas – because it implies that alternative conceptions are contextually valid and rational and can lead to even more fruitful conceptions."[14] Driver and Easley[15] developed a theme for classifying alternative conception studies into two groups. In one group, the nomothetic studies, student knowledge is assessed by its conformity to (or deviation from) accepted scientific knowledge. The data from these studies tend to be more quantitative. In the other group, the idiographic studies, the students' conceptual understanding of chemistry is probed and analyzed at a personal level. The qualitative methodology of these studies incorporates interviews that result in rich data[14].

Several "emergent knowledge claims"[16] (a collective term to describe the knowledge born out of several research projects) have been identified in regard to students' alternative conceptions. These claims[14] include:

Claim 1: Learners come to formal science instruction with a diverse set of alternative conceptions concerning natural objects and events.
Claim 2: The alternative conceptions that learners bring to formal science instruction cut across age, ability, gender, and cultural boundaries.
Claim 3: Alternative conceptions are tenacious and resistant to extinction by conventional teaching strategies.
Claim 4: Alternative conceptions often parallel explanations of natural phenomena offered by previous generations of scientists and philosophers.
Claim 5: Alternative conceptions have their origins in a diverse set of personal experiences including direct observation and perception, per culture and language, as well as in teachers' explanations and instructional materials.
Claim 6: Teachers often subscribe to the same alternative conceptions as their students.
Claim 7: Learners' prior knowledge interacts with knowledge presented in formal instruction, resulting in a diverse set of unintended learning outcomes.
Claim 8: Instructional approaches that facilitate conceptual change can be effective classroom tools.

The above list applies to all misconceptions; however, in this study misconceptions about light and acid/base theory were studied in detail.

Misconceptions about Light:

Rosalind Driver[17] points out that students are not given any formal definition for light other than it is "a form of energy." Therefore, students are left to construct their own understanding of what light is and what are its properties[18]. Rather than accurately describing light, students often describe the source (light bulb) or state (brightness). Even if children have a notion of light as an entity, they often do not think of light as a traveling entity. In addition, the majority of surveyed students in a study by Watts[18] could not accurately explain why red light is seen coming from a red projector slide. Anderson and Smith[19] found that 72 percent of students sampled did not think of white light as a mixture of colors. Some other common misconceptions about light and the postulates of the quantum theory have been identified for students studying waves, light, and atomic emissions. Although this is not an exhaustive list, these should be considered in the process of planning for activities to address the misconceptions about light.[20]

1.) Waves transport matter.
2.) Waves do not have energy.
3.) Big waves travel faster than small waves in the same medium.
4.) Different colors of light are different types of waves.
5.) Light is just a particle or a mixture of particles and waves.
6.) Light waves and radio waves are not the same thing.
7.) There is not interaction between light and matter.
8.) Particles cannot have wave properties.
9.) All photons have the same energy.
10.) Gamma rays, X-rays, ultraviolet light, visible light, infrared light, microwaves, and radio waves are all very different entities.
11.) When waves or pulses interfere, they bounce off each other and go in opposite directions.
12.) When a wave moves, particles move along with the wave.

Misconceptions of Acids and Bases:

Malcolm Carr[21] points out that students will develop their ideas about acids and bases from experiences in the laboratory, in the classroom, and in textbooks. Unfortunately, students often form alternative conceptions by confusing key phrases and ideas associated with several models and theories (such as Lewis and Bronsted-Lowry models). Hand and Treagust[22] identified five key misconceptions about acids and bases:

1. An acid is something which eats material away or which can burn you.
2. Testing for acids can only be done by trying to eat something away.
3. Neutralization is the breakdown of an acid or something changing from an acid.
4. The difference between a strong and a weak acid is that strong acids eat material away faster than a weak acid.
5. A base is something which makes up an acid.

Other research has shown that students often believe that the salts produced from a neutralization reaction are neutral and the products have a pH equal to 7.0[13]. Nakhleh[23] concludes that "students were unable to fully understand the acid-base chemistry because they tended to have weak understandings of the particulate model of matter and of how that model relates to some of chemistry's classification systems, such as molecules, atoms, and ions. Nakhleh further proposes that educators allot time for students to observe acid/base phenomena and help these students develop an understanding of these phenomena at the molecular level.

In order to understand how students construct their understanding of the natural world and how to address the misconceptions formed by students, it is necessary to examine learning theory as it relates to conceptual understanding.

Learning Theory

To address the teaching framework in chemistry to deal with student misconceptions, one must look at both learning theories and modes of presentation of the curriculum. Constructivism is one learning theory that is consistent with the teaching framework necessary to address the concerns of Nakhleh and Mitchell[12].

Constructivism

Constructivists believe that each learner constructs his/her own understanding of the world in which they live. In the process, individuals search for tools to help them understand personal experiences. Each learner makes sense of his/her world by assimilating new experiences into what has been previously learned and to which the learner has attached a concept. When a learner encounters an object, idea, relationship, or phenomenon that doesn't make sense; the learner interprets what is seen to conform to present theories, generates a new theory to better understand these discrepant events, or simply chooses to ignore the event[24]. We, as observers, are bombarded with mountains of sensory data on a daily basis. Much of our daily sensory input is ignored. However, when we can apply this sensory data to a preexisting cognitive scheme, *assimilation* of this data occurs. Information the learner already knows strongly influences this learning process. Sometimes we are unable to assimilate sensory information into preexisting cognitive schemes. This is known as *disequilibration*. Resolving the perceived discrepancy can restore equilibrium of our cognitive constructs. The modification of existing structures to assimilate discrepant events is known as *accommodation*. Together these processes of assimilation and accommodation work in tandem to maintain the state of equilibration of cognitive functions. Constructivists believe this mechanism is fundamental to the learning process[25]. In addition to assimilating and accommodating for new sensory information, learning must be meaningful. Bretz[26] makes reference to the *meaningful learning set* in her recent paper on human constructivism. She points out that, in addition to the other notions of constructivists, three important conditions must be met for meaningful learning to occur:

1.) The prior knowledge must be relevant and can be related in a non-arbitrary manner.

2.) The information must be "meaningful in and of itself."

3.) A chemistry student must make a conscious, non-arbitrary decision to incorporate the information.

The greatest challenge for the chemistry teacher, thus, becomes making the material meaningful and appealing to the student and making certain that the student's understanding of the concepts coincides with that of the teacher[26]. According to Dr. Michael Grote[27] of the Sandia National Laboratory, teachers can address this challenge by considering the following when preparing a science lesson:

1.) The teacher should seek and value the students' points of view. This helps the teacher to customize instruction to address the prior knowledge and correct any misconceptions.
2.) The curriculum should address the students' suppositions. When educators permit students to construct knowledge that challenges their current suppositions, learning occurs.
3.) The teacher should pose science problems that are of emerging relevance to the students. This does not mean that students should freely study whatever. A good problem meets the following criteria:
    a.) It demands that students make a testable prediction.
    b.) It makes use of relatively inexpensive equipment.
    c.) It is complex enough to elicit multiple problem-solving approaches.
    d.) It benefits from group collaboration.
    e.) At some point, the children view the problem as relevant to them.
4.) The lessons should be structured around the big ideas, not small bits of information. Constructivists do not say that factual knowledge is worthless; they do say concept understanding should come before learning a lot of facts and vocabulary.
5.) The teacher should assess student learning in the context of daily classroom investigations, not as separate events.

Rationale for Using Constructivism:

Science lends itself easily to the application of the theory of constructivism to instructional strategies. The greatest scientific discoveries of the ages have happened as a result of investigating, discovering, communicating, theorizing, and even sometimes by sheer serendipity. Research shows that the best way to remember a body of information is to organize it actively by looking for internal patterns and relating it to what is already known[28]. Scientists do this on a daily basis in their laboratory. Also, considerable research shows that active engagement in learning may lead to better retention, understanding, and active use of knowledge[28]. In addition, Staver[29] points out (in agreement with Grote[27]) that constructivist theory used in the instruction of science allows the teacher to deal head on with students' alternative conceptions. The teacher can deal with alternative conceptions and experience conceptual change for the students over time. That truly would be the goal -- to lure the "second tier" into the physical sciences, get a grasp of the students' conceptions and misconceptions, then use instruction to obtain a "shared meaning"[26] of concepts between both teacher and student.

Cautions for Using Constructivist Instructional Strategies:

Constructivism has enjoyed strong activism over the past decade due to persistent shortfalls in students' understanding and a lot of passive learning. Also, considerable research shows that active engagement in learning may lead to better retention, understanding, and active use of knowledge. However, complications do arise when using constructivist teaching practices. First, it is time consuming. Second, students can arrive at the wrong scientific theory. Finally, students can view it as deceptive and manipulating[28]. A teacher wishing to use constructivist teaching strategies for the first time must be conscious of these issues.

Guided Inquiry Laboratories: Is This the Constructivist's Answer to Improving Conceptual Understanding and Correcting Misconceptions?

The *National Science Education Standards*, published in 1996 by the National Research Council[6], specifically organize the expectations for a top-notch K-12 science program. They prescribe that students should spend less time memorizing facts and more time reasoning and solving problems. The standards also stipulate that science students should learn in cooperative groups, use more hands-on materials, and study fewer science topics in much more depth[1]. The aim of the *National Science Education Standards* is for students to understand the nature of science and the skills necessary for inquiry[30]. However, it has been experience in fifteen years of teaching chemistry, that the majority of chemistry laboratory manuals do not address this need. A possible solution to this dilemma (which also addresses the lack of conceptual understanding described by Nurrenbern, Pickering, and Sawrey[9-11]) is for the teacher to use the inquiry (discovery) laboratory approach.

According to Perkins[28], conceptually difficult knowledge is commonly found in mathematics and science classes. In fact, most of chemistry is conceptually difficult knowledge because much of what we discuss cannot be seen. Students usually display a mix of misunderstandings and ritual knowledge (knowledge that is routine and meaningless). Students learn the ritual responses and algorithms for solving problems, but lack the correct intuitive beliefs for the qualitative-conceptual understanding of the question. For example, a student may be able to solve equilibrium concentration problems applying the quadratic formula and the Law of Mass Action successfully. However, the student may not have a conceptual understanding of what "x" represents in the species table and how it is related to the stoichiometry of the equilibrium process. This can lead to a misunderstanding that the student may develop in thinking that the amount of product formed is always significant, even in situations of a K value less than 10^{-5}. This would, in turn, lead to difficulty for the student knowing why and how to apply a small K approximation to equilibrium problems and a lack of understanding how weak acids tend to have small K_a values.

It helps most with conceptually difficult knowledge for the teacher to introduce the qualitative concepts first before discussing the quantitative aspects of the concept. The students can be given a chance to rediscover the theory before mastering computational routines[28]. This is essentially what discovery/guided inquiry chemistry is all about. Inquiry labs do not serve to verify concepts taught in class. Instead, they serve to illustrate the scientific method. Each experience in the laboratory has elements of data gathering, data analysis, hypothesis formation, and hypothesis testing. Very little instruction occurs on the underlying theory prior to conducting the experiment. Discussion of concepts comes after the students have the direct experience with the phenomenon. It is ultimately the responsibility of the student to generalize and apply what he/she learned[31].

How are guided inquiry laboratories consistent with constructivism? Constructivists believe that all students can and will learn; however, each student learns at a different pace and with three different modalities. These three modalities are the *active learner*, the *social learner*, and the *creative learner*[28]. The active learner acquires knowledge actively through discussing, debating, hypothesizing, and investigating. The social learner constructs knowledge and understanding through group work and consultation with other students. The creative learner creates or recreates knowledge and understanding by being guided through the process of rediscovering concepts. All three roles can easily relate to one another[28]. Inquiry laboratories are consistent with these constructivist principles. The learner is actively engaged and thinking in class. The learner constructs knowledge and draws conclusions by analyzing and discussing ideas. The learner experiences how to work together and to understand concepts and solve problems. And, finally, the instructor serves as a facilitator to assist groups, not instruct them -- "the guide on the side, not the sage on the stage"[32].

Guided inquiry/discovery chemistry has been shown to have many benefits. First, it has addressed (not necessarily provides a solution to) some of the concerns that Bodner[33] listed in his 1992 article:

1.) The present curriculum, coupled with the mode of presentation that characterizes most large general chemistry courses, often leads to knowledge without understanding.
2.) The present structure of general chemistry courses produces a system of knowledge that students cannot apply to the world in which they live.
3.) The classical mode of teaching general chemistry focuses on the teacher, not the students.
4.) Learning is best facilitated when the focus is on the students who are doing the learning, not the teacher.
5.) The classic mode of instruction often consists of providing students with answers to questions they don't understand.

Second, it has been shown that all learners learn new concepts better when "concept invention" or "term introduction" is the second phase of the learning cycle[34]. Also, Farrell, Moog, and Spencer[32], demonstrated in their research that fewer students being taught according to the principles of guided inquiry earned a grade of D, F, or W (decreased from 21.9% to 9.6% when compared to traditional lecture instruction). In addition, these same students scored as high as or higher on tests than those students in a more traditional course. Finally, in a study by Allen[35] from 1983-1984, he reported that the majority of students in the study preferred to do inquiry laboratories and felt it had enhanced their understanding of chemical concepts.

What Must a Teacher Consider When Implementing Guided Inquiry Laboratories?

According to Keys[36], the individuals best suited to conduct research studies on inquiry are those who have a firm understanding of both cognitive constructivism and social perspectives. Knowledge of social perspectives is important because humans react to language and actions based on their cultural models. These cultural models then affect communication in the classroom as teachers and students interact. When teachers work with students who are attempting inquiry, they must interact with the students in a dialogic way, allowing for open thought on the part of the student. Any teacher using the guided inquiry approach must be conscious of his/her own beliefs. Teacher beliefs strongly affect curriculum. Teacher beliefs, just like those of others, are episodic, value laden, and are built on presumptions. Also, teacher beliefs about student age and the need for drill and practice can stand in the way of implementing the inquiry method. The teacher must be a learning and knowledge constructivist, seeking and recognizing prior knowledge and using a wider variety of teaching strategies. The instructor must also overcome teacher myths[36]: the transmission myth (transmitter of knowledge), the efficiency myth, the myth of rigor, and the myth of preparing students for examinations. In addition, teachers who do inquiry-based teaching must have a high level of pedagogical content knowledge, including a deep understanding of the nature of science and how students come to understand the concepts[36].

Allen[35], in his 1986 article, provided guidance as to how a teacher can convert a verification experiment to a guided inquiry laboratory. According to Allen, the teacher should select an experiment that is relatively simple to perform with uncomplicated apparatus. Presentation of principal concepts in the introductory material should be minimal. Detailed procedural steps should be reduced so that the students must devise a way to collect data. Finally, there should be reinforcement of the observed phenomena through the use of data analysis and conclusions. Also, guided inquiry activities should start out small to allow the students to experience success. Over time they should increase in both level of involvement and level of difficulty. When the students are more experienced with the concept of guided instruction, students can then be assessed on a much greater scale with a culminating assessment task.

Traditional labs serve to verify a concept after it has been taught in the laboratory. For example, after Boyle's Law of gases is taught in lecture, students often perform an experiment where they measure the volume of air as a function of how much it is compressed in a syringe by weights placed on the syringe plunger. To convert this whole scenario to guided inquiry, the teacher could begin a discussion and capture interest (before any in-class discussion of Boyle's Law) by placing a marshmallow in a bell jar and drawing a vacuum. Students would observe and record observations. The students would also be expected to write a possible explanation for what they observed.

Afterwards, students would be given a Boyle's Law syringe apparatus and would be asked to collect data about how the volume varies as a function of the weight applied to the syringe plunger. Some basic physics would be explained at this point to help the students understand that the weight is equivalent to the applied pressure since the weight ($W = mg$) is equal to the force vector and the area to which the force is being applied remains constant. The students would be asked to graph the data and use their Algebra knowledge to generalize about the relationship between the pressure and volume of air. After all groups had completed their work, a class discussion would ensue to discuss their generalizations and to form a plausible theory as a class. From these generalizations, Boyle's Law would be developed with the assistance of the teacher to help with the mathematics. The extension would then be made to generalize Boyle's Law for all "ideal" gases.

The Application of the Literature Review to this Study

As Nakhleh and Mitchell[12] point out, students experience difficulty understanding concepts in chemistry when their ideas are not congruent with the teacher and the scientific community. This leads to the cognitive formation of student misconceptions[13]. Students come to chemistry class with a diverse set of these alternate conceptions, and it has been generalized that these misconceptions are tenacious and resistant to change by conventional teaching techniques[14]. Therefore, an alternative method of instruction is necessary to confront student misconceptions. Guided inquiry, an application of constructivism in science[28], is an alternative to lecture that can be implemented to address this issue. As Staver[29] reported, application of guided inquiry in the instruction of science allows the teacher to deal head on with students' alternate conceptions. In addition, guided inquiry permits the student an opportunity to observe phenomena and deal with sensory data by following the steps of the assimilation-disequilibration-accommodation cycle[25]. As a result, students may experience many benefits such as learning the concepts easier[34] and experiencing more success academically[32]. In addition, it has been reported that students tend to prefer to do inquiry labs over lecture and felt that it enhanced their understanding of chemical concepts[35]. Therefore, guided inquiry was chosen as a technique in this study to confront student misconceptions about chemical concepts to see if this teaching technique did, in fact, improve student understanding.

Chapter 3:

Methodology

Sample Population:

The high school where this study was conducted is a semi-rural district in northwestern Pennsylvania. The student population in the district is approximately 1350 with about 425 students in the high school. Sixty-four students from all three levels of chemistry offered at the high school (Conceptual Chemistry, Chemistry I, and Advanced Placement Chemistry) participated in the study. The researcher, who was also the instructor of record for all three courses, had access to the site on a daily basis, Monday through Friday, during the 2003/2004 school year. The students were taught using the curriculum adopted by the Sharpsville Area School District and approved by the Sharpsville Area School Board in 1996. No changes were made to the existing content of the curriculum according to the Pennsylvania State Science Standards. However, the method of instruction in each course was adapted to guided inquiry to facilitate the research study.

Each student participating in the study was required to complete a Human Subjects Informed Consent Form signed by his/her parents and the participant. This form, along with an introductory letter, clearly informed parents/guardians about the nature of the study and assured them that there would be no harm to their son/daughter as a result of participating in the study. Parental consent was required because minors cannot grant informed consent due to their protected population status. The letter that was sent home to the parents/guardians prior to data collection may be found in Appendix A.

Documentation of approval from the Youngstown State University Human Subjects Research Committee and a copy of the Human Subjects Informed Consent Form may be found in Appendices B and C, respectively. Any student not willing to participate in the study did not have their data included. However, these students participated in the guided inquiry activities along with the rest of the class to satisfy requirements of the core curriculum. The decision to participate or not participate in the study was NOT reflected in the students' grades in either a positive or negative manner.

The Light Unit:

The light unit was completed by chemistry students from all levels: Conceptual Chemistry, Chemistry I, and Advanced Placement Chemistry. The mode of instruction for each of the seven modules of the unit on light was guided inquiry. The portfolio of activities on the quantum theory and light called "The Enlightening Mystery of the White Powder Gang" [written by the researcher as a final assignment for Chemistry 6973 at Youngstown State University of Ohio] was used as the lab and activity manual for the guided inquiry unit. The modules of the portfolio included:

Module 1: Making Waves
Module 2: The Wave Particle Duality of light
Module 3: Diffraction Simulation
Module 4: Construction of a Spectroscope
Module 5: When Atoms Get Excited
Module 6: The Firefly Reaction
Module 7: Introduction to Spectroscopy

Module 4: Construction of a Spectroscope has been included in Appendix D as a sample of a guided inquiry activity written by the researcher.

Upon completion of the seven modules in this portfolio, each student was expected to have an understanding of the following concepts: properties of waves, wave-particle duality of light, diffraction, emission spectra, chemiluminescence, and basic spectroscopy. The level of understanding was to be ability specific and was assessed at varying levels. The mysterious white powder activity in this portfolio was adapted from an article by Jerry A. Bell called *Mystery Powders: An Inquiry Activity*[37]. Each student was placed in a simulated situation where he/she had just entered the Academy for Forensic Science as "Agent Atom". Agent Atom was given tasks to learn in each module of the portfolio. Each task assisted the student in understanding the principle concepts as related to light, waves, and emission spectroscopy. The student was then presented with an authentic crime to solve. The crime report was written to spoof a real world situation where a thief had stolen a holographic image from a museum and left evidence behind in a taunting manner. The student's final, culminating assessment was a performance task. Each student group of two was given a sample of the white powder supposedly left behind by one thief from the White Powder Thief Team, adapted from Bell[37]. Each student was then expected to identify the thief. Upon successful completion of this assessment, the student was awarded a position as Master Investigator. The underlying concept throughout this portfolio was that atoms absorb energy and then emit portions of this energy in discrete quanta. These quanta of energy can be measured using various techniques which take advantage of diffraction and spectroscopy.

The Acid/Base Unit:

Unlike the light unit, the acid base unit was completed only by the participants in the Chemistry I class. Conceptual Chemistry students did not complete this unit because much of the material was not germane to the curriculum for that course. Advanced Placement Chemistry students did not complete this unit because they had a unit similar to this one two years before. In addition, the date for the Advanced Placement Examination was quickly approaching, and much more detailed information on acid/base equilibria and buffers had to be covered.

The mode of instruction in this unit was also guided inquiry. The activities in this unit included:

Module 1: What is an acid?
Module 2: Strong vs. weak acids, concentrated vs. dilute acids
Module 3: What is a base?
Module 4: Strong vs. weak bases, concentrated vs. dilute bases
Module 5: Acid/Base Titrations
Module 6: Analysis of an Antacid
Module 7: Culminating Assessment: Analysis of a Vinegar

In the culminating assessment, the student investigator acted as a quality control inspector for the H.J. Heinz Company. It was to be their first day on the job, and they had to learn the methods for evaluating the vinegar for its percent vinegar content. The culminating assessment was used as the student's grade on the final examination for the Chemistry I course. A copy of this culminating assessment may be found in Appendix E.

Two-Tiered Multiple-Choice Questions:

All participating students were asked to respond to two-tiered multiple-choice questions in regard to light as a pretest of the students' understanding of the major concepts of the light unit. Two-tiered multiple-choice questions ask students to select a correct choice in the first question and to explain their choice in the second question[22]. The questions were constructed from existing literature on common student misconceptions about the quantum theory and light[18-20]. Students were then asked the same two-tiered multiple-choice questions after completion of the modules on the quantum theory and light as a post test. A copy of the pre/post test for the light unit may be found in Appendix F.

Chemistry I students were also asked to respond to two-tiered multiple-choice questions regarding acids and bases as a pretest of the students' understanding of the major concepts of the unit. The questions were constructed from existing literature on common student misconceptions about acids and bases[13,21-23]. Students were then asked the same two-tiered multiple-choice questions after completion of the modules on the acid/base theory as a post test. A copy of the pre/post test for the acid/base unit may be found in Appendix G.

Interviews:

At the end of this study, two students were selected from each class level (Conceptual Chemistry, Chemistry I, and Advanced Placement Chemistry) to respond to in-depth interview questions about the mode of instruction and the concepts of both guided inquiry units. A student who earned an "A" grade and a student who earned a "C" grade were selected randomly from each class level and were invited to participate in the interviews, resulting in a total of six interviews. A semi-structured interview guide (Appendix H) was followed by the instructor regarding the student's:

1. understanding of the common misconceptions about the quantum theory, light, and
acids and bases.
2. comfort level with guided inquiry and with traditional lecture.
3. perception of the teacher's role in instruction during guided inquiry versus traditional lecture.
4. perception of the student's role in instruction during guided inquiry versus traditional lecture.
5. ability to apply the scientific method.

Delimitations:

A measurement instrument is said to be valid if it measures what it was intended to measure. There are four types of validity[38] that must be considered in a measurement instrument. *Face validity* indicates that there is a logical tie between the instrument and its intended purpose. *Content validity* indicates how well the items in an instrument adequately represent the constructed purpose. *Criterion related validity* indicates that there is a relationship between the subject's performance on the instrument and the subject's true behavior. Finally, *construct validity* indicates how well an instrument measures the trait or concept being examined.

Delimitations deal with the issues of another type of validity known as *external validity* or *generalizability*. External validity refers to the truth of the conclusions that involve generalizations, i.e. to what extent the conclusions in a study would apply to other persons in other places at other times. Some delimitations in this research were:

a.) This study was delimited to high school students attending a semi-rural school district in Western Pennsylvania.

b.) Pretesting may have had some effect on the sample population that may not be observed in populations that are not pretested.

c.) The students had knowledge that they were part of a study since they were asked to fill out a Human Subject Consent Form.

Any of the delimitations listed above may have influenced the outcome of the study. Hence, a one-sided blind study on inner city high school students, who would only be posttested, may yield very different conclusions. It would be interesting for teachers in different communities to conduct a similar study to compare conclusions and possibly strengthen the external validity.

Quantitative (Nomothetic) Data Treatment:

A method had to be devised to assess the level of understanding on the two-tiered multiple-choice pre/post test questions for both the light and acid/base units. The scoring scheme for this assessment was modified from the six category scoring scheme Abraham[40] used in his study: *Understandings and Misunderstandings of Eighth Graders of Five Chemistry concepts Found in Textbooks*. Upon development [See Appendix I for scoring scheme development], the scoring scheme for this study was comprised of ten categories which are listed and defined in Table 1 below.

Table 1: Scoring Scheme for Two-Tiered Multiple-choice Pre/Post Tests

Code	Name	Description
INR	Incorrect, No Response	Incorrect choice, blank or "I don't know/I don't understand" written response
INU	Incorrect, No Understanding	Incorrect choice, irrelevant written response
ISM	Incorrect, Specific Misconceptions	Incorrect choice, illogical or incorrect written response
IPU	Incorrect, Partial Understanding	Incorrect choice, written response shows understanding, but some misconceptions
CNR	Correct, No Response	Correct choice, blank or "I don't know/I don't understand" written response
CNU	Correct, No Understanding	Correct choice, irrelevant written response
CSM	Correct, Specific Misconception	Correct choice, illogical or incorrect information in written response
CPU	Correct, Partial Understanding	Correct choice, written response shows understanding, but some misconceptions
CBU	Correct, Basic Understanding	Correct Choice, written response missing details
CSU	Correct, Sound Understanding	Correct Choice, all components of a valid written response present

An answer key was developed for the questions on the pre/post tests for both the light and acid/base units. The researcher and another member of the Chemical Education Research Group at Youngstown State University scored the pre/post tests for the light and acid/base units. This was done in order to establish inter-rater reliability of the measuring instrument.

In short, a measurement instrument is said to be reliable if it accurately reflects true scores. For any measurement, there is some margin of error for each response:

Observed Score = True Score + Error

Therefore, a measurement instrument is reliable to the point that it reduces this error component to a minimum. Reliability refers to the ability to repeatedly use the measurement instrument, internal consistency within the instrument, and the ability of the instrument to yield the same results independent of the administrator[38]. Establishing the reliability of the scoring system used for the two-tiered multiple-choice pre/post tests through inter-rater reliability was an established technique used to ensure that the findings were independent of the scorer.

Both the light and acid/base pre/post tests were scored independently by the two researchers, and the scores were considered to not be significantly different if they differed up or down on the scoring hierarchy [Table 1] by one. The researcher was concerned about personal bias since the researcher was familiar with the students, had knowledge of the course each test came from, and also had knowledge of whether each test was a pretest or a posttest. Therefore, to also establish objectivity in the researcher's scoring, the assisting researcher was given the same tests to score without prior knowledge of class level or date so that he could not determine the class level the test came from or if each was a pretest or a posttest. Tests were randomly selected from both pretests and posttests and all course levels. An inter-reader reliability of 91% was established for the light unit pre/post tests, and an inter-reader reliability of 97% was established for the acid/base unit pre/post tests. Sample data for the inter-reader reliability may be found in Table 4 of Appendix I.

After the data was scored for all the pre/post tests, the data was then entered into an SPSS (Statistical Package for the Social Sciences) file to be further analyzed. The data was coded in such a way as to assign a higher value to a correct response than one that was incorrect. A written response that demonstrated more understanding was also coded higher than a written response which showed little or no understanding. In addition, the class level was coded into the data file as well to distinguish data based on the class level during analysis. A sample of the coding system used for the data entry in SPSS may be found in Appendix J.

After the raw data was entered into SPSS, the frequency of each score (i.e. CSM, CBU, ISM) was counted for the pretest and posttest data sets for the light unit and acid/base units. In addition, the sum of all the code values 1-10 was calculated for each participant for the pretest and posttest data for the light unit and acid/base units. This sum was named as either the "prescore" or the "postscore". Histograms were prepared to show the frequency of each score code for each class level for a particular test. In addition, histograms were prepared of the prescore and postscore values for each class level.

Since the data in this study, like in most social science research, could have been skewed to the high or low end; the conservative assumption to apply non-parametric statistics was used[41]. Although, parametric statistics are more powerful than non-parametric techniques, the use of parametric statistics requires the assumption that the distribution of scores in the sample population is normal.

One of the sub-questions of this research was "Is there a change in scores on the two-tiered multiple-choice tests from the time of the pretest to the time of the posttest for each unit?" The non-parametric technique selected to determine this was the Wilcoxon Signed-Rank Test[41]. This test is designed for use with repeated measures, as in this case where the subjects were measured on two occasions under two different conditions. The Wilcoxon converts scores to ranks and compares them at Time 1 and at Time 2.

Another sub-question of this research study was "Are the pre/post scores different among the levels of chemistry courses?" The non-parametric technique selected to determine this was the Mann-Whitney U Test[41]. This statistical technique tests for differences between two independent groups on a continuous measure. The test converts the scores on the continuous variable to ranks across the two groups and then evaluates whether the ranks for the two groups differ significantly.

Qualitative (Idiographic) Data Treatment:

The written response data from the pretests and posttests from both the light and acid/base units were compiled from each class for each unit completed. In addition, each of the six interviews was transcribed verbatim. Two samples of student interviews are included in the appendices. In Appendix K, a sample interview from an "A" student enrolled in Advanced Placement Chemistry can be found. In Appendix L, a sample interview from a "C" student enrolled in Conceptual Chemistry can be found. These sample interviews were selected in order to give the reader a sampling of responses from the extremes of ability levels. In each case a manageable classification or coding scheme was developed. This served to categorize the responses. Convergent coding was then applied to determine recurring regularities. The categories were judged on internal homogeneity (how well the data fits together in a category) and external homogeneity (the extent to which separate categories appear disjoint). The categories for the qualitative data and convergent coding used in the analysis are summarized in Appendix M. In addition, sample field notes can be found in Appendix N.

The substantive significance of the data was also determined. When doing qualitative studies, the researcher's findings are judged on their substantive significance[39] rather than statistical significance. Several questions were addressed to determine the substantive significance of this research:

1. How solid, coherent, and consistent were the findings?
2. To what extent and in what ways do the findings increase and deepen the understanding of the phenomenon studied?
3. To what extent were the findings consistent with other knowledge?
4. To what extent were the findings useful for some intended purpose?

Chapter 4:

Data Analysis and Research Findings

The Research Question:

The short term and long term effects on student misconceptions as a result of teaching chemistry through guided inquiry were examined. The content focus was primarily on two units: production of light by atomic emissions (including characteristic properties of both waves and light) and acid/base chemistry. The research question that was examined in this study was: ***Does teaching chemistry by the method of guided inquiry correct student misconceptions?***

Quantitative Findings:

Light Unit:

There were 19 questions on the pre/post test for the light unit. Using a coding scheme of 1-10, this would result in a maximum score possible of 190.

Advanced Placement Chemistry:

Histograms were prepared for both "prescore" and "postscore" data on the light unit for Advanced Placement Chemistry so the distributions of scores and the means could be compared from the time of the pretest to the time of the posttest. Two changes are noted. First, the mean score changed positively from 126.85 on the pretest to 138.46 on the posttest. Second, the distribution curve became more narrowed around the mean with a much smaller standard deviation on the posttest. This implies that scores were not as spread out, and the lowest score had risen by as much as 20 points.

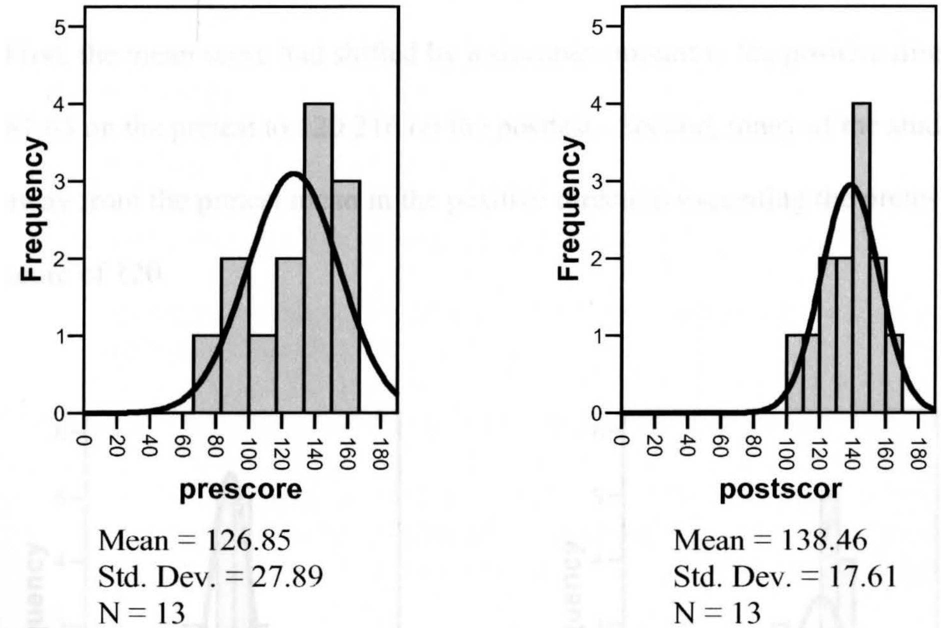
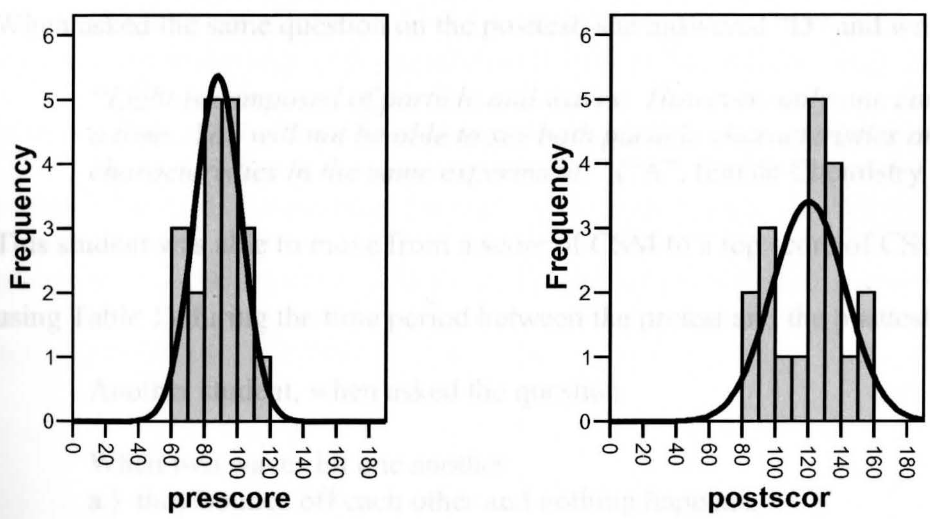


Figure 2: Distributions for Prescores and Postscores for Advanced Placement Chemistry on Light Unit

A Wilcoxon Signed-Ranks non-parametric test [Table 6, Appendix O] was performed on the "prescore" and "postscore" data to determine if the change in mean score from the pretest to the posttest was statistically significant. The value of interest in a Wilcoxon is the associated significance levels reported as Asymp. Sig. (2-tailed)[41]. An Asymp. Sig. (2-tailed) of $p \leq 0.05$ implies statistical significance. In this case the Asymp. Sig. (2-tailed) value was $p = 0.780$. This indicates that, although the mean scores did change, the change was NOT statistically significant.

Chemistry I:

Histograms were prepared for both "prescore" and "postscore" data on the light unit for Chemistry I so the distributions of scores and the means could be compared from the time of the pretest to the time of the posttest. Two changes in the data are noted. First, the mean score had shifted by a sizeable amount in the positive direction from 87.63 on the pretest to 120.216 on the posttest. Second, many of the students moved away from the pretest mean in the positive direction exceeding the pretest maximum score of 120.



Mean = 87.63
Std. Dev. = 14.13
N = 19

Mean = 120.16
Std. Dev. = 22.30
N = 19

Figure 3: Distributions for Prescores and Postscores for Chemistry 1 on Light Unit

A Wilcoxon Signed-Ranks non-parametric test [Table 7, Appendix O] was performed on the "prescore" and "postscore" data to determine if the change in mean score from the pretest to the posttest was statistically significant. In this case the Asymp.

Sig. (2-tailed) value was $p \leq 0.000$. This indicates that the substantial change in mean scores from the pretest on light to the posttest on light was statistically significant.

Some examples from the second tier of the pre/post tests further support for some students there were significant gains in understanding. When asked the question

Light is composed of
a.) particles
b.) waves
c.) none of the above
d.) both particles and waves

a student in Chemistry I answered "D" and wrote on the pretest:

> *"Light travels in waves from the lights and particles from the sun."* ("A", female Chemistry I student)

When asked the same question on the posttest, she answered "D" and wrote:

> *"Light is composed of particle and waves. However, only one can be observed at a time. You will not be able to see both particle characteristics and wave characteristics in the same experiment."* ("A", female Chemistry I student)

This student was able to move from a score of CSM to a top score of CSU (as coded using Table 1) during the time period between the pretest and the posttest.

Another student, when asked the question

When two waves hit one another
a.) they bounce off each other and nothing happens.
b.) the peaks join one another and they become larger.
c.) the peaks cancel each other out and the waves flatten.
d.) none of the above happens.
e.) more than one of the above happens.

answered "D" and responded:

> *"They pass through each other without change."* ("B^-/C^+", male Chemistry I student)

When asked the same question on the posttest, he answered "E" and wrote:

> *"When two waves meet they can either have constructive interference or destructive interference which is what letters B and C are describing."* ("B^{-}/C^{+}", male Chemistry I student)

This student was able to move from a score of ISM to a top score of CSU during the time period between the pretest and the posttest. In both cases, documented misconceptions from the literature were corrected and the level of understanding greatly increased.

Conceptual Chemistry:

Histograms were prepared for both "prescore" and "postscore" data on the light unit for Conceptual Chemistry so the distributions of scores and the means could be compared from the time of the pretest to the time of the posttest. Two changes are noted in the data. First, the mean score changed in the positive direction from 79.93 on the pretest to 96.83 on the posttest. Second, many of the students moved away from the pretest mean in the positive direction exceeding the pretest maximum score of 120, but not to the extent seen in Chemistry I.

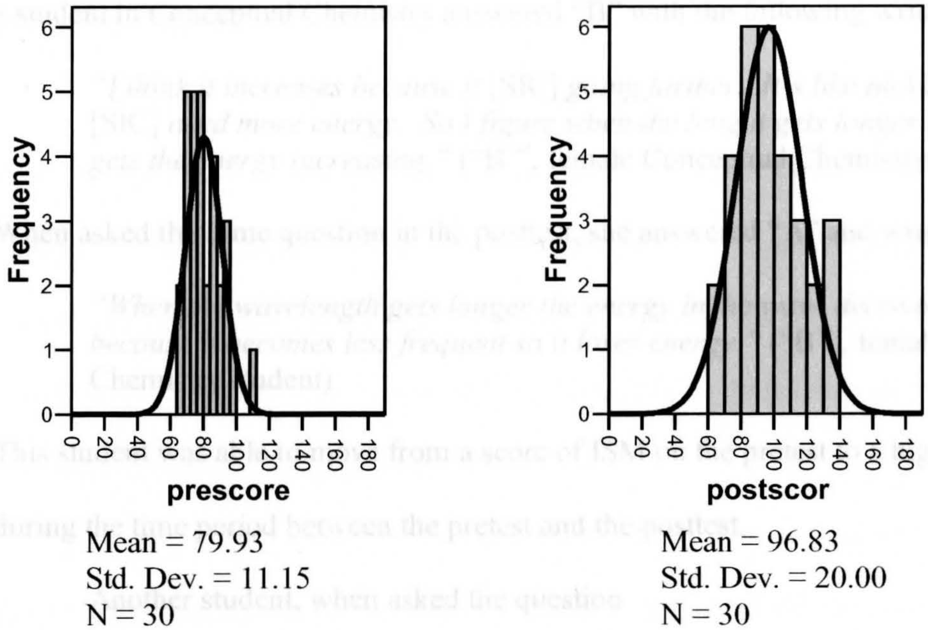


Figure 4: Distributions for Prescores and Postscores for Conceptual Chemistry on Light Unit

A Wilcoxon Signed-Ranks non-parametric test [Table 8, Appendix O] was performed on the "prescore" and "postscore" data to determine if the change in mean score from the pretest to the posttest was statistically significant. In this case the Asymp. Sig. (2-tailed) value was also $p \leq 0.000$. This indicates that, although the change in mean score from the pretest to the posttest on light was not as substantial as Chemistry I, it still was statistically significant.

Again, examples from the second tier of the pre/post tests help further support the fact that for some students there were significant gains in understanding. When asked the question

As the wavelength of a wave increases, the energy
a.) decreases
b.) increases
c.) remains the same

a student in Conceptual Chemistry answered "B" with the following written response:

> *"I think it increases because it* [SIC] *going farther. It's like picking up speed. U* [SIC] *need more energy. So I figure when the length gets longer the wavelength gets the energy increasing."* ("B^+", female Conceptual Chemistry student)

When asked the same question in the posttest, she answered "A" and wrote:

> *"When the wavelength gets longer the energy in the wave decreases. This is because it becomes less frequent so it loses energy."* ("B^+", female Conceptual Chemistry student)

This student was able to move from a score of ISM on the pretest to a high score of CBU during the time period between the pretest and the posttest.

Another student, when asked the question

Which of the following waves would be most energetic?
a.) green light waves
b.) X-ray waves
c.) microwaves
d.) radio waves

he answered "D" and explained:

> *"Radio waves because they need to travel long distances in short amount of time. Micro waves do not go far. Neither do X-rays."* ("A", male Conceptual Chemistry student)

When asked the same question in the posttest, he answered "B" and gave the following written response:

> *"Because they have the smallest wavelength which means a higher frequency and that has a higher energy."* ("A", male Conceptual Chemistry student)

This student was able to move from a score of ISM to a top score of CSU during the time period between the pretest and the posttest. In both cases, documented misconceptions from the literature were corrected and the level of understanding greatly increased.

Across Class Levels

The Mann-Whitney U test was then applied between several combinations of pretest/posttest and class levels to determine if any of the differences among these groups (Advanced Placement Chemistry, Chemistry I, and Conceptual Chemistry) was statistically significant. The value of interest in a Mann-Whitney also is the associated significance levels reported as Asymp. Sig. (2-tailed)[41]. An Asymp. Sig. (2-tailed) of $p \leq 0.05$ implies statistical significance.

When the "prescores" of Conceptual Chemistry were compared to the "prescores" of Chemistry I using the Mann-Whitney [Table 9, Appendix O], the Asymp. Sig. (2-tailed) value was $p = 0.049$, which is statistically significant. Therefore, Conceptual Chemistry and Chemistry I did not start at the same level of understanding.

When the "postscores" of Conceptual Chemistry were compared to the "postscores" of Chemistry I using the Mann-Whitney [Table 10, Appendix O], the Asymp. Sig. (2-tailed) value was $p = 0.001$, which is statistically significant. Therefore, Conceptual Chemistry and Chemistry I did not finish with equivalent levels, either, with the Chemistry I students having a greater conceptual understanding than the conceptual chemistry students.

However, when the "postscores" of Conceptual Chemistry were compared to the "prescores" of Chemistry I using the Mann-Whitney [Table 11, Appendix O], the Asymp. Sig. (2-tailed) value was $p = 0.137$, which is NOT statistically significant. This would imply that the students in Conceptual Chemistry were able to achieve (by the time of their posttest) the same level of understanding that was observed for the Chemistry I students at the time of their pretest.

When the "prescores" of Advanced Placement Chemistry were compared to the "prescores" of Chemistry I using the Mann-Whitney [Table 12, Appendix O], the Asymp. Sig. (2-tailed) value was p = 0.001, which is statistically significant. Therefore, Advanced Placement Chemistry and Chemistry I did not begin with the same level of understanding, as to be expected since the Advanced Placement Chemistry students had already completed one year of chemistry study.

When the "postscores" of Advanced Placement Chemistry were compared to the "postscores" of Chemistry I using the Mann-Whitney [Table 13, Appendix O], the Asymp. Sig. (2-tailed) value was p = 0.019, which is statistically significant. Therefore, Advanced Placement Chemistry and Chemistry I did not end with the same level of understanding as well.

However, when the "postscores" of Chemistry I were compared to the "prescores" of Advanced Placement Chemistry using the Mann-Whitney [Table 14, Appendix O], the Asymp. Sig. (2-tailed) value was p = 0.328, which is NOT statistically significant. This would imply that the students in Chemistry I were able to achieve (by the time of their posttest) the same level of understanding that was observed for the Advanced Placement Chemistry students at the time of their pretest.

Similarly, Mann-Whitney U tests were done to compare the data between Advanced Placement Chemistry and Conceptual Chemistry for similar combinations. As one would expect, there was no statistical significance in any of these cases. Therefore, the Conceptual Chemistry students clearly were not able to achieve to the level of understanding of the Advanced Placement students at any point.

To further understand how the different levels of chemistry classes compared in terms of changes in levels of understanding between the pretest and the posttest, histograms were constructed using the frequency of a particular score code on the pretest and posttest for each level of chemistry. This provides a higher number of items than number of students because the pretest and posttests had 19 questions each. Therefore, there would be 19 responses per student, or a total of 1178 separate responses for both the prestest data and the posttest data.

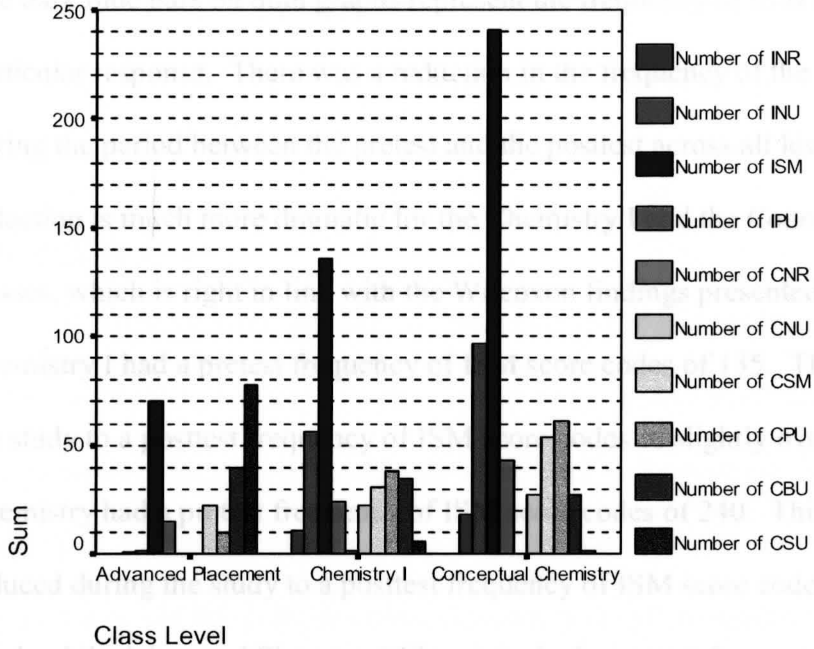


Figure 5: Frequencies of Scoring Codes for Light Pretest for All Levels

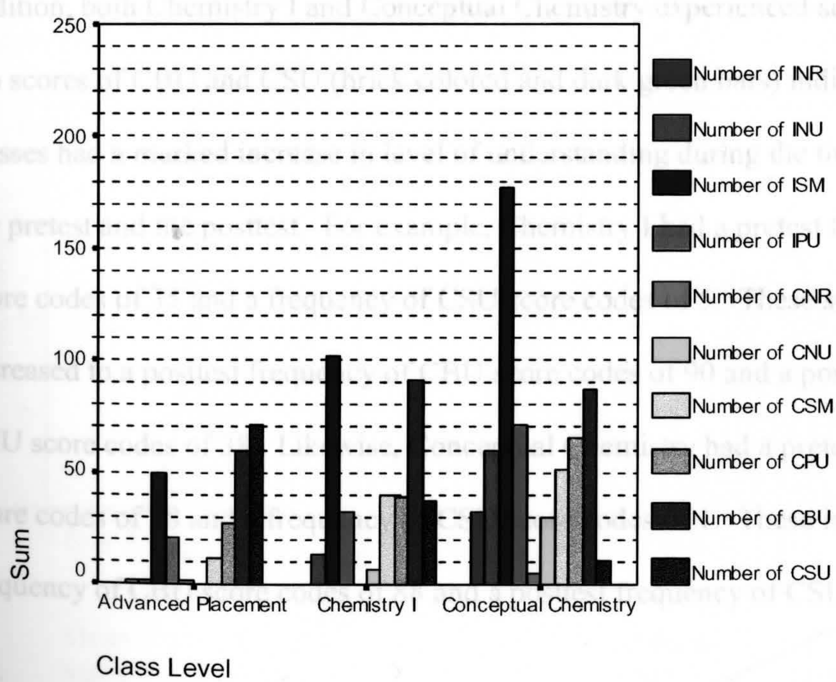


Figure 6: Frequencies of Scoring Codes for Light Posttest for All Levels

The dark blue bars on both graphs represent the frequency of ISM codes assigned to a particular response. There was a reduction in the frequency of the ISM score codes during the period between the pretest and the posttest across all levels of chemistry. This reduction is much more dramatic for the Chemistry I and the Conceptual Chemistry classes, which is right in line with the Wilcoxon findings presented earlier. For example, Chemistry I had a pretest frequency of ISM score codes of 135. This was reduced during the study to a posttest frequency of ISM score codes of slightly over 100. Conceptual Chemistry had a pretest frequency of ISM score codes of 240. This was considerably reduced during the study to a posttest frequency of ISM score codes of 177. On the other hand, while Advanced Placement Chemistry had a pretest frequency of ISM score codes of 70; this was only reduced to a posttest frequency of ISM score codes of 50. In addition, both Chemistry I and Conceptual Chemistry experienced substantial gains in the top scores of CBU and CSU (brick colored and dark green bars) indicating that both classes had a marked increase in level of understanding during the time period between the pretest and the posttest. For example, Chemistry I had a pretest frequency of CBU score codes of 35 and a frequency of CSU score codes of 5. These substantially increased to a posttest frequency of CBU score codes of 90 and a posttest frequency of CSU score codes of 38. Likewise, Conceptual Chemistry had a pretest frequency of CBU score codes of 28 and a frequency of CSU score codes of 1. These increased to a posttest frequency of CBU score codes of 88 and a posttest frequency of CSU score codes of 10.

Acid/Base Unit

There were 22 questions on the pre/post test for the light unit. Using a coding scheme of 1-10, this would result in a maximum score possible of 220.

Chemistry I:

Histograms were prepared for both "prescore" and "postscore" data on the acid/base unit for Chemistry I so the distributions of scores and the means could be compared from the time of the pretest to the time of the posttest. Three changes are noted in the data. First, the mean score had changed in the positive direction from 114.00 on the pretest to 143.95 on the posttest. Second, many of the students moved away from the pretest mean in the positive direction exceeding the pretest maximum score of 150. Third, the standard deviation increased for the posttest scores due to a much greater distribution of scores.

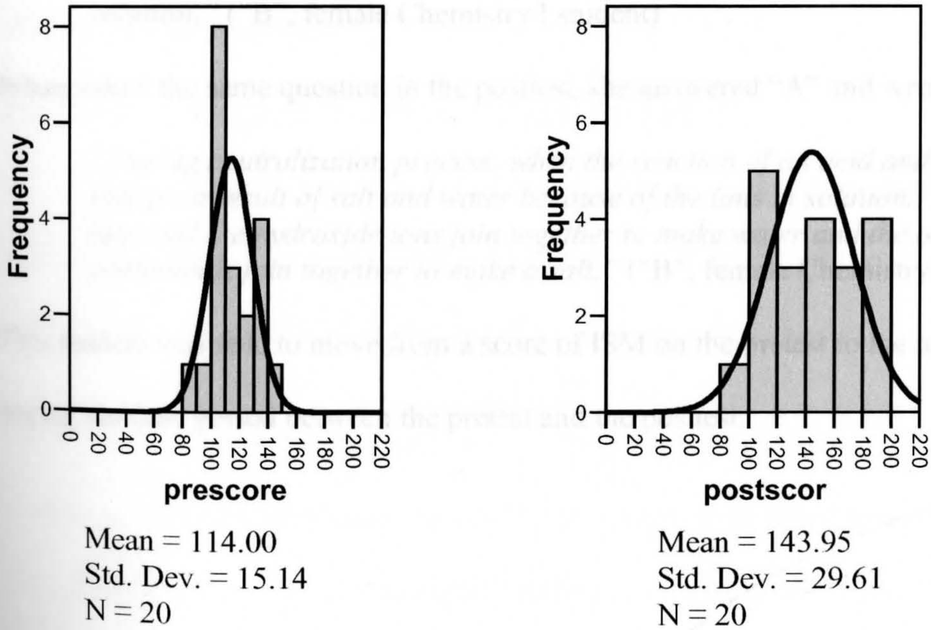


Figure 7: Distributions for Prescores and Postscores for Chemistry I on Acid/Base Unit

A Wilcoxon Signed-Ranks non-parametric test [Table 15, Appendix O] was performed on the "prescore" and "postscore" data to determine if the change in mean score from the pretest to the posttest was statistically significant. In this case the Asymp. Sig. (2-tailed) value was $p \leq 0.000$. This indicates that the change in mean scores from the pretest on light to the posttest on light was statistically significant.

Some examples from the second tier of the pre/post tests further support the fact that for some students there were significant gains in understanding. When asked the question

> During the neutralization process, the reaction of an acid and a base
> a.) forms a salt and water
> b.) causes the acid to break down
> c.) the acid changes to a base
> d.) the base changes to an acid

a student in Chemistry I answered "B" and had the following written response:

> *"I think it causes the acid to break down because that's what a base is suppose to do I think. If you put an acid and a base together I would guess that one would change into the other. I think they would just combine to form a different solution."* ("B", female Chemistry I student)

When asked the same question in the posttest, she answered "A" and wrote:

> *"During neutralization process, when the reaction of an acid and a base happens you get a result of salt and water because of the ions in solution. The hydrogen ions and the hydroxide ions join together to make water and the other ions in the compounds join together to make a salt."* ("B", female Chemistry I student)

This student was able to move from a score of ISM on the pretest to the top score of CSU during the time period between the pretest and the posttest.

Another student, when asked the question

What is the difference between a strong acid and a weak acid?
a.) The strong acid eats away material faster than a weak acid.
b.) A weak acid is more dilute than a strong acid.
c.) A weak acid only partially dissociates in solution.
d.) none of the above

she answered "A" and had the following written response:

> *"A strong acid has a higher pH level than a weak acid therefore it will eat away at a material faster."* ("A", female Chemistry I student)

When asked the same question in the posttest, she answered "C" and explained:

> *"A weak acid is also a weak electrolyte; therefore it only partially dissociates. However, a strong acid, which is also a strong electrolyte, will completely dissociate."* ("A", female Chemistry I student)

This student moved from a score of ISM to the top score of CSU during the time period between the pretest and the posttest. In both cases, documented misconceptions from the literature were corrected and the level of understanding greatly increased.

Qualitative Findings:

Feelings Toward/Perceptions of Guided Inquiry

When students were asked the question "Do you know what guided inquiry is?", most did not know how to respond to that question. Three out of the six participants interviewed answered "No" to that question. One student answered:

> *"You don't give a student all they need to know and you let them try to figure it out and learn....lab, hands-on."* ("C" Chemistry I student)

However, once the interviewer clarified for the participants that the modules they had been doing in class were guided inquiry activities, it became much easier for the participants to answer the questions about guided inquiry.

When asked about the process of guided inquiry, all of the participants recalled some aspect of doing the experiment without the assistance of the teacher and "learning for yourself" in their responses. Each student was asked to write down an explanation that he/she would give to a new student about the process of guided inquiry. One student said

> *"I wrote that it's a chance to explore an area of chemistry and make completely objective observations of your own and that you should try to make your own connections. That way you'll understand and remember the concept better than if you read about it in a chapter of your book or heard the teacher explain it. And it's a hands-on way of learning."* ("A" AP Chemistry student)

Another student wrote

> *"Ah, I put guided inquiry is when you do an experiment yourself not when your teacher and by doing it yourself and being told what happened you find out first hand ...gives you a better understanding for it and you learn more. Then after you're done with your experiment or lab and you find out that you may not have the right answer you'll have an easier time finding out what you're doing wrong by doing it yourself."* ("A" Conceptual Chemistry student)

When asked "What do you do during guided inquiry?" most students indicated they made several observations and recorded them and tried to figure out what was going on with the phenomenon being observed. One student indicated also that the class often reconvened after the guided inquiry activity for group discussion. In addition, several of the students indicated that it was necessary to work cooperatively with their lab partner to complete the task. One student stated:

> *"Well, I'm always discussing things with my partner to make sure that we both know, that we're on track. And we discuss and throw ideas back and forth to see, um, what sounds the best to us or to, like, what might be the answer or what we saw and what we did."* ("C" Conceptual Chemistry student)

When asked what the teacher's role is during a guided inquiry lesson, most of the students viewed the teacher as a hands-off guide on the side. At least two of the students mentioned that the teacher still was the primary monitor of safety during a laboratory activity. Most of the students viewed the teacher as unwilling to answer questions that were probing for answers. More often than not, their questions were met with another question. The students saw the teacher spending more time directing students to sources or giving examples to prod them toward discovering the correct conception. However, this did not come without frustration. One student, when asked what she wished the teacher would do, said

> *"Sometimes, just tell me! I get frustrated when I don't understand."* ("A" Chemistry I student)

Although the norm of responses was for the teacher to just tell the student the answer to the question, one student stated:

> *"I like the way you do it. You don't, ah, give people the answer. You let them find it out for themselves. It gives them a better understanding."* ("A" Conceptual Chemistry student)

As far as the learning environment, the students described the room to be noisy with students at their lab stations having interactions with their lab partners and others around them. The students felt that this was necessary to allow discussions to occur about the natural phenomena they were observing.

Feelings Toward/Perceptions of Lecture

When asked a similar question about how they would describe the process of a lecture to another student, most students indicated that taking notes and paying attention were important. Other varied activities that take place were described by one student:

> *"Well, sometimes we read out of science magazines and we watch videos about science, and there's a lot of questions asked like lots of people ask questions. And a lot of them, all of them are answered. And we work out of books and with partners, and we take some notes, but things are always explained."* ("C" Conceptual Chemistry student)

When asked "What do you do during a lecture?", most of the students said they took notes, paid attention, listened to the conversations in the classroom, and asked questions. Several also indicated that it was difficult to do this either because class was too early in the morning or they found it hard to sit quietly without drifting off in thought or falling asleep. One student stated:

> *"As honest... Yea, I told you, you need to be as accurate as possible. O.K., um, I write down everything you have on the board. If I'm really tired, I zone out and hurry up and copy everything down I just missed. Um, I try to, I do try and listen because I know there's a lot of things you do not write down that I, I am gonna need to write down in my notebook. Um, and that's what was hardest for me in studying, going back through my notebook was that I had obvious missing holes because I didn't write things down that you had written on the board that I should have been paying attention to or just didn't remember it. Um, I followed along in the book in a lot of cases, if you were addressing someone else for a question that they had and there was something from earlier that I wanted to see written down I'd find it in the book and read a section underneath a diagram or, um, ah, paragraph that looked like it would be helpful. Um, sometimes if you were explaining something and I didn't understand what it was I would ask the person next to me or I would just ask you if you weren't looking too agitated with our lack of [laughter] accelerated learning."*

The students viewed the teacher as the omnipotent dispenser of information during a lecture. One Chemistry I student felt that the teacher should "know everything and present it in a manner that you'll understand." They described teachers who lecture as standing in front of the room talking the whole time, posing questions, and answering questions. In addition to answering questions, the students saw the teacher bringing students to the board to help with problems and drawing pictures to serve as examples for the students. The students further described the teacher as the bank of answers in a lecture. Some students indicated that they also have consulted their peers as well to get the answer to certain questions during a lecture, as not to interrupt class.

As far as the learning environment, the students described the classroom during a science lecture to be relatively quiet. They described the students arranged orderly in their seats facing the front and ready for instruction.

Guided Inquiry vs. Lecture

The students saw guided inquiry as a more hands-on form of learning than lecture. One student described it as:

> *"Guided inquiry is not just sitting there. You're going back in the lab working with materials on your feet and using your hands and interacting. Lecture is just sitting and being uncomfortable."* ("C" Advanced Placement Chemistry student)

When asked which form of instruction leaves a greater impression on them, the students indicated that guided inquiry did because "you remember a lot more because it's hands-on….lectures tend to get forgotten the next day because it is memorizing." One student described:

> *"More people talk about what happened with the lab. They…the labs are a lot more fun. The, um, lectures, like, you'll talk about it, but you're kinda getting out of a seat, like, when lecture's over, like it's just another day."* ("C" Conceptual Chemistry student)

When asked what method of instruction they preferred, the students unanimously agreed upon guided inquiry. They tended to "prefer to learn by doing rather than listening." One student went as far to say:

> *"I'm a kinesthetic learner rather than a …I mean auditory and visual helps, but for me to really understand something I have to do it. And you make more of your own connections, um, in guided inquiry. You can, um, try and make your own connections during lecture, but you don't always, you don't have the opportunity to think at a pace faster than the teacher's teaching. Um, you asked how they're*

different, right? [I nods] I would say, I would say…it's a more casual learning environment, um, doing the guided inquiry, but it's still, um….hmm…
You usually don't remember anything from the lecture. You wrote it down, but it went in one ear and out the other. Um, with the guided inquiry, um, the fact that you did it yourself, um, it's an actual memory, um, and if you need to recall a concept, you can recall a memory from something you did rather than a word you read on the board, which is a lot harder to remember to me than something that I actually made and observed in the lab myself." ("A" AP Chemistry student)

Even though the students favored guided inquiry, they did list some concerns or disadvantages to using this method of instruction. Most said that it was more difficult than lectures at times and the student doesn't always know if he/she is doing the experiment correctly or making the correct interpretations until the group reconvenes after the activity. One student in Chemistry I stated:

"If you don't understand and can't work it out, you might not get it." ("C" Chemistry I student)

Comfort Level with Guided Inquiry

Most of the students reported having some level of anxiety or frustration the first time the class did a guided inquiry activity. Many were "unsure what was going on." One student reported:

"It was frustrating a little bit. I knew the qualities [referring to physical and chemical changes], but I didn't know what was going on. It was stressful. Um, I thought 'How am I supposed to know? What if I turn it in and I get it wrong?'" ("A" Chemistry I student)

Other students indicated similar frustrations because they couldn't figure out how the phenomena worked immediately in the first guided inquiry experience, and they were concerned about their grades and were very focused on getting the <u>one</u> right answer.

Every one of the students reported that their comfort level with guided inquiry improved with more exposure to the process. Equally important, each student reported an increase in confidence as each student had more exposure to guided inquiry. One student stated:

> *"Because like I knew how it was going to work, and I knew like how much, how fast and how slow we had to go through the experiment with the amount of time."* ("A" Conceptual Chemistry student)

Another student in the same class (which is populated with students who tend to have a low interest level) reported:

> *"Yea, I felt that I was learning more on my own than somebody telling me what was going on. So, I felt that, you know, my opinion actually matters. So, I got more confident with what I was doing. I was like 'My answer can't be wrong here. It can't be wrong!'"* [laughter] ("C" Conceptual Chemistry student)

Yet another student described:

> *"O.K. I felt stupid, but it was actually kinda exciting to try and do something different than everybody else, um, and come up with a different way. Not that it was a new way, but it was a different way to identify something, and I will probably remember that lab better than any other lab."* ("A" Advanced Placement Chemistry student)

Each of the students also indicated that he/she participated more frequently as the class gained more familiarity with guided inquiry. It seemed as though working with lab partners and the time for interaction and discussion gave the students the initiative to participate at a higher level. One student said

> *"I liked getting to talk with my lab partner and having time to figure things out."* ("C" Chemistry I student)

Another student in the same class stated:

> *"I was more comfortable working with lab partners…more comfortable because I knew what had to be done, and I understood what was expected of me."* ("A" Chemistry I student)

When the students were asked what they liked least about doing the guided inquiry activities, they mainly reported they liked least the process of cleaning up and figuring out procedural skills. As one student reported:

> *"If you didn't rub the chemical on right to the wire, it would not show the light, color. And if you didn't clean it right, it would show colors of the other chemicals."* ("C" Chemistry I student)

Comfort Level with Lecture

The majority of the students used words such as "uncomfortable", "uneasy', "frustrated", and "overwhelmed" to describe how they felt during the lecture they were being asked about. On student said that he was

> *"kind of overwhelmed....It was like just being thrown out. It took a couple of days to understand."* ("C" Chemistry I student)

Another student said

> *"I was thinking 'Slow down!' It was all blurred together and moving too fast. I was sitting there thinking 'What is going on?'. There were so many K's....K_c, K_p, K_a, K_b, K_w. I, also, couldn't find where these numbers were coming from. I didn't realize they were in charts in my book."* [laughter] ("C" Advanced Placement Chemistry student)

In addition to not liking the fact that they had to sit and take notes, some students did not like the repetition of lecture and having to go home and read out of the book to be able to get understanding. Also, one student felt:

> *"...it's harder for me to ask you questions, um, about things that I don't understand when you're trying to teach it to the entire class. When you are available and everybody is doing their own thing, it is a lot easier to have you explain something, um, to a small group of people who don't understand and let the group of people who do understand continue with their own learning. Um, I felt better about asking you questions during the guided inquiry, um, because number one, I didn't want to feel stupid [B giggles], um, but I also felt like I was taking up everybody else's time in which they could be learning, so..."* ("A" Advanced Placement Chemistry student)

Scientific Method:

Although the students used the scientific method frequently during guided inquiry activities, not all the students could easily explain how they applied it to solve problems. One student was particularly articulate, however:

> *"We made some initial observations and researched what we were supposed to do. Then we wrote a hypothesis. Then....we made up a procedure to follow. We went into the lab and took final observations and used them to make a conclusion. Some data was calculations, and the rest was observations......hypothesis...our hypothesis was 'The unknown nitrate salt was sodium nitrate ($NaNO_3$) and Sentry Sodium was the white powder thief......during the experiment we took initial observations during the flame tests and compared then to the previous knowns from the modules. We could have used the spectroscope like everyone else, but we chose to use the results from the hydrate experiment to help us to figure out that it was sodium."* ("A" Chemistry I student)

The previous student wasn't the only one who made reference to the procedure of comparing to a known standard when identifying the white powder. Unfortunately, both Conceptual Chemistry students and the "C" level Chemistry I student reported that they did not have a hypothesis during the culminating assessment.

Chapter 5:

Interpretation of the Findings

The level of understanding of concepts for both light and acids and bases increased over time with exposure to guided inquiry activities related to these concepts. In addition, specific misconceptions in the literature were corrected. In several cases, students moved from a specific misconception about a particular concept to the correct conception. Chemistry I students experienced the greatest gains from this study. This may possibly be explained because these students were more conscientious and more eager to learn than those in Conceptual Chemistry. Therefore, their greater willingness to participate at a serious level may have resulted in a more profound effect. Nonetheless, the Conceptual Chemistry students still experienced meaningful gains in their level of understanding. For example, when one student from Conceptual Chemistry was asked how green light and microwaves were similar, he responded that

> *"They both give off waves that have a wavelength and a frequency."* ("A" Conceptual Chemistry student)

He was also able to answer the question "Is visible light the only form of electromagnetic radiation that involves waves?"

> *"No….you also have gamma radiation, microwaves, and ultraviolet radiation."*

Although the Advanced Placement students did not make statistically significant gains throughout the study, misconceptions were corrected for these students as well. For example, when one "C" level Advanced Placement Chemistry student was asked on the pretest the question

Which of the following waves would be most energetic?
a.) green light waves
b.) X-ray waves
c.) microwaves
d.) radio waves

she answered "C" and had the written response

> *"Microwaves travel the fastest and are the closest together. Therefore, they have the most energy."* ("C", female Advanced Placement Chemistry student)

When asked the same question on the posttest, she answered "B" and had the written response:

> *"X-ray waves would be the most energetic because their wavelength is the shortest of the forms of waves listed in the question. Therefore, their frequency is the greatest out of all that are listed. Since energy and frequency are directly proportional, X-rays would have the greatest energy."* ("C", female Advanced Placement Chemistry student)

As seen in the findings (Refer to Figure 2), rather than the mean changing substantially in the positive direction, the distribution narrowed around a somewhat higher mean for these students. This can be attributed to the fact that the students in Advanced Placement Chemistry have seen this material before in both Chemistry I and in Physics. Therefore, this unit served more as a review for these students while correcting some misconceptions. Other misconceptions did not get corrected. Not all the Advanced Placement Chemistry students had the same instructor for Chemistry I. Therefore, some had previously been exposed to guided inquiry, while some had not. In addition, physics is taught in a more traditional manner at the research site. Therefore, these students had longer to develop misconceptions and ingrain them into their understanding. As pointed out in Wandersee et. al.[14], alternative conceptions are tenacious and resistant to extinction by conventional teaching strategies. In particular, Wandersee argues that "alternative conceptions have their origins in a diverse set of personal

experiences…..as well as teachers' explanations and instruction materials."

Not only did students in the study develop better understanding of chemical concepts, they also developed more sophisticated answers as the school year progressed, and they were expected to write written responses more often. For example, one student in Chemistry I wrote when asked to explain how a strong acid was different from a weak acid

> *"A weak acid is a weak electrolyte. Therefore, it only partially dissociates in solution. However, a strong acid is a strong electrolyte and will completely dissociate in solution."* ("A", female Chemistry I student)

When asked about the strong base sodium hydroxide, she wrote

> *"The sodium ion has a positive charge while the hydroxide ion has a negative charge. When NaOH dissociates in water, the base will separate into its ions completely. Therefore, NaOH is a strong base and will completely dissociate like a strong acid."* ("A", female Chemistry I student)

These written responses show a sophisticated level of understanding of acids and bases for a tenth grade chemistry student. The information written is correct, clear, and concise; she uses appropriate terminology when needed to explain the phenomenon.

These gains in understanding and clarity in writing persist. The Advanced Placement Chemistry students who had not completed the acid/base guided inquiry since tenth grade still demonstrated a high level of conceptual understanding. For example:

> *"Yea, an acid would be a proton donor because an acid, every acid has a hydrogen, an H^+, um, as a part of it. And all a hydrogen is, is a proton and an electron. When you take away the electron to make it H^+, it is just a proton. Um, so that would be why it's called proton donor because in neutralization, um, an acid and a base will…I may say this totally wrong….the hydrogen is taken off of the acid….um, and sometimes forms HOH or water with the OH from the base. Um, an acid ….don't eat them…um…it's an electron acceptor because…I think this might…I missed the*

electron acceptor donor thing because I was zoned out for that section of it. So, I'm not going to be able to explain that part.....
Yea, electrodes in the solution, and if the light's very bright, it would be a strong acid. If it was either not...I don't remember if a weak acid was a poor electrolyte or not an electrolyte at all...but it would either be a very dim light or not light up at all."
("A", Advanced Placement Chemistry student)

In the qualitative findings, students reported that they were frustrated with their first experience with guided inquiry. This may be a direct reflection of the fact that prior to this study, many of the participants had not been exposed to guided inquiry. As the students indicated, they were used to being told what they need to know and the teacher answering all the questions. Although the lecture method of instruction is efficient, it doesn't necessarily result in a higher level of understanding. In addition, the students had not had experience with the assimilation-disequilibration-accommodation cycle. Therefore, they had not had much experience with dealing with sensory data in science as it relates to natural phenomena. Hence, this may have led to their frustrations.

Allen[35] reported that the majority of the students in his study preferred to do inquiry laboratories and felt it enhanced their understanding of chemical concepts. This was confirmed by the students in this study as well. Most preferred to be out of their seat, doing hands-on experiments; and they really were proud that they were able to learn for themselves. Lecture to them was dull, boring, and hard to understand.

Furthermore, Perkins[28] pointed out that it helps most with conceptually difficult knowledge for the teacher to introduce the qualitative concepts before the quantitative aspects. Many of the students also felt, like Perkins, that it helped them to have a deeper level of understanding to see the natural phenomena first in the laboratory before participating in the lectures, which involved more complex mathematical concepts.

Students also reported that guided inquiry better met their needs as students. For example, the student who pointed out that she is more of a kinesthetic learner is actually referring to the fact that guided inquiry addressed her learning modality of the active learner. Many of the students indicated that it was better to be out of their seat and doing hands-on activities. Guided inquiry also addressed the learning modality of the social learners and the creative learners. Students had the opportunity to interact with other students and discuss the natural phenomena they were observing. In addition, they were permitted opportunities to go off on tangents and explore alternate ways of solving problems. As supported by the literature review for this research, this allows the learner the opportunity to construct knowledge and draw conclusions by analyzing and discussing ideas. The learner also experiences how to work together and to understand concepts and solve problems[32].

It should be noted, however, that even though many of the findings in this study have been positive, teaching chemistry by guided inquiry is not a panacea. As mentioned before, misconceptions are tenacious and resistant to change, and sometimes have their roots in teachers' explanations and instructional materials[14]. For example, when a "C-" Advanced Placement Chemistry student was asked the following question on the Light Unit pretest:

Which of the following waves would be most energetic?
a.) green light waves
b.) X-ray waves
c.) microwaves
d.) radio waves

she answered "B" and wrote:

"I picked "B" b/c [SIC] when you go to get an X-ray they make sure you aren't pregnant and put a really heavy tarp-like thing over you. When you see green it doesn't harm you and if your [SIC] listening to a radio you don't have to protect your belly if you're pregnant. I didn't pick a microwave b/c [SIC] they have been around for so long that there are many things that they have fixed to make them less harmful. They are in our everyday lives, so I hope they aren't harmful."

When asked the same question in the posttest, she answered "C" and wrote:

"They produce heat and when something is heated the molecules are more "happy" than when not heated."

This is an example of where prior experiences and teacher lingo surface in misconceptions. This student had remembered that no transfer of energy due to heating was observed during her experiences with green light, X-rays, and radio waves. However, she did observe microwaves producing "heat" as a result of exciting the water molecules in food. Therefore, she drew the conclusion that microwaves must be in a higher energy class than the others. In addition, the term "happy" arose from a middle school teacher who habitually uses the term to describe a system at lowest energy, particularly the noble gases. This resulted in the student owning this term and using it haphazardly in explanations such as above. When a student does not assimilate sensory data properly, and then it further gets complicated by a teachers' explanation, it is very difficult for the student to move beyond a level of misconceptions. In this case, when confronted with discrepant events during the light unit, she may have simply chosen to ignore those events, and she did not alter her framework of conceptual understanding. When this occurs, correction of student misconceptions cannot occur.

Future Research Directions:

Since teaching chemistry through guided inquiry was shown to correct student misconceptions in this study, this could have direct value to any educator teaching chemistry. This serves as further evidence to educators why the *National Science Education Standards* stipulate that science students should spend less time memorizing facts and more time reasoning and solving problems. Also, the *standards* stipulate that students should learn in cooperative groups, use more hands-on materials, and study fewer science topics in much more depth. Educators teaching chemistry can then attempt to incorporate guided inquiry more frequently into their lessons realizing the direct benefit will be fewer misconceptions and correction of pre-existing ones. Therefore, the findings of this research validate one way to meet the challenge of the *NSES*.

In addition to these extensions, it would be interesting to repeat this study in a city school where the school population is not as homogenous in order to see if this study yields the same results for culturally and economically disadvantaged individuals. This would be important to know since

> The alternate conceptions that learners bring to formal science instruction cut across age, ability, gender, and cultural boundaries. Alternate conceptions have their origins in a diverse set of personal experiences including direct observation and perception, per culture and language….
>
> Wandersee et. al. (14)

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Appendix A:

Information Letter to the Parents/Guardians of Participating Subjects

Sharpsville Area High School

301 Blue Devil Way, Sharpsville, Pennsylvania 16150
Principal's Office (724) 962-7861
Fax (724) 962-7730
E.O.E. Institution

December 12, 2003

Dear Parent/Guardian:

I am pursuing a Masters of Science in Chemistry and Chemical Education with Youngstown State University. As part of my requirements for the Chemical Education aspect of my graduate degree, I must complete legitimate and testable classroom research. I have chosen to complete this research over the 2003/2004 school year with my chemistry classes at Sharpsville. Since your son/daughter is a student in my class, I wanted to take some time to give you some preliminary information about my research topic.

According to many learning theory specialists, students often form misconceptions about fundamental concepts they are learning in science because they have preconceived notions about natural phenomena they observe. In a traditional science classroom, presentation of the curriculum is very lecture oriented with laboratories that only serve to confirm the concepts being presented. Since these traditional classrooms are so teacher-centered, the student never gets the opportunity to explore the natural phenomena and make meaningful observations before being exposed to the accepted explanation of the concept. Therefore, many times, students can simply memorize a set of definitions and explanations without having a firm understanding of the underlying concepts of the science. Learning theorists who support the constructivist theory of student learning propose a possible solution to this problem. According to the constructivist learning theory, a student exposed to a phenomenon and allowed to make meaningful observations of that phenomenon with the assistance of the teacher can construct a personal understanding of the underlying concepts. The teacher executes these activities prior to the introduction of the concept in class. The student is then able to test his/her ideas prior to learning the concept. This mode of instruction is often referred to as guided inquiry. It is alleged that guided inquiry is a preferred method of science instruction. The goal of my research is to determine if teaching chemistry through guided inquiry helps to correct student misconceptions. Data will be collected from each student participating in the multiple choice pretests and posttests. In addition, data will be collected from students who volunteer to participate in an in-depth interview about each guided inquiry unit and the chemical concepts in those units.

Attached is a Human Subjects Informed Consent Form. Please take time to discuss this letter with your son/daughter, and then complete the form to be submitted by December 22, 2003. Please be aware that this project has been presented to and approved by the Sharpsville Area School Board and Dr. Stufft, Superintendent. Feel free to contact me with any questions you may have. Thank you for supporting exciting classroom research that may influence how chemistry is taught in the future!

Sincerely,

Mr. Les McSparrin
Chemistry Teacher

Appendix B:

Approval Letter from Youngstown State University Human Subjects Research Committee

YSU

Youngstown State University / One University Plaza / Youngstown, Ohio 44555-0001
Dean of Graduate Studies
330-941-3091
FAX 330-941-1580
E-Mail: graduateschool@cc.ysu.edu

November 12, 2003

Dr. Stacey Lowry Bretz, Principal Investigator
Mr. Leslie D. McSparrin, Co-investigator
Department of Chemistry
UNIVERSITY

RE: HSRC Protocol #44-2004
Title: Does Teaching Chemistry Through Guided Inquiry Correct Student Misconceptions?

Dear Dr. Bretz and Mr. McSparrin:

The Human Subjects Research Committee of Youngstown State University has reviewed the above mentioned protocol, and determined that it fully meets YSU Human Subjects Research Guidelines. Therefore, I am pleased to inform you that your project has been fully approved.

Any changes in your research activity should be promptly reported to the Human Subjects Research Committee and may not be initiated without HSRC approval except where necessary to eliminate hazard to human subjects. Any unanticipated problems involving risks to subjects should also be promptly reported to the Human Subjects Research Committee.

Sincerely,

Peter J. Kasvinsky
Dean, School of Graduate Studies
Research Compliance Officer

PJK:cc

c: Dr. Timothy Wagner, Acting Chair
Department of Chemistry

Sharpsville Area School District
513 Main Street, Sharpsville, Pennsylvania 16150
Superintendent's Office (724) 962-7874
Business Office (724) 962-7872
Fax: (724) 962-7873
E.O.E. Institution

August 22, 2001

Mr. Les McSparrin
142 North Oakland Avenue
Sharon, PA 16146

Dear Mr. McSparrin:

At the regular meeting of the Sharpsville Area School Board held on August 20, 2001, the Board of Education gave approval for you to use students in testing as part of a research study. Only raw data is to be used. Student's names and/or student's personal information are not to be included as a part of this research study.

Please feel free to contact me if you have any questions.

Sincerely,

Derry L. Stufft, Ed.D.
Superintendent of Schools

DLS/daz

Appendix C:

Human Subjects Informed Consent Form

Human Subjects Informed Consent Form
Sharpsville Area High School

Dear Parent/Guardian:

I am conducting research in my classroom to determine if teaching chemistry through guided inquiry will aid in correcting student misconceptions. In this study, your child will be taking a multiple choice survey before and after guided inquiry units are taught. In addition, some students will be asked to volunteer to participate in an in-depth interview for each unit.

Your child will be asked to allow me to use the data from his/her survey and/or interview in the analysis of data. There are no risks to your child, and all information/data collected will be handled in a strictly confidential manner, so that no one will be able to identify your child when the results are reported. There will be no penalty assigned to any student's grade if he/she chooses not to participate. In addition, no data will be collected for the non-participating students.

Please feel free to contact me, Dr. Stacey Lowery Bretz, or the Office of Grants and Sponsored Programs at YSU if you have any questions:

Dr. Stacey Lowery Bretz
Department of Chemistry
Youngstown State University
One University Plaza
Youngstown, OH 44555
(330) 941-7112
slbretz@ysu.edu

Mr. Les McSparrin
Sharpsville Area High School
301 Quarry Way
Sharpsville, PA 16150
(724) 962-7861
lmcsparrin@sharpsville.k12.pa.us

Office of Grants and Sponsored Programs
Tod Hall – Room 357, Youngstown State University
One University Plaza
Youngstown, OH 44555 (330) 941-2377

I understand the study described above and have been given a copy of the descriptions as outlined above. I agree to allow my son/daughter's data to be included with his/her assent.

____

Signature of Parent/Guardian Date

I understand how my data will be used in this study and am willing to take part in the study.

____

Signature of Child/Ward Date

Appendix D:

Sample Guided Inquiry Activity:

Construction of a Spectroscope

Name ______________________ Per. _______ Date __________

Module 4: Construction of a Spectroscope
Chemistry – Mr. McSparrin

Objective and Discussion: Agent Atom, you make the score since you are on module 4. I believe you will find this module fun since you will be making a common science toy while studying the diffraction of light. The objective of this module is to make a spectroscope. A spectroscope is an instrument used to detect and study the light emissions of various substances. A spectroscope is a simple instrument which contains a diffraction grating or a prism. In this module, we will be using a diffraction grating. Remember you learned in Module 3 that a diffraction grating separates various wavelengths of light because they are not all scattered in the same way. The colors are then separated much like what happens with a prism. However, remember also that diffraction patterns are created by wave interference with diffraction gratings. On the other hand, diffraction patterns are created by refraction with prisms. Good luck and enjoy, Agent Atom. My scope is on you!

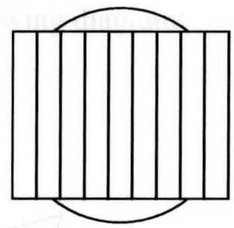
Materials:

replica diffraction grating on a 2"x2" slide mount
paper towel roll
tape
construction paper
H_2, He, and Hg discharge tubes
sharp scissors

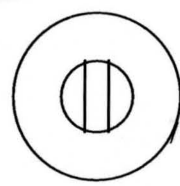
Procedure for Construction of Your Spectroscope:

1.) Obtain a replica diffraction grating from Investigator Indium.

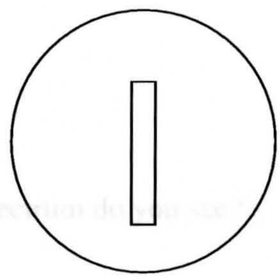
2.) Using Scotch tape, tape the diffraction grating to one end of the paper towel roll in the orientation below. DO NOT PUT TAPE OVER THE GRATING!



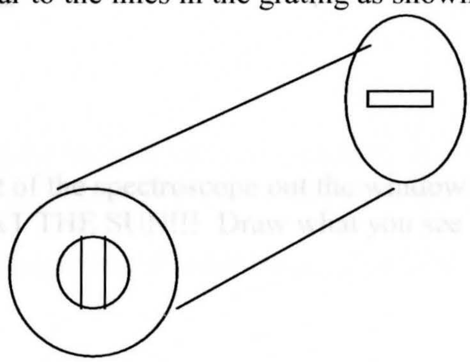
3.) Cut out a round piece of black construction paper to fit over the diffraction grating. Using a pair of pointed scissors, cut an observation hole in the center to enable you to look through the diffraction grating. Tape it over the diffraction grating. The end of your tube should look like this.



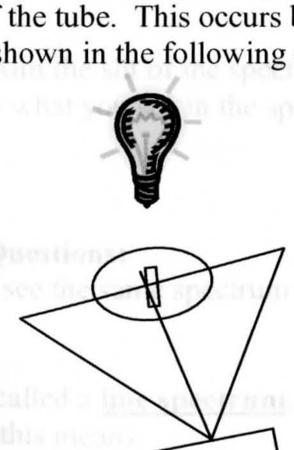
4.) Now, cut a second piece of black construction paper to fit over the opposite end of the tube. Using the pointed scissors, cut a slit in the center of the construction paper. The slit should be as thin as possible to avoid stray light getting into the spectroscope. Your piece of construction paper should look like this:



5.) Tape the construction paper with the slit over the open end of the tube such that the slit is perpendicular to the lines in the grating as shown below.



6.) Now it is time to test your spectroscope. Hold the end of the tube with the slit up to the fluorescent lights while looking into the other end with the observation hole. If you have constructed your spectroscope correctly, you should see rainbows on both sides of the tube. This occurs because the diffraction grating scatters the light in the angles shown in the following diagram:



Task 1: Aim the slit of the spectroscope at a fluorescent bulb again. Draw what you see below using colored pencils.

Focusing Questions

a.) What colors of the visible spectrum do you see?

b.) This is known as a **continuous spectrum**. Explain in your own words what you believe that means.

Task 2: Aim the slit of the spectroscope out the window to look at sunlight. DO NOT LOOK DIRECTLY AT THE SUN!!! Draw what you see in the spectroscope below using colored pencils.

Focusing Questions:

a.) Do you see the same spectrum as you did for fluorescent light?

b.) Why or why not?

Task 3: Aim the slit of the spectroscope at the center of a lighted hydrogen discharge tube. Draw what you see in the spectroscope below using colored pencils.

Focusing Questions:

a.) Do you see the same spectrum as that from fluorescent light and sunlight?

b.) This is called a **line spectrum**. Explain this term in your own words what you believe this means.

Task 4: Repeat the same procedure in Task 3 for the helium and mercury discharge tubes. Draw what you see in the spectroscope for each discharge tube below using colored pencils.

Focusing Questions:

a.) Are these line spectra that same as that for hydrogen?

b.) Are the line spectra for helium and mercury the same?

Details:

Regroup with Investigator Indium and your academy classmates. Discuss the results of your observations. Also, have a discussion to answer the following question.

a.) How can a spectroscope or diffraction grating be used to determine the identity of an atom?

Terms:

Define the following terms in your own words:

a.) spectroscope -

b.) replica diffraction grating –

c.) continuous spectrum –

d.) line spectrum -

Appendix E:

Acid/Base Authentic Assessment Final

Name ____________________________

Per. ______

Date ____________________

Chemistry I Performance Task Final
May 2004

I. The Task:

You and your old chemistry lab partner have been hired as employees for the H.J. Heinz Co. in Pittsburgh. The personnel department was impressed with your success in high school chemistry and was willing to give you a trial period as one of their quality control technicians in the foods analysis department. Your job description includes the following: You are to analyze random samples of the distilled vinegar product for percent acidity by means of titration. They assumed, based on your comments in your job interview, that you had a full year of chemistry. As a result, your direct boss would expect you to: perform the titrations, determine the percent acidity of the distilled vinegar, and complete the analysis report.

II. Procedure:

You vaguely remember a titration from your Chemistry I class. So, you consult the technician's manual for the standard distilled vinegar analysis procedure. You find the following procedure:

1. Measure the mass of a clean, dry 250-mL Erlenmeyer flask.
2. Obtain a 25.0 mL sample of distilled vinegar. Be sure to measure the sample using a graduated cylinder with accuracy.
3. Pour the sample of vinegar into a 250-mL Erlenmeyer flask and measure the mass again.
4. Add 5-7 drops of phenolphthalein indicator solution.
5. Fill a buret with 0.500 M NaOH and record the initial buret reading. Remember to read the buret to 2 decimal places.
6. Titrate the sample until the **slightest** color of pink and record the final buret reading.
7. Be certain to occasionally rinse the tip of the buret and the sides of the flask to make sure that all of the NaOH makes it into the sample being analyzed.
8. Repeat this procedure two more times for a total of three consistent trials.

III. Analysis Data:

Table Final. 1: ***Data for the Analysis of Heinz Distilled Vinegar***

	Trial 1	Trial 2	Trial 3
Mass Erlenmeyer Flask			
Mass Erlenmeyer Flask + Vinegar			
Final Buret Reading			
Initial Buret Reading			
Volume NaOH Used in Titration			

Average Volume of NaOH Used in the Titration = ______________

IV. Calculations and Data Analysis:

REMEMBER: Always show ALL work to get partial credit. Pay careful attention to significant figures!!

1. What is the formula for the acidic component of vinegar?

2. Draw the Lewis Structure for this molecule. Realize that acetic acid is an organic acid. Use Pg. 465, particularly the margin, to help.

3. Using a molecular model kit, put together a model of this molecule. Draw its structure below.

4. What types of bonds do you observe in this molecule (single, double, triple)?

5. How many bonds surround each carbon?
6. The shape is different around each of the carbons. Describe this difference.

7. According to your notes from Chemistry I, would this be classified as a strong or weak acid?

8. Confirm your prediction for question #7 using a conductivity meter. Test the vinegar and the strong acid, HCl, for comparison. Describe your observations below. Was your prediction correct?

9. Describe the nature of the acidic component of vinegar in terms of dissociation and electrolytic nature. Write an equation describing the dissociation process using the appropriate arrows to indicate acid strength.

10. Write a complete balanced molecular equation describing the reaction that occurred during the titration. Don't forget states of matter.

11. Write a NET ionic equation to describe the reaction that occurred during the titration. Remember that using H^+ is really not correct.

12. Using the molecular equation and stoichiometry, calculate the number of moles of acid in a 25.00 mL sample of analyte using the average data.

13. Convert the number of moles of acid to grams using the molar mass of the acid.

14. Calculate the % acidity of your vinegar sample.

$$\% \text{ acidity} = \frac{\text{grams of acid}}{\text{grams vinegar}} \times 100$$

15. Read the label and compare your results to the company's advertising on the bottle. Do a percent error analysis taking their advertising as the accepted value. Comment on your performance for the first day on the job.

16. Describe below how this type of final was easier than a traditional final.

17. Describe below how this type of final was more difficult than a traditional final.

Appendix F:

Light Unit Pre/Post Test

Name ____________________ **Date** ________________

Two-Tiered Multiple Choice Questions on Light

1. An object is blue because it
   a.) absorbs blue light from its surroundings
   b.) reflects blue light to its surroundings
   c.) is a mixture of green and yellow light

Explain your choice thoroughly:

2. Which of the following situations does not involve waves?
   a.) water in an ocean
   b.) sound traveling through the room
   c.) a moving baseball
   d.) all of the above would have wave properties

Explain your choice thoroughly:

3. Sunlight produces “white light”. Which of the following is not a component of white light?
   a.) red
   b.) blue
   c.) violet
   d.) none of the above
   e.) all of the above

Explain your choice thoroughly:

4. Light is composed of
   a.) particles
   b.) waves
   c.) none of the above
   d.) both particles and waves

Explain your choice thoroughly:

5. Which of the following waves would be most energetic?
   a.) green light waves
   b.) X-ray waves
   c.) microwaves
   d.) radio waves

Explain your choice thoroughly:

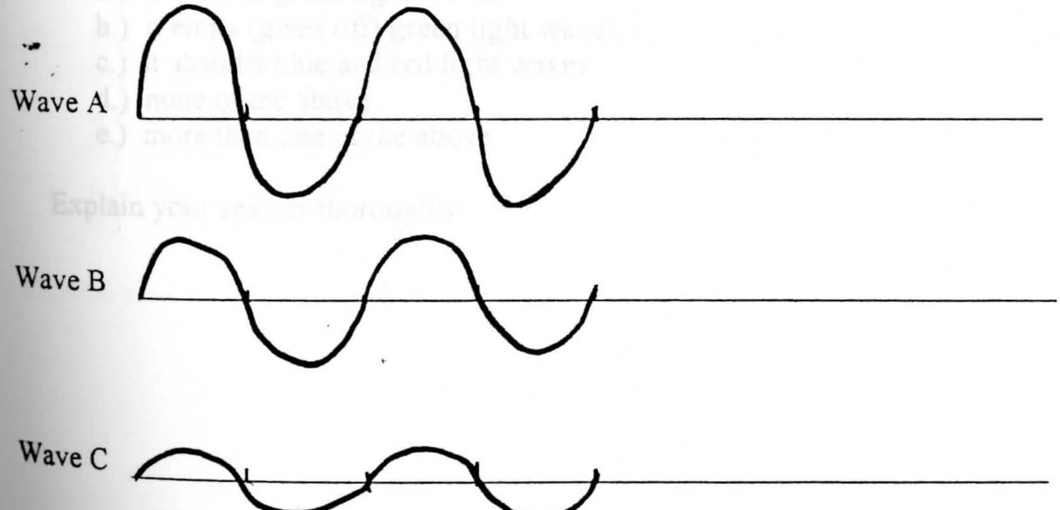
6. Which of the following waves would not belong in the same category as the others?
   a.) red light waves
   b.) microwaves
   c.) radio/television waves
   d.) ultraviolet waves
   e.) none of the waves belong to the same category
   f.) all the waves belong to the same category

Explain you choice thoroughly:

7. When two waves hit one another:
   a.) they bounce off each other and nothing happens
   b.) the peaks join one another and they become larger
   c.) the peaks cancel each other out and the waves flatten
   d.) none of the above happens
   e.) more than one of the above happens

Explain your choice thoroughly:

8. Examine the diagram below. Which wave will travel faster?



Explain your answer thoroughly:

9. Light is composed of
   a.) waves
   b.) particles
   c.) both waves and particles
   d.) neither waves nor particles

Explain your answer thoroughly:

10. A chemical is green because
   a.) it absorbs green light waves
   b.) it emits (gives off) green light waves
   c.) it absorbs blue and red light waves
   d.) none of the above
   e.) more than one of the above

Explain your answer thoroughly:

11. Which one of the following is not a possible source of light generation?
   a.) an atom emitting photons
   b.) a fluorescent bulb
   c.) a vacuum in space
   d.) two pieces of metal rubbed together
   e.) all of the above
   f.) none of the above

Explain your answer thoroughly:

12. The general relationship between energy and the wavelength of an electromagnetic wave can be described as
   a.) directly proportional
   b.) inversely proportional
   c.) magnetically proportional
   d.) disproportional

Explain your answer thoroughly:

13. The general relationship between energy and the frequency of an electromagnetic wave can be described as
    a.) directly proportional
    b.) inversely proportional
    c.) magnetically proportional
    d.) disproportional

Explain your answer thoroughly:

14. Which of the following is true?
    a.) Red light has less energy than blue light.
    b.) Radio waves are more energetic than microwaves.
    c.) Gamma radiation has a higher frequency than X-rays.
    d.) None of the above is true.
    e.) Two of the above is true.

Explain your answer thoroughly:

15. As the wavelength of a wave increases, the energy
   a.) decreases
   b.) increases
   c.) remains the same

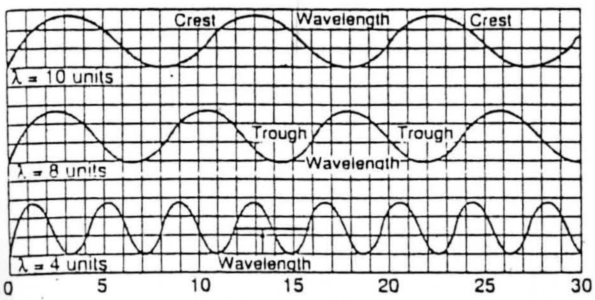
Explain your answer thoroughly:

16. As the frequency of a wave increases, the energy
   a.) decreases
   b.) increases
   c.) remains the same

Explain your answer thoroughly:

17. The waves in the diagram below all have the same
    a.) frequency
    b.) wavelength
    c.) amplitude

Explain your answer thoroughly:



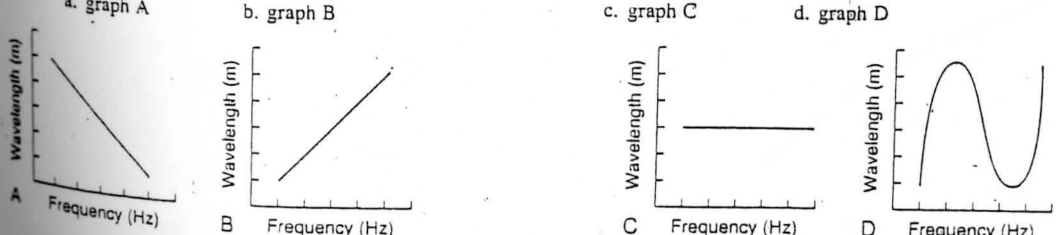
18. As the wavelength of a wave decreases, the frequency
    a.) decreases
    b.) increases
    c.) remains the same

Explain your answer thoroughly:

19. Which of the following graphs represents the relationship between wavelength and frequency the best?

Explain your answer thoroughly:

a. graph A b. graph B c. graph C d. graph D



Appendix G:

Acid/Base Unit Pre/Post Test

Name ______________________ Date ________________

Two-Tiered Multiple Choice Questions on Acids/Bases

1. Which of the following compounds would be considered to be an acid?
   a.) $CH_3CH_2CH_3$
   b.) $BaSO_4$
   c.) HNO_3
   d.) $CuCO_3$

Thoroughly explain your choice:

2. Which of the following compounds would be considered to be a base?
   a.) NaOH
   b.) $CH_3CH_2CH_3$
   c.) $BaSO_4$
   d.) HNO_3

Thoroughly explain your choice:

3. Acids are substances that
   a.) eat away material
   b.) can always burn you
   c.) form H_3O^+ ions in solution
   d.) all of the above

Thoroughly explain your choice:

4. Bases are substances that
   a.) eat away material
   b.) make up an acid
   c.) form OH^- ions in solution
   d.) all of the above

Thoroughly explain your choice:

5. A neutral pH is
   a.) below 7.0
   b.) equal to 7.0
   c.) above 7.0

Thoroughly explain your choice:

6. An acidic pH is
   a.) below 7.0
   b.) equal to 7.0
   c.) above 7.0

Thoroughly explain your choice:

7. An acid is a(n)
    a.) electrolyte
    b.) a proton donor
    c.) an electron acceptor
    d.) all of the above

Thoroughly explain your choice:

8. A base is a(n)
    a.) electrolyte
    b.) a proton acceptor
    c.) an electron donor
    d.) all of the above

Thoroughly explain your choice:

9. During the neutralization process, the reaction of an acid and a base
   a.) forms a salt and water
   b.) causes the acid to break down
   c.) the acid changes to a base
   d.) the base changes to an acid

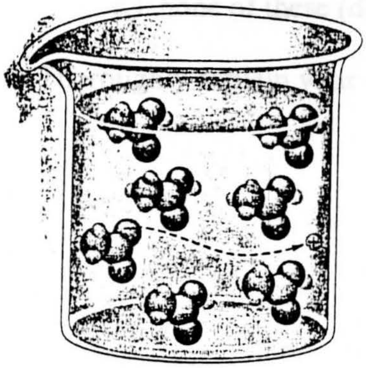
Thoroughly explain your choice:

10. After neutralization, the pH of the solution is
   a.) above 7.0
   b.) equal to 7.0
   c.) below 7.0
   d.) all the above could be correct

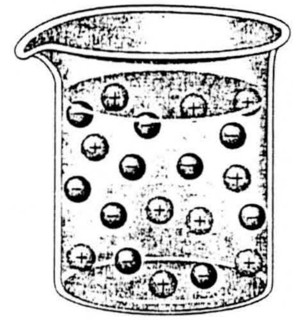
Thoroughly explain your choice:

Below are two possible diagrams of substances dissolved in water. Use these diagrams to answer questions 11-13.

A



B



11. Choose the beaker that would best describe HCl in water.
    a.) beaker A
    b.) beaker B
    c.) none of these (draw the correct one in your explanation)

Thoroughly explain your choice:

12. Choose the beaker that would best describe NaOH in water.
    a.) beaker A
    b.) beaker B
    c.) none of these (draw the correct one in your explanation)

Thoroughly explain your choice:

13. Choose the beaker that would best describe $HC_2H_3O_2$ in water.
a.) beaker A
b.) beaker B
c.) none of these (draw the correct one in your explanation)

Thoroughly explain your choice:

14. Which of the following substances would **NOT** be acidic?
a.) vinegar
b.) lemon juice
c.) ammonia
d.) all of the above are acidic

Thoroughly explain your choice:

15. Which of the following substances would **NOT** be basic?
    a.) bleach
    b.) ammonia
    c.) stomach juice
    d.) all the above are basic

Thoroughly explain your choice:

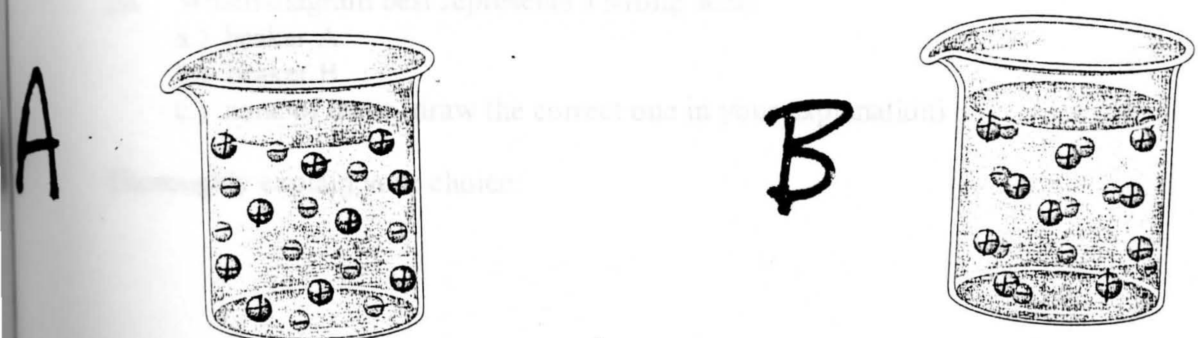
16. What is the difference between a strong acid and a weak acid?
    a.) The strong acid eats away material faster than a weak acid.
    b.) A weak acid is more dilute than a strong acid.
    c.) A weak acid only partially dissociates in solution.
    d.) none of the above

Thoroughly explain your choice:

17. What is the difference between a strong base and a weak base?
   a.) The strong base eats away material faster than a weak base.
   b.) A weak base is more dilute than a strong base.
   c.) A weak base only partially dissociates in solution.
   d.) none of the above

Thoroughly explain your choice:

Below are two possible diagrams of substances dissolved in water. Use these diagrams to answer questions 18-21.



18. Which diagram below best represents a weak acid?
   a.) beaker A
   b.) beaker B
   c.) none of these (draw the correct one in your explanation)

Thoroughly explain your choice:

19. Which diagram best represents a weak base?
a.) beaker A
b.) beaker B
c.) none of these (draw the correct one in your explanation)

Thoroughly explain your choice:

20. Which diagram best represents a strong acid?
a.) beaker A
b.) beaker B
c.) none of these (draw the correct one in your explanation)

Thoroughly explain your choice:

21. Which diagram best represents a strong base?
   a.) beaker A
   b.) beaker B
   c.) none of these (draw the correct one in your explanation)

Thoroughly explain your choice:

22. Which of the following is a strong acid?
   a.) HCl
   b.) HNO_3
   c.) H_2SO_4
   d.) all the above are strong acids
   e.) none of the above are strong acids

Thoroughly explain your choice:

Appendix H:

Interview Guide

Interview Guide – Guided Inquiry - May 2004

I= It's ________morning/afternoon May ___, 2004. I am interviewing __________ from Period __ Chemistry __________. OK, ______________. I'm going to be interviewing you today about the guided inquiry process we have been using in class this year. (Go over informed consent form) Do you understand all the points I have gone over with you in regard to the informed consent with you?

I= Do I have your permission to tape you?

I= I'd like to start out the interview with just some general questions about you. What are some extracurricular activities you've been involved in recently and what was your role in those activities?

I= Before I get into the actual questions about guided inquiry, I want to make sure that you understand that if there are any questions I ask you that you don't want to answer, that you don't have to answer those questions. Do you understand that?

I= Do you understand that all the data I collect will be kept confidential?

I= I will be using a pseudonym for you, and all the information here on the tape will destroyed afterwards. Do you understand that?

I= Do I have your permission to proceed?

I= Now I am going to ask you several questions about your chemistry experiences throughout the school year. I would like you to answer in a very candid manner to each question. If at any time you are not sure what I am asking you, please stop me and ask for clarification. Remember that I need for you to answer these questions as accurately as possible, as accurately as you remember them, and I need to hear about your feelings, attitudes, and perceptions. Don't anticipate how I would like for you to answer, since I have no expectations on the outcome of this interview. And also remember that none of the responses to these questions will influence your grade in either a positive or negative way. Are you comfortable with that?

I= I am going to start with some questions about light (first). The first question I have is "What is light?". Don't answer right away. Try not to give me what other people said in class. Tell me what that question means to you and respond to it.

I= I am now going to ask you some questions about the properties of waves. How would define the terms: wavelength, frequency, and amplitude?

I= Here is a sheet of blank paper. On this sheet of paper I want you to draw two waves having different wavelengths and frequencies. (Pause)

I= Describe to me how these waves are different from one another. Similar.

I = How are wavelength and frequency related to each other?

I = What does the speed of electromagnetic radiation have to do with all of this?

I = If I have two objects….one blue and one red….answer a few questions about these objects. Why is the blue object blue? Why is the red object red? What is similar about these objects? What is different about these objects?

I = Is visible light the only form of radiation that involves waves?

I = Let's talk about two forms of radiation….green light and microwaves….how are they similar? How are they different?

I = What does the term "Wave particle duality" mean to you?

I = Here I have a common CD. What phenomenon do you observe on the surface of the CD? Where else have you seen this phenomenon? What does diffraction have to do with this phenomenon?

(This is the point where Chemistry I and AP diverge)

I = How would you define the terms photon and quantum?

I = What do these terms have to do with light (radiation)?

I = If I were to use the two terms emission and absorption….how are these two terms related? Are they the same terms? Are they different? What does this have to do with light (radiation)?

I= OK. I'm going to shift gears now and you some questions about guided inquiry. (Query about student knowledge of guided inquiry) A recent guided inquiry activity we did was Module 4: Construction of a Spectroscope.

I = Do also remember our recent guided inquiry lesson on solutions and electrolytes? (Diffraction Simulation for Conceptual Chemistry)

I= I'd like to give you a few minutes to find the handouts from these experiences and refresh your memory. And take your time, there's no rush.

I= Now, suppose we just got a new student in our chemistry class and I asked you to describe the process of guided inquiry laboratories to them. Let's take some time to think about what you would say to them. I'm going to give you three minutes to write down what you would say to them, and let's see what you have to share with me at the end of this time.

I= Alright, __________, our three minute time period is over and I'd like you to share with me what you've written.

I= Good. Now, what would the student be expected to do ahead of time before class?

I= Alright, what do you do during class time when you're performing a guided inquiry experience?

I= Where are the people located in the lab setting?

I= Would you characterize as noisy or quiet?

I= What do you think is the teacher's role in the guided inquiry experience?

I= What do you see me doing during our guided inquiry experiences? What do I do?

I= Now, how do I assist students without actually giving out answers?

I= What don't I do?

I= And, as a student doing a guided inquiry experience, what do you wish I did do?

I= Have you seen my role change any since we started guided inquiry way back at the beginning of the year when we were investigating states of matter?

I= How does the student go about getting assistance during a guided inquiry experience?

I = What are some important things a student must do to get the most out of a guided inquiry experience?

I= Now suppose again that a student has just joined our chemistry class and I asked you describe to this student how we learn chemistry concepts in a lecture rather than using a discovery learning experience. I'm going to give you again 3 minutes what you would say to them. And let's see what you have to share with me at the end of this time.

I= Alright, I'd like you to share with me what you have to say about lectures.

I= Alright, now, along the same lines, what would the new student be expected to do ahead of time before class?

I= What do you doing class time when you're performing or participating in a lecture?

I= Where are the people located in the classroom setting during a lecture?

I= Is it noisy or quiet?

I= What do you think is a teacher's role in a lecture setting while learning chemistry concepts?

I= And how do I assist students during a lecture?

I= What do you think is a student's role in a lecture while learning chemistry concepts?

I= What are some activities you do while we're going through lecture?

I= How does a student get assistance during a lecture?

I= How do you see these two types of learning experiences as being different?—guided inquiry versus lectures—physically different and maybe in terms of experiences.

I= ___________, do you see any pros or cons of using any one method of learning versus the other?

I= We did our first discovery inquiry back when we were talking about states of matter (solutions for AP Chem). And..what I'd like you to do is to take out the activity on physical and chemical changes. And I'm going to give you about a minute to look through it just to refresh your memory, and then I'll have a few questions for you.

I= What were you thinking when we did this activity?

I= Ah, what was your level of comfort as we did this activity?

I= Did your comfort level change at all throughout the activity? Did you feel any anxiety possibly in the beginning of the activity?

I= Did you feel comfortable with the activity? Did you feel comfortable with the questions that were asked to you?

I= Alright. Um, we just had a lecture the other day on ___________. Now, I'm going to give you a minute to think about what happened during this lecture. So, take a minute and think about that lecture.

I= What were you thinking during this lecture?

I= How would you describe now your comfort level during that lecture?

I= What during the lecture made your comfort level relatively high or low?

I= What did you like most about this lecture?

I= What did you like least about this lecture?

I= Now I would like for you to look at the discovery lab we did later in the year while we were learning about hydrates. I'm going to give you one minute to look through the activity and refresh your memory.

I= What were some things you were thinking while we did this activity?

I= How did your comfort level change as we completed the activity—from when we started the activity toward when we completed the activity?

I= What made the experience more comfortable as the time went on.

I= What did you like most about this activity?

I= What did you like least about this activity?

I= Did your role in discovery experiences change between when we did the physical and chemical changes and when we did the water as a hydrate?

I= Do you think that you participated more or less?

I= Did you feel more confident as you did this discovery experience?

REPEAT FOR MOST RECENT GUIDED INQUIRY ACTIVITY

I = Alright, now we are going to shift gears again and discuss acids and bases?

I = How would you describe an acid?

I = How can you test to see if something is acidic?

I = Can you list some items from your everyday life that could be considered to be acidic?

I = What is the difference between a strong acid and a weak acid?

I = Here is a sheet of blank paper. On this paper, I want you to draw what a strong acid would look like in an aqueous solution….in a beaker. Then draw what a weak acid would look like in an aqueous solution….in a beaker.

I = Describe to me what you have drawn.

I = How could a chemist tell the difference between a strong and weak acid in the laboratory?

I = How would you describe a base?

I = How can you test to see if something is basic?

I = Can you list some items from your everyday life that could be considered to be basic?

I = What is a neutralization reaction?

I = What is the pH at the end of a neutralization reaction?

I = Are all neutralization reactions the same?

I = OK…we are on the home stretch? At the end of the unit on light, you were asked to identify the white powder thief who stole the precious hologram. Tell me how you applied the scientific method to solving this problem.

I = I would like to thank you for participating in this interview. (Go over informed consent again.) Do you have any questions for me? Comments?

Appendix I:

Scoring Scheme for Two-Tiered Multiple Choice

A method had to be devised to assess the level of understanding on the two-tiered multiple choice pre/post test questions for both the light and acid/base units. The scoring scheme for this assessment was modified from the six category scoring scheme Abraham[40] used in his study: *Understandings and Misunderstandings of Eighth Graders of Five Chemistry concepts Found in Textbooks*. Abraham had six categories in his study.

Table 2: <u>Abraham's Scoring System</u>

Degree of Understanding	Criteria for Scoring
No response	Blank, I don't know, I don't understand
No understanding	Repeats question, Irrelevant or unclear response
Specific misconception	Responses that show illogical or incorrect information
Partial understanding with specific misconceptions	Responses that show understanding of the concept but also demonstrate misconceptions
Partial Understanding	Responses with at least one component of the validated response[1]
Sounds Understanding	Include all components of the validated response

[1] The validated responses were developed from state-approved texts.

In order to accommodate this study, it was necessary to develop categories for both incorrect and correct responses. In addition, it was decided to have only one category for "partial understanding" where the student had some level of understanding, but had some misconceptions. A category of "basic understanding" was added to classify those responses that had a correct written response, but very little detail. Table 3 below lists the codes and descriptions of each code for the scoring scheme used in this study.

Table 3: Scoring Scheme for Two-Tiered Multiple Choice Pre/Post Tests

Code	Name	Description
INR	Incorrect, No Response	Incorrect choice, blank or "I don't know/I don't understand" written response
INU	Incorrect, No Understanding	Incorrect choice, irrelevant written response
ISM	Incorrect, Specific Misconceptions	Incorrect choice, illogical or incorrect written response
IPU	Incorrect, Partial Understanding	Incorrect choice, written response shows understanding, but some misconceptions
CNR	Correct, No Response	Correct choice, blank or "I don't know/I don't understand" written response
CNU	Correct, No Understanding	Correct choice, irrelevant written response
CSM	Correct, Specific Misconception	Correct choice, illogical or incorrect information in written response
CPU	Correct, Partial Understanding	Correct choice, written response shows understanding, but some misconceptions
CBU	Correct, Basic Understanding	Correct Choice, written response missing details
CSU	Correct, Sound Understanding	Correct Choice, all components of a valid written response present

Table 4: Sample Inter-Reader Reliability Data for RR's Pretest

Question	Researcher Score	Assistant's Score
1	CBU	CPU
2	CSM	CSM
3	ISM	ISM
4	CBU	CPU
5	CBU	CBU
6	CBU	CBU
7	IPU	ISM
8	IPU	ISM
9	ISM	ISM
10	ISM	ISM
11	INU	ISM
12	ISM	ISM
13	INU	INU
14	CBU	CSU
15	ISM	ISM
16	ISM	ISM
17	CNU	CNU
18	CNU	CNU
19	INU	INU
20	CNU	CNU
21	INU	INU

22	ISM	INU

Appendix J

Sample Coding System for Pre/Post Data as Entered into SPSS

Appendix J:

Sample Coding System for Pre/Post Data as Entered into SPSS

Table 5: Sample Coding System for Pre/Post Data as Entered into SPSS

Variable	Variable Name	Code
lighta1	Question 1 Light Pretest	1 = INR 6 = CNU 2 = INU 7 = CSM 3 = ISM 8 = CPU 4 = IPU 9 = CBU 5 = CNR 10 = CSU
class	Class Level	1 = AP Chemistry 2 = Chemistry I 3 = Conceptual Chemistry

Appendix K:

Sample Interview of an "A" Student Enrolled in AP Chemistry

I: It's Friday afternoon, May 28th, 2004. I am interviewing BA from Period 10/11 AP Chemistry. O.K., B, I'm going to be interviewing you today about the guided inquiry process we've been using in class this year. And, uh, first of all, I want to go over the Informed Consent form. It says in this paragraph here that your child will be asked to allow me to use his or her data. Are you comfortable with that?

B: I am.

I: O.K. There are no risks to you personally. The data will be collected and handled in a strictly confidential manner. No one will be able to identify your data personally as yours, and there will be no penalties for anyone not willing to participate or there will be no positive things added to your grade as a result that you have participated. O.K.?

B: O.K.

I: Um, do I have permission to tape you?

B: Yes.

I: O.K. I'd like to start out the interview with just some general questions about you. What are some extracurricular activities that you have been involved in recently, and what was your role in those activities?

B: In Natural Helpers I was the Secretary. I was a member of the Drama Club a number of debate forums and a number of Art Club. I am also a member of National Honor Society, and I'm involved in the plays in the school.

I: O.K. Now before I get into the actual questions about guided inquiry I wanted to make sure that you understand that there are if there are any questions I ask you that you don't want to answer, you don't have to answer those. Do you understand that?

B: I do.

I: O.K. Do you understand that all the data I collect will be kept confidential?

B: Yes.

I: O.K. I will be using a pseudonym for you, and all the information here on the tape will be destroyed afterwards. Do you understand that?

B: I do.

I: O.K. And do I have your permission to proceed with the interview?

B: Yes.

I: Now, I'm going to ask you several questions about your chemistry experiences throughout the school year. I would like you to answer in a very candid manner to each question. Uh, if at any time you're not sure what I'm asking you, please stop me and ask for clarification. Remember that I need for you to answer these questions as accurately as possible, as accurately as you remember them, and I need to hear about your feelings, attitudes, and perceptions…which has never been a problem for you. [B laughs] Don't anticipate how I would like for you to answer, since I have no expectations on the outcome of this interview. Also, remember that none of these responses will influence your grade. Are you comfortable with that?

B: I am.

I: Considering I've already turned your grade in, so...[B and I laugh]. I'm going to start with some questions about light. The first question I have is what is light. Now, don't answer this question right away.

B: O.K.

I: And try not to give me what other people said in class. Tell me what the question means to you personally and respond to it. If somebody were to come up to you and ask you, "B, what is light?", how would you answer that?

B: Energy.

I: O.K.

B: It's photons.

I: Now, while we're doing this interview, I won't affirm or give you any concept of whether you're answering correctly or incorrectly, just so you know that.

B: I know. [B laughs] This is going to be interesting for you. Um, energy and photons…I don't know…it can…What is it? I can tell you how it behaves. It can behave in wave or as particles.

I: And don't get frustrated. Just tell me your perceptions. There are no right or wrong answers to these questions.

B: O.K. Um, how detailed do you want this answer to be?

I: As detailed as you would like to give me. [B laughs] If you told me all that you have to say, that's fine. We can move on to the next thing.

B: Well, I might have.

I: O.K. Um, I'm going to ask you some questions about the properties of light.

B: O.K.

I: So, how would you define the following terms. The first one is wavelength.

B: The distance from one point on a single wave to the same point on the next wave or mixed with trough to trough or crest to crest.

I: frequency

B: Um, how many waves pass a certain point in a given time frame.

I: And how about amplitude?

B: The distance from the wave at rest or the origin…I'm not sure what the correct term for that is…..to the highest point on the crest or the trough.

I: O.K. I'm going to give you a blank sheet of paper. On this blank sheet of paper I want you to draw two waves having different wavelengths and frequencies. [long pause] Alright, B, I'm going to have you put your name at the top because I'm going to use what you draw for me as data. [pause while subject draws waves] Describe for me how these waves are different from one another.

B: Um, in about the same distance from where the wave starts, um, there are four waves on the second diagram, and there are only two on the first. The wavelength is greater at the top on the first diagram than it is on the second, but the frequency is greater with the second diagram than it is with the first.

I: And can you tell me how they're similar?

B: They're amplitude is about the same.

I: O.K. Anything else that makes them similar?

B: Um…

I: Not that there has to be..

B: They're inverse…well…I don't think so.

I: O.K. How are wavelength and frequency related to each other?

B: Inversely.

I: And what does that mean?

B: It means as the wavelength increases the frequency will decrease and vice versa.

I: What does the speed of electromagnetic radiation have to with all of this?

B: [B laughs] Um…

I: We may have used the term speed of light.

B: Well, yea…that would be the only thing I….hmmm….The speed of light has a specific, um…Electromagnetic radiation all travels at the same speed. It's….I'm confused as to what exactly you mean by the question.

I: O.K. We just…I just asked you how are frequency and wavelength related to each other.

B: Uh, huh

I: And I, now I'm asking you what does the speed of light or electromagnetic radiation have to do with wavelength and frequency.

B: Um, wave….

I: Was there any equation in class or anything we learned

B: Yes [B laughs]

I: that related

B: Um, the speed of light is equal to the wavelength times the frequency of a wave.

I: O.K.

B: I think.

I: You think?

B: If I'm remembering that correctly. Because I believe it was c=□□.

I: Umm, huh…

B: Yes

I: Now…If I have two objects one that's blue and one that's red. We know that you like these questions. [B laughs] After a few questions, I want you to answer a few questions about these. O.K.?

B: Yea

I: Why is the blue object blue?

B: Because it, um, absorbs all wavelengths of light with the exception of the blue unless it absorbs them all and re-emits the blue. That's what it does.

I: And why is the red object red?

B: It absorbs all wavelengths of light and then re-emits the red.

I: What is similar about these two objects?

B: Um, they both only reflect…they both absorb, um, orange, yellow, blue…orange, yellow, purple, green, and purple wavelengths.

I: What's different about these objects?

B: One reflects…one emits blue, one emits blue wavelengths, one emits red wavelengths.

I: Is visible light the only form of radiation that involves waves?

B: No.

I: So, what are some others?

B: Um, infrared and ultraviolet are the closest to the visible light spectrum. There's also radio waves, microwaves, X-rays, and gamma rays.

I: Now, let's talk about two forms of radiation. Let's suppose we have one object emitting green light and another object emitting microwaves. How are they similar?

B: Um, they're both being emitted in waves. They….how are the waves similar?

I: or just the objects in general.

B: An object emitting green light and an object emitting microwaves?
I: Right. Um, how are those two forms of radiation similar? Is there any way they're similar.
B: I'm probably missing something very obvious right now, but, um….
I: Well, let's deal with how they're different, and then maybe you'll feel more comfortable answering that first.
B: Well, one of them has a longer wavelength and, I believe….I have to think about this because I usually mix up the…
I: That's alright, take your time.
B: wavelength and frequency. Um, more energetic waves have a higher frequency. And I believe that X-rays and gamma rays have a higher energy level than the opposite side of the spectrum. So, the wavelength of the microwaves will be greater with the green light. Um, because visible…microwaves are less energetic than visible light. So, they have…wait…so, they have a lower frequency; and, therefore, a higher wavelength.
I: Sounds like a good answer. Now, you said that they are similar because they both involve waves.
B: Yea.
I: Do you have any other ways that they are similar. Not there have to be any other ways, but…I'm just trying to get as complete information from you as possible.
B: They're…
I: If you don't know of any other ways, then we'll move on.
B: I'm gonna say no…
I: O.K…What does the term wave-particle duality mean to you?
B: That light can act as both as particles and as waves. It can….[pause] I have the worst memory…um, it has…[pause]…Well, light has many different properties. It acts in two different ways. Like it can be diffracted and reflected and a lot of other words I can't think of right now. But, um, they, in some cases, light will act as though it is a wave. In other cases it will act as though it's in separate photon particles.
I: Can a scientist observe both characteristics at the same time?
B: No.
I: O.K. I'm going to give you a CD here. That's a common CD.
B: Uh, huh.
I: What phenomenon do you observe on the surface of the CD.
B: Light being diffracted.
I: O.K.
B: If that's the right word.
I: Do you see anything.
B: White light is being reflected from the CD as the rainbow.
I: And what colors do you see in the rainbow?
B: red, orange, yellow, green, blue, and violet
I: Where else in your everyday life do you see this phenomenon?
B: Um, after it rains.
I: After it rains? O.K. Anywhere else?
B: Um, in the hose, when you spray it outside.
I: O.K.

B: Um, in oil.
I: In oil. O.K.
B: Um, prisms.
I: Where would you find prisms in your everyday life?
B: In a stained glass window in front of my house that's just class cut at different angles and it, um, turns the whole front hall into rainbow things [B laughs]
I: O.K. What does the term diffraction have to do with this phenomenon?
B: Um, white light is all the wavelengths of light together and, um, when it hits the grooves at different angles it reflects, I think it reflects different wavelengths of light. It bends the light at different…because the wavelengths….let me start over. The light hits, white light hits the grooves in the CD and, since all those different wavelengths of light bend at different angles, it comes out…it reflects back to out to our eyes as separated colors rather than one beam of white light.
I: O.K. How would you defined the following terms? Photon
B: One individual particle of light. Hmm, the smallest…[pause] yea.
I: O.K. How about quantum?
B: A bundle of photons, a cluster of photons.
I: What do these terms have to do with light or radiation?
B: Um, when light is emitted it's in photon form, I guess. Um, this is going to be a hazy area.
I: O.K. If I were to use the two terms emission and absorption, how are these two terms related?
B: Um, well energy can be emitted or absorbed. Um, when an object absorbs energy…[pause]…I like to make things into words….um
I: Let me ask you this. Are they the same terms?
B: No, when you…
I: Are they different?
B: Yes.
I: And what, how are they different?
B: When you absorb energy…I don't know if this will be the correct usage of the words system and surroundings…
I: That's O.K.
B: but, um…
I: Give it a try.
B: When you're absorbing energy, the energy is going from…no…you can't…because energy can be absorbed from the system. If something absorbs energy, it takes energy from the outside or its surroundings and it now has that energy. If it emits energy, it lets energy…can I talk about exothermic and endothermic?
I: Sure, you can talk about anything you'd like to. [B laughs]
B: O.K. Um, an endothermic reaction would emit heat, right? No, heats not the correct term. Umm
I: Don't get hung up on terminology.
B: O.K. Um…the energy flow would be from the system to the surroundings. Um, so the surroundings are absorbing heat from the system, and the system is emitting heat to the surroundings.
I: What do these terms have to do with light at all?

B: Well, a red object absorbs all wavelengths of light and then re-emits the red wavelength. I....

I: Does it have anything to do with the production of light?

B: I know I didn't think so before this class, and I can't remember if you said that it....

I: For example, say a gas discharge tube, how is that working...

B: Um?

I: A gas discharge tube....those are the black things I set up that had plugs in them and there was a glass tube that I put in them. One was hydrogen, one was helium, one was mercury.

B: Yea.

I: And you looked at them through the spectroscope.

B: Yea, yea

I: What absorption/emission is going on there?

B: It's absorbing the white light....wait...

I: How do those tubes work?

B: That's a really good question. [B laughs] Um...

I: If you don't, I don't want to muddy the waters.

B: I actually don't know how they work.

I: O.K., then let's move on. O.K. I'm going to shift my gears now and ask you some questions about guided inquiry.

B: O.K.

I: Do you know what guided inquiry is?

B: Let me guess it has something to do with those pre/post test things you kept giving [B laughs]

I: Yes. If someone asked you to define guided inquiry, how would you define it?

B: Um...finding out what we know before we actually do activities or hear, learn something...find out what we know before hand and then, um, find out what we know after we spend some time working on, with the specific subject [B giggles]

I: O.K. Uh, an actual guided inquiry activity is when you made a spectroscope. So, when you think about that, what I was doing was allowing you to experiment with it, and I told you nothing about the theory behind it beforehand. You did not learn about a continuous spectrum or a line spectrum until you actually performed the lab. And that's where you were exposed to it. So, guided inquiry gives you an opportunity to see the phenomenon, and YOU think about it rather than the teacher telling you about it.

B: O.K.

I: Does that make sense?

B: Yea.

I: Do you remember and activity also dealing with diffraction where...we, uh,....no...I have to cut that one because we didn't have the slides yet. So, you would not remember that. But you do remember looking at the CDs, right?

B: Yes

I: And, also, the ICE slides where we passed the laser through the ICE slides to form the diffraction patterns. Do you remember those?

B: Yes.

I: Those are all guided inquiry activities. Um, I'd you to take a few minutes and have you, um, find the handout from that experiment. And what you can do is actually borrow one of the Conceptual folders back there…

B: O.K.

I: Because they have them nice and neatly organized. [B retrieves one of the folders] Now, suppose we just got a new student, say Joe. And this student just entered our class, and I didn't have time to sit down with Joe to tell him what guided inquiry was about. And Joe never did any guided inquiry at his previous school. And I ask you to tell Joe, um, what guided inquiry is all about. I'm going to give you another sheet of paper, and I want you to write down what you would say to Joe about guided inquiry. I'll give you maybe like about 3 minutes or so to do that. [3 minute pause] Alright, B, our time's up. So, would please share with me what you've written.

B: I wrote that it's a chance to explore an area of chemistry and make completely objective observations of your own and that you should try to make your own connections. That way you'll understand and remember the concept better than if you read about it in a chapter of your book or heard the teacher explain it. And it's a hands-on way of learning.

I: Alright…What would Joe be expected to do ahead of time before class for guided inquiry.

B: Um, read the directions for the papers. You'd…uh, wait…is this…would you have given us any packets of papers [I shakes head NO]…then absolutely nothing.

I: O.K.

B: Just to show up and follow directions.

I: What do you do during class time when you're performing guided inquiry?

B: Um, can I use the example of the spectroscope?

I: Sure, absolutely.

B: Um, we put a spectroscope together with a cardboard tube and some black paper and a diffraction grating and, um, we observed different types of light like the fluorescent light in the room [bells ring] and the sunlight from outside, um, and how that light, um, is diffracted inside the tube. And you had set up for us the black…What are they called again?

I: The gas discharge tubes

B: Yea…the gas discharge tubes with the different elements inside, um, so we could view those through the spectroscope and record our observations and…

I: So, what tasks do you see yourself doing, then.

B: Um, in making it or…

I: Just in general…if you're doing guided inquiry. What types of tasks do you see yourself doing?

B: Um…

I: Not specific, just general tasks.

B: making an observation

I: O.K…observing.

B: Yea.

I: Um, where are the people located during guided inquiry?

B: Other people in the room?

I: Yea.

B: Spread out doing their own thing.
I: Would you characterize guided inquiry as noisy or quiet?
B: Um…[pause]…I would say that people helped each other with something like looking through the wrong end of the spectroscope. I would say it's quieter than…hmmm…I'd have to compare it to something else. Um, in comparison to taking notes, I'd say it's louder, noisier than taking notes.
I: Um, what do you think is the teacher's role in guided inquiry?
B: Um, if you have a question, you're welcome to ask. Um, you're mostly just there to let you know if you're heading in the right direction with your own observations and connections.
I: Now, what do you see me doing during guided inquiry.
B: [flippantly] Sitting at your computer saying you hate hearing your name. [both laugh]
I: O.K. That will be a very interesting response. [both laugh more]
B: Looking pleased when people ask you questions that let you know they are on the right path and, um, letting someone know if they are going off on a tangent, basically.
I: O.K. How do I assist students without actually giving out answers?
B: Hints…I, um, you told us what to do, and you would give us examples of, say, a phenomena like light diffracting through a prism and telling us to think about something like that and see how it would relate to something like this. I don't know if that's a good example for that particular, um task…
I: How it relates to the spectroscope?
B: Yea, how something from real life would relate to something in a chem lab.
I: Uh, what don't I do?
B: Directly answer questions, but we want you [B laughs] to.
I: So, I'm notorious for that?
B: Oh, yes!
I: Um, as a student doing a guided inquiry experience, what do you wish I did do?
B: Um, as far as learning things, I think, you not answering the questions was more helpful than it would have been…ah, as much as I wanted you to tell me what the answer was so I could write it down and take a nap, but…What would I have changed?
I: No. I think you've answered the question.
B: I did answer the question?
I: Yea.
B: O.K. Alright.
I: So, you would have preferred for me to answer your questions
B: well
I: directly.
B: The lazy me, yes.
I: Yea. The lazy me [I smiles]. O.K. Have you seen my role change throughout the year as we've done more guided inquiry.
B: Um, yea, definitely. Um, [B giggles] I did have to read more in the book, um, to fully understand things I didn't understand myself. Um…you've done a lot more handing us the instructions and telling us to have fun in the lab. [both laugh] Um, you've done a lot less lecturing, and you still gave us notes, but, um, you didn't really

beat the concept into our heads. You just kinda had us write stuff down and have us figure it out for ourselves.

I: Now, what do you personally do during guided inquiry?

B: Um, look for shortcuts [B laughs] to be completely honest. Um…

I: So, you're saying your goal is to get to the final answer as quickly as possible?

B: I'm..sometimes. I would say that…yea…yea…I…I definitely want to get to the answer as quickly as possible, but I like finding…probably has nothing to do with this particular question, but I'd rather be efficient, um, in the lab and multitasking isn't efficient, but I try to make it [B giggles] work like that.

I: How does the student go about getting help or assistance during the guided inquiry experience?

B: From you or some other students?

I: In general.

B: Um, if you don't understand the directions for something or don't understand what you're supposed to be doing, you can either ask, um, another student or ask you. But, um, sometimes I sit around and watch everyone else [both laugh] and hope they would do the right thing. Um…

I: But we all know about sheep jumping off a bridge.

B: Oh, yea…that's happened plenty of times [B laughs]. Trial error a lot, you know, put something together and see if it works, if not, try again.

I: What are some important things a student must do to get the most out of a guided inquiry experience?

B: Not copy the paper from someone else [B laughs]. Make an honest attempt to understand the concept and follow the directions and try to make your own connections rather than asking everyone else what they did.

I: Alright, now, suppose again we get a new student. This time the student's, say, Mary, O.K.?

B: O.K.

I: And…I ask you to describe to Mary what we do during lecture rather than guided inquiry. I'm going to give you time again and I want you to write on that paper what you would tell Mary about lecture. [3 minute pause] Alright, B, I'd like you to share with me what you have to say about lectures.

B: Um, it's important to take notes, um, not just what you write on the board, but also, um, any concept that you don't understand fully and you want to ask a question about it later or anything that might be important later or something you won't remember. Um, but if you do write it down from the board, if it's important enough for you to write it down, it's definitely important enough for us to write it down in our notebooks. Um, and to ask questions, because if you don't understand something, um, you should ask because if you don't get it now, you're not going to understand the next concept, because everything builds on the next thing. Um, if we don't understand redox equations, we never would have been able to understand equilibrium. It would have been pointless to go through all that learning just to not get it at the end because you misunderstood it at the beginning. Also, to read the chapters afterwards as a review. Um, because a lot of times, something that did not quite make sense when you heard it will make more sense when you see it written down on paper.

I: I think you already answered this, but I'm going to ask you again what would the new student be expected to do ahead of time before class?

B: Um, read the chapters. Um, read anything you asked us to read. Um, a lot of the time you said to wait to read some things, um, as to not have any misconceptions about something the book either explained in a confusing way or erroneous, but..

I: Although, Dr. Zumdahl is RARELY erroneous. [both laugh] Um, what do you do, um, during class time when you're participating in a lecture?

B: Do I have to be honest with you? [B laughs]

I: As honest…Yea, I told you, you need to be as accurate as possible. O.K., um, I write down everything you have on the board. If I'm really tired, I zone out and hurry up and copy everything down I just missed. Um, I try to, I do try and listen because I know there's a lot of things you do not write down that I, I am gonna need to write down in my notebook. Um, and that's what was hardest for me in studying, going back through my notebook was that I had obvious missing holes because I didn't write things down that you had written on the board that I should have been paying attention to or just didn't remember it. Um, I followed along in the book in a lot of cases, if you were addressing someone else for a question that they had and there was something from earlier that I wanted to see written down I'd find it in the book and read a section underneath a diagram or, um, ah, paragraph that looked like it would be helpful. Um, sometimes if you were explaining something and I didn't understand what it was I would ask the person next to me or I would just ask you if you weren't looking too agitated with our lack of [B laughs] accelerated learning.

I: Where are the people located during lecture?

B: Sprawled across the room looking very comfortable [both giggle]. Um, when it was a double period lecture, we all just kinda got comfortable and pulled out our pencils and paper. Um, M likes to look at the ceiling.

I: Is it noisy or quiet during lecture?

B: Um, there isn't talking going on over you, but people do ask questions if they don't understand something, um, or whisper to each other explaining something. It's not too noisy to pay attention, but it's not weirdly quiet either.

I: Except when K is talking. [both laugh]

B: Yes.

I: Now, what do you think is the teacher's role in a lecture setting while learning chemistry?

B: Um, to present the information and make sure that everybody has a general idea of the concept especially if they're going to be working with it and have a chance to build a better understanding. Um, just that everybody gets the main concept to understand what's going on. Um, and have different ways to explain it to someone if they are not quite understanding the first way that you present the information.

I: O.K. And how do I assist students during a lecture?

B: Um, would you consider doing board problems, the board problems would be lecture?

I: Yea.

B: O.K. Um, when someone's up at the board doing a problem, um, you're directing the entire class, um, kinda pushing us in the right direction of where the problem's is to go. Um, letting the person on the board know if they're going way off track, and you let them go a little bit off, off on something, but you let them try to find their own errors. Um, what was the question again?

I: How do I help or assist?

B: How do you help or assist. O.K. If you're up in the front talking and somebody's completely lost on a subject, you try to find out where they got lost and backtrack to that point because you can't explain something if they don't understand the concept before it. Or you tell them to come in to tutoring because they're too [B laughs] lost to go back.

I: Hmm...that's fair. What do you think is a student's role in a lecture while learning chemistry?

B: Paying attention mostly. And, um, not just mechanically writing everything you put on the board. Um, actually trying to think and, um, understand things ahead of time. Um, it's nice to try to figure out where heading with something before you get there because it's easier to understand if you make the connection yourself.

I: Alright, do you have anything to add to what you do during our lectures?

B: Um, you count sleeping? [B laughs] I've done that a couple of times. Um, what did I say before, just take notes and ask questions? [I nods] Sometimes if the person next to me doesn't understand something, I'll take time out and explain it to them, especially if it's something simple, um, so that you can continue explaining the whole thing rather than interrupting the whole class for one little misunderstanding. Um...[pause]...doodle.

I: Doodle? O.K. [both laugh] If a student's having problems, how does a student get assistance during a lecture?

B: Either by asking you or asking the person next to them. Um, there are times that I just waited for the next problem to see if I could just follow along with that one and understand that one. In the book there's a lot, the book helps in somewhere to go with the problem, and if I don't understand that rather than, you think a lot of times I ask you how to do a problem...but if I never looked at the book, you'd have a lot more questions [both giggle] Um, and sometimes I would go people outside of class, um, who I knew understood something like T, actually wasn't very good at explaining some things. It made sense to him, but, um, just somebody who knew what they were doing. Um, just like five minutes explaining a problem to you.

I: Alright, now, how do you see these two types of learning experiences as different, guided inquiry and lecture? First of all physically different, how do you see them as physically different?

B: Lecture's a lot more boring. Um, it's harder for me to pay attention during lecture. Um, because I'm not actually doing anything. I'm....is...is the word kinesthetic?

I: Uh, huh.

B: I'm a kinesthetic learner rather than a ...I mean auditory and visual helps, but for me to really understand something I have to do it. And you make more of your own connections, um, in guided inquiry. You can, um, try and make your own connections during lecture, but you don't always, you don't have the opportunity to think at a pace faster than the teacher's teaching. Um, you asked how they're different, right? [I nods] I would say, I would say...it's a more casual learning environment, um, doing the guided inquiry, but it's still, um....hmm...

I: As far as experiences when a student leaves my classroom after guided inquiry versus a lecture, how do you think the experiences are different for that, that student.

B: You usually don't remember anything from the lecture. You wrote it down, but it went in one ear and out the other. Um, with the guided inquiry, um, the fact that you did it yourself, um, it's an actual memory, um, and if you need to recall a concept, you can recall a memory from something you did rather than a word you read on the board, which is a lot harder to remember to me than something that I actually made and observed in the lab myself.

I: Do you see any pros or cons of using any one method of learning versus the other?

B: Um, with the lecture, all the information is there and you are just regurgitating it onto your paper. With the guided inquiry, um, you don't even answer all the questions that we have, um, directly. Whereas, most of the time you would in a lecture. Um, with the guided inquiry, we are forced to think for ourselves. Um, what I think prepares us better for college and a job. I mean, there's not going to be someone there all the time telling you what the answer is. In a lot of job settings, especially in chemistry, your job is to find the answer for yourself, um, or for, doing for other people.

I: We did our first discovery or guided inquiry lesson back when we were talking about solutions. Um, and what I'd like for you to do is to take out this activity on solutions and I'm going to give you about a minute to go through it just to refresh your memory. [1 minute pause]. What were you thinking when we did this activity?

B: Um, before, during, after?

I: Anytime.

B: Um…

I: Is there anything that stands out in your mind that you were thinking?

B: I was trying to figure out how, I was trying to decide whether the actual solution with, when you were trying to light the light bulb, whether it would or wouldn't and how I would be able to tell, um, beforehand. I was trying to figure out how exactly that worked.

I: How would you describe your level of comfort while you were doing this activity?

B: I get frustrated with myself when I can't figure things out. So, at some points I was frustrated. But other than that, um…

I: Did your comfort level change at all throughout the activity?

B: Yea. Um, I became less frustrated as I began to understand the concepts of like how an electrolyte worked, how the magnets oriented themselves, you know, in such a way as they would be as far away from the like charge and as close to a positive, no, to an opposite charge as they could get.

I: Did you feel any anxiety as you were doing this activity?

B: Um, not really, other than being frustrated with myself. Actually, it was probably less frustrating than listening to someone explain something that I didn't understand that is to observe and try to wait to understand it.

I: Did you feel comfortable with this activity?

B: Yea.

I: How about the questions that were asked after the activity? Where you were asked to draw the structures and…

B: Um…

I: explain why that, the structure had something to do with the conductivity.

B: That's actually something I…I like drawing. To me it's almost like a puzzle with pieces, and I like having to try to figure out how the puzzle works, um, and how the pieces fit together. So, that was pleasant and I actually enjoyed doing.
I: Now, not too long ago, we were lecturing on acids. Do you remember when were talking about acids
B: Yes.
I: and equilibrium…
B: that was…yea….I still don't fully understand acids and bases. [both laugh]
I: Now, I'm going to give you a minute to think about that.
B: O.K.
I: So, put your mind back to when we were doing acid equilibrium and pH and maybe equilibrium, all those lectures on equilibrium. What were you thinking during these lectures?
B: Overwhelmed feelings. But that was mostly at the end of the year. I had finals coming up and, um, I would…it was hard for me to pay attention to double period lecture on acids and bases because I don't have the attention span to sit and listen [B giggles]. Um…I'm trying not to go off onto an ADD tangent right now.
I: That's O.K.
B: Alright, well, um, one thing that I've been talking to my mom about a lot is ADD, and she thinks our whole family has it. Um, you don't, you can't get medication or diagnosed with it unless you have a specific problem that, or you're obviously failing in some aspect, either socially or academically.
I: So, you've survived in spite of your ADD?
B: That's my mom's biggest qualm with the, ah, the way it's dealt with now is that people can adjust to learning in different ways and most of my learning I don't do during a lecture, um, because I can't retain the information because I can't pay attention. Um, I would not even realize that I was thinking about something totally different than what was going on. There were whole other sections of the board that were written on, and I had no idea where they came from. [both laugh] That's mostly why I don't understand acids and bases section. I don't know. I would try and follow, but I would get lost, and I would try and go back and copy things down and understand and I'd miss something else.
I: So, would I be correct in drawing the analogy it's kinda like not seeing a soap opera for six months…
B: Yea.
I: then all of the sudden turning it on and wondering what happened to…
B: Yea…yea….
I: How would you describe your comfort level during these lectures?
B: Really frustrated. Um, it was, the frustration level in comparison to doing the solutions activity was a lot higher.
I: What made your comfort level so low?
B: The fact that I didn't understand it. I couldn't, um, mostly frustrated with myself for not being able to pay attention. Um, but also just frustrated that I didn't understand something that I'm, in a lot of cases all through high school I've caught on to things fairly quickly, and this particular thing I wasn't…and a lot of other things that I've

learned that are new now when I'm lectured with them, I don't catch on and I …just personal frustration. It's easier for me to understand something in a lab setting.

I: What did you like most about these lectures?

B: Partly having the information handed to me. Um, but at the same time, later on it was harder for me to go back and study something that I didn't understand when I wrote it down, how I had no idea what I wrote down. At the time, at the time it's easier to have someone say something and you just write it down.

I: What did you like least about these lectures?

B: Not having a desk in front of me so I could my feet up. [both laugh] Not…it's harder for me to ask you questions, um, about things that I don't understand when you're trying to teach it to the entire class. When you are available and everybody is doing their own thing, it is a lot easier to have you explain something, um, to a small group of people who don't understand and let the group of people who do understand continue with their own learning. Um, I felt better about asking you questions during the guided inquiry, um, because number one, I didn't want to feel stupid [B giggles], um, but I also felt like I was taking up everybody else's time in which they could be learning, so…

I: Now, I'm going to take us back to when we did the guided inquiry experiment related to limiting reagent..

B: O.K.

I: where you were told to start with 1.000 g of lead (II) nitrate and 1.000 g of potassium iodide, and you were to determine what was the limiting reagent and how much would be left over. Do you remember doing that?

B: Yea, I do.

I: O.K. What were some things you were thinking while you were doing this guided inquiry activity?

B: Um…I don't…I don't know if you can clarify. Am I thinking of the lab where we had to separate the precipitate from the solution to find out what in the solution, what ions were left?

I: Yes, that's the same one.

B: Would that be the one that my group did differently. You asked us…

I: Yes, yes..

B: to think of a way..

I: yes

B: O.K. I felt stupid, but it was actually kinda exciting to try and do something different than everybody else, um, and come up with a different way. Not that it was a new way, but it was a different way to identify something, and I will probably remember that lab better than any other lab.

I: Did it work?

B: I think it did. Yea, it did. Um, yea…it was more than what everybody else did, but it did end up coming out with the right answer.

I: Now, how did your comfort level change as we did this activity?

B: Um, I was glad I was done, but I felt that I had accomplished something. Um..

I: What made the experience more comfortable for you as time went on?

B: Um, actually having a plan and having it written out how, knowing how we were going to do it. Because some of the time I felt that were just kinda winging it [B giggles] because we weren't exactly sure how we were going to separate it, and I didn't, we knew about what we wanted, but how we were going to keep things separate and test them, we weren't really sure. The one we had figured out and a better idea of how we were going to identify the leftover solution.

I: What did you like most about the activity?

B: The fact that we could do it differently. Um, it kinda sucked that we couldn't ask anybody else how to do it, how they were doing it [both giggle] but um…

I: So, I'm going to ask you what you liked least about the activity. Was that..

B: Well, that, but I also learned better. I think I remember it better because I didn't every say "Well, what do I do next?". I had to decide what I was going to do next for myself, and our group had to decide for ourselves how we were going to do it next.

I: Did your role in guided inquiry experiences change between when we did the solutions experiment and then when we did this experiment?

B: Yea, um, with the solutions experiment, you were performing experiments and having us write down our observations. Um, it almost seemed like a cross between lecturing and doing our own guided inquiry because you were doing something but wouldn't explain why it worked that way. Um, you just wanted us to watch and figure things out for ourselves. With the….

I: the stoichiometry

B: stoichiometry one, we had to do it ourselves, which I think they're both effective ways of doing it, um, they have…they're different, um, in that, in one, you're actually learning for yourself, but in the other you do have a chance to sit back an observe something rather than think so hard about how you're going to do it next so you do it right.

I: Do you think you participated more or less by the time we got to the stoichiometry one?

B: more

I: And..did you feel more confident or less confident?

B: In that my answers were right?

I: just your confidence in general. And I guess you could compare it or discuss about your answer, how correct you were because that tends to give you confidence because you feel that you're doing this in a correct manner or finding meaningful information.

B: With the stoichiometry I knew exactly what I did with the, um, chemicals and how I set something up because I, our group set it up ourselves. We didn't have somebody else. If I had watched that experiment and not know what was going on, I don't think I would have been able to, um, answer my questions as fully or accurately as they were with me doing the work myself.

I: O.K. We're going to talk about a more recent one. You did an activity with the balloons while we were talking about shapes of molecules. You remember doing that guided inquiry activity?

B: Yea.

I: O.K. Uh, what were some things you were thinking as you were doing that activity? It was actually called Molecular Geometry with Balloons.

B: I had a lot of green balloons. That made me happy. Um, I thought it was really interesting how the balloons, the size of the balloons and having them all tied together at the same point, they would actually form the same, form the molecule, and it made molecular structure feel less random. Um, I kinda understood why a molecule with a lone pair of electrons would take up a lot more room than a molecule with a full outer shell. And I kept wanting to tie balloons on because I wanted to see what it would do next, and the balloons didn't want to stay on. [both laugh] That was kinda frustrating.

I: How did your comfort level change as you completed the activity?

B: Um, I feel like I understood the, ah, molecular structure a lot better. Um…

I: What made the experience more comfortable as time went on?

B: Um, working with somebody else helped. Um, cause I wasn't feeding off that person, but we were helping each other understand how it worked and having two extra hands was a lot easier.

I: What did you like most about the activity?

B: The balloons.

I: The balloons…O.K. What did you like least about the activity?

B: Tying the balloons to get them to stay together.

I: Ah, tricky to tie them together.

B: Yea.

I: Did your role in this discovery or guided inquiry experience, did you take a more active role in this compared to stoichiometry and then the beginning of the year?

B: Yea, because, um, with…well…with stoichiometry you didn't tell us anything other than here's a gram and here's a gram, which one's the limiting reagent. And we had to figure out how to do it ourselves. With the balloons, you did give us a packet of information. We were kinda following directions, but at the same time we didn't know where [bells ring] the directions were going to go with the balloons, um…hmm…I think the balloon activity was fun and it's gonna help me remember that how that, ah, molecular structure works, but I think I did learn more with the stoichiometry in that I had to figure out how to do it myself. I don't know if you would have been able to do that with the balloons.

I: How would you describe your confidence level?

B: Um, probably higher with the balloons because I had directions and, um, I mean with the experiment where we had to design it ourselves we could have been doing it completely wrong. And there's always that fear that it would be totally wrong and be not the best.

I: Now, I'm going to shift gears again and we're going to talk about acids and bases. And we know how much you all love those.

B: ugh

I: How would you describe an acid?

B: Um, O.K.

I: If somebody asked you what is an acid, how would you describe that?

B: Um…

I: from a chemist's point of view

B: Geez, I don't know how to pronounce it…a Lewis acid is an electron donor, I think because…let me start at a different place….the…what's the one with the u or the o with the two dots? Bronsted?

I: Bronsted

B: Bronsted

I: Bronsted-Lowry

B: Yea, an acid would be a proton donor because an acid, every acid has a hydrogen, an H^+, um, as a part of it. And all a hydrogen is, is a proton and an electron. When you take away the electron to make it H^+, it is just a proton. Um, so that would be why it's called proton donor because in neutralization, um, an acid and a base will…I may say this totally wrong….the hydrogen is taken off of the acid….um, and sometimes forms HOH or water [bells ring] with the OH from the base. Um, an acid ….don't eat them…um…it's an electron acceptor because…I think this might…I missed the electron acceptor donor thing because I was zoned out for that section of it. So, I'm not going to be able to explain that part.

I: O.K. How can you test to see if something's acidic?

B: pH paper

I: O.K. What pH range would you be looking for if something's acidic.

B: Well, if the paper turned red, it would less, less than 7.

I: Alright.

B: I think from 0-7 would be acidic. It's more acidic towards the zero and closer to neutral, um, the higher around 6 to 6.5.

I: Can you list some items from your everyday life that can be considered to be acidic?

B: Oranges, um, any citrus fruits are going to have citric acid in them. Um, your stomach has acid in it, batteries have acid, um…blood either slightly acidic or slightly basic. I think it's slightly acidic, but I'm thinking it's 7 point something for some reason…

I: So, that would make it…

B: basic. So, maybe it's slightly basic.

I: The number's actually 7.4.

B: It is 7.4? O.K. So, blood is slightly basic.

I: What's the difference between a strong acid and a week acid?

B: Um, a strong acid will completely dissociate in water, um, whereas a weak acid will not. It doesn't have anything to do with concentration. [B laughs]

I: Aha!

B: I remember that.

I: Here's a sheet of blank paper. On this sheet of paper I want you to draw a picture of what a strong acid would look like in an aqueous solution in a beaker and then draw what a weak acid would look like in an aqueous solution in a beaker. [4 minute pause] Describe to me what you've drawn.

B: Um, in the weak acid I have molecules or compounds, I don't know…they're…

I: Don't get hung up on the terminology.

B: One of them has broken apart into separate ions. Um, but the majority of the solution is actually still not dissociated. In the strong acid everything is completely broken apart.

I: How can a chemist tell the difference between a strong and a weak acid?

B: Um, a strong acid is a better electrolyte, I believe. Um….

I: So, what would a chemist do to determine that?

B: Um, use the light bulb contraption and have a solution and put the two ends of the…

I: electrodes

B: Yea, electrodes in the solution, and if the light's very bright, it would be a strong acid. If it was either not…I don't remember if a weak acid was a poor electrolyte or not an electrolyte at all…but it would either be a very dim light or not light up at all.
I: Well, um, what's required for the light bulb to light up? Or let me ask you…
B: Is it complete dissociation?
I: Let me ask you this….what are you measuring with the light bulb?
B: Um, whether it's got electro…if it conducts electricity.
I: O.K. And, um, what's needed to conduct electricity? What must you have?
B: ions
I: O.K.
B: So, a weak acid would be a poor electrolyte.
I: O.K. How would you describe a base?
B: Um, well, in the Bronsted-Lowry definition where an acid is a proton donor, a base would be a proton acceptor because it would accept the hydrogen from the acid. Um, I'm not try for the Lewis…
I: You're not going to try for the Lewis one? [I laughs]
B: [B laughs] because I think I slept through that one. It is like an acid in that a strong completely dissociates and a weak one only partially dissociates. Um, it's the opposite on the pH scale. Anything above a 7 is more basic. It's more basic the bigger the number is. The closer it is to 7, the closer it is to neutral. Um, and an acid and a base will make water.
I: mmmO.K.
B: Sometimes if it's a strong acid, it has OH in it…wait, no….
I: We're talking about bases right now.
B: Yea. [B laughs] Um…I don't remember if a strong, does the base have anything to do with dissociation?
I: Yes.
B: I was right? Why was I thinking a base with OH in it is strong and a base without OH in it is weak…
I: Well, you're talking about structure.
B: Yea.
I: Think about ammonia. O.K. And if you add water to ammonia, what's formed on the right hand side?
B: OH ions and ammonium ions.
I: So, it also makes what type of ions.
B: OH As long as it makes OH, it qualifies as strong. That makes sense. I should know that.
I: How could you test to see if something is basic?
B: Um, pH paper [both giggle]
I: And what range on the pH paper?
B: Oh, um, from 7.1 to 14.
I: Can you list some items from your everyday life that would be considered to be basic?
B: Baking soda, um, well, blood is slightly basic…um…your cleaning supplies at home would tend to be more basic. Um, you wouldn't want acid on your windows. Um, that's all I can think of for the moment.

I: What's a neutralization reaction?

B: Um, a reaction in which, I think in most, I don't know if it's in all cases, an acid and a base create water or it's just when the pH at the end the equation is 7. [B laughs]

I: I was going to ask you that. What's the pH at the end of a neutralization reaction?

B: 7 sometimes, I think.

I: What do you mean sometimes?

B: When there's a really strong acid and a weak base, um, the pH will be more acidic than it would, um, if you had a strong acid/strong base. And if you strong base and a weak acid, it would be more basic than 7.

I: What creates that?

B: I remember the diagrams…but I…[B laughs]

I: O.K. That's fine

B: Yea, I don't.

I: Alright, we're on the home stretch. At the end of the unit on light, you were asked to identify the white powder thief who stole the precious hologram. Tell me how you applied the scientific method to solving this problem.

B: Um…

I: Do you remember you were to select any technique from modules 1-7.

B: Yes. I'm trying to remember what technique I used. Um, wow…I remember doing it, um…

I: I'll go through the units: Unit one was observing waves. Unit two was the wave particle duality. Unit three was diffraction. Unit four was spectroscope. Unit 5 was when atoms get excited. Six was the firefly reaction. And then 7 was spectroscopy where we determined the wavelength of maximal absorbance.

B: That was the big machine.

I: Uh, huh.

B: I think you required us to use the seventh one and then any other one. And I believe I used five. What was that one again?

I: When Atoms Get Excited: Flame Test

B: Yes…um, we burned the powder, on…we dissolved the powder in….What was the question before I go on and tell you stuff I don't need to?

I: Oh, yea..tell me how you applied the scientific method to solving this problem.

B: Yea, um, the first…in the modules we had all the knowns and all the different things the powder could be, and we observed how they burned, um, what their flames looked like. And we wrote down all of our observations. And then with our unknown powder we dissolved it in a solution. We used Petri dishes and ignited them in the initial module, and then we dissolved them in…into…I don't know what we dissolved them in…

I: methanol

B: methanol…We made them into a solution and then, um, dipped wire into the solution. We had to clean the wires first to make sure there was no other residue. And then we would observe what color the flame was when the wire was burned with the methanol in the solution and what color that would be. We used those observations and also the wavelength of maximal absorbency testing it in the blue machines…

I: spectrophotometer

B: Spectrophotometer…um…

I: Did you have a hypothesis?
B: Before we ever started the…um, lab or after the first half of the..
I: However, you did it. So, you tell me..
B: Um, when we started they were all white powders. So, we really didn't know what it was. There was no way to know without doing experiments. After the first, the flame test we had an idea, um…
I: Was your idea your hypothesis?
B: That's what I meant. We had a hypothesis for what it could be, um, and we confirmed that hypothesis with the wavelength of maximal absorbency test and the spectrophotometer.
I: What type of data did you collect?
B: Um, observations…If I'm remembering this correctly, it was qualitative thing, it wasn't…
I: Even with the spectrophotometer?
B: No, no…Why am I saying that? Um, I'm just not remembering correctly. We had to measure…I remember I didn't like using those things very much [B laughs] because you had to be very precise. Um, well, actually, my problem is that I wanted it to stop moving, and I kept getting hung up on the numbers stopping, fluctuating…actually get through it in an efficient way. Um, yea.
I: How did you come to your conclusion?
B: Um, as far as what kind?
I: Identification, yes.
B: Um, taking the data from the two experiments and making sure they matched up to the knowns that we that they matched each other. The knowns, we identified them with the same in each equation. Doing both tests and coming out the same for both was a good indication that it was probably that particular element.
I: O.K. Well, I'd like to thank you for participating in this interview. You've given me some excellent data that I can use in my research. I want to remind you again that everything will be kept in a confidential manner. Do you understand that? And that all of this data will be destroyed afterwards.
B: O.K.
I: O.K. Do you have any questions for me?
B: I don't

Appendix L :

Sample Interview of an "C" Student Enrolled in Conceptual Chemistry

I: It's (um) Thursday afternoon, May 27th, 2004 and I'm interviewing MM from Period 7/8 Conceptual Chemistry. O.K., M, I'm going to be interviewing you today about the guided inquiry process we've been using in class this year. The first thing I want to do is to go over the Informed Consent form. Did you understand that there are no risks to you by participating in this interview?

M: Yes

I: …that the data will be handled in a strictly confidential manner?

M: Yes

I: and that no one will be able to identify you?

M: Yes

I: O.K., very good. Um, and you have signed this and we're set and ready to go. Um, do I have permission to tape you?

M: Yes

I: I'd like to start out the interview with some general questions about you. What are some extracurricular activities you have been involved in recently and what was your role in those activities?

M: Well, I am currently the president of my 4-H group. It's a horse 4-H group. I ride horses, and I've been working with horses for 6 years. I am in marching band, and I am going to be, next year, the drum major for marching band.

I: Hmmm, excellent! So, you're in the footsteps of CD?

M: [laugh] ha, possibly.

I: Alright, before I get into the actual questions about guided inquiry, I want to make sure that you understand that if there are any questions I ask you that you don't want to answer, that you don't have to answer those questions.

M: O.K.

I: Do you understand that?

M: Yep

I: Do you also understand that all the data I collect will be kept confidential?

M: Yes

I: I will be using a pseudonym for you. [bells ring] Everybody's interviews have bells in it today. [MM laughs] Do you understand that I will be using a pseudonym for you?

M: Yes

I: Do you know what a pseudonym is?

M: Like a replacement name?

I: Yes, or like a nickname. O.K.…and all the information here on the tape will be destroyed right afterwards?

M: Oh, O.K.

I: So, nothing will be kept. Do I have your permission to proceed with the interview?

M: Yes

I: O.K. Now I am going to ask you several questions about your chemistry experiences throughout this school year. I would like you to answer in a very candid manner to each question. If at any time you are not sure what I'm asking you , please stop me and ask for clarification.

M: O.K.

I: Remember that I need for you to answer these questions as accurately as possible, as accurately as you remember them, and I need to hear about your feelings, your attitudes, and your perceptions. Don't anticipate how I would like for you to answer since I have no expectations of the outcome of this interview.

M: O.K.

I: And also remember that none of the responses to these questions will influence your grade in either a positive or negative way. Are you comfortable with that?

M: Yea.

I: O.K. I'm going to start with some questions about light. O.K.?

M: O.K.

I: The first question I have…if somebody came up to you on the street and said "M, what is light?" How would you answer that question?..but don't answer right away. I want you to try not to give me what other people said in class. I want you to tell me what the question means to you personally and respond to it.

M: Well, I think that light is something that helps you see by. It also brings life, like, sun brings, helps plants photosynthesize so they can bring life so we can eat so the animals can eat them so that we can eat them so we can live.

I: O.K., anything else you'd like to add to that?

M: mmm, that's pretty much all I remember [giggle]

I: O.K. I'm now going to ask you some questions about properties of waves. How would you define the following terms? If I ask you what is wavelength, how would you define that?

M: The length that the wave travels, like, how long it is.

I: O.K. and...frequency, how would you define frequency?

M: How high or low it is…the wave is. How low or high it goes.

I: And how about amplitude?

M: [pause] um…I can't remember anything about amplitude.

I: O.K. I want honest answers, so that's good. Alright, I'm going to give you a blank sheet of paper. I want you to put your name on that paper since, um, I need to know who you are when I look at the data. I want you to draw two waves. And, on the two waves, I want you to draw two waves that have different frequencies and wavelengths. [long pause with bells ringing] Did I give you enough time?

M: Uh, huh.

I: O.K. I need you to put your name up here so that I remember that was you. [pause] Describe to me, M, how these waves are different from one another.

M: Well, the one is, uh, longer, but its, like, frequency is shorter. And the other one, it has more frequency and it's a shorter wavelength.

I: Now, you said it's longer. What is the "it" that you're talking about?

M: [laugh] the wave.

I: O.K. Show me on there what wavelength would be.

M: [M points] This wavelength's longer because it goes out more.

I: So, if I were going to measure wavelength, how would I do it on your drawing. Show me what I'd measure.

M: Going across.

I: Alright. How are wavelength and frequency related to each other.

M: Well, the wave, the frequency is, you, it determines how high or low it is and the wavelength is how long it is. So, when you're studying it, when you study wavelength you also know what the frequency is and vice versa.

I: O.K., um…what does the speed of light have to do with all of this?...wavelength and frequency.

M: Oh, how far it travels and how much travels through it.

I: O.K. M, if I have two objects, one blue and one red….I want you to answer a few questions about these objects. Why is the blue object blue?

M: Because it absorbs blue light.

I: O.K. and…I noticed you're looking for me for confirmation. [both laugh] I'm not going to say if any of your responses are correct or not. So, um, as far as you're concerned, you are doing a wonderful job.

M: O.K. [sigh]

I: Why is the red object red?

M: I would say because it absorbs red light.

I: O.K. And what is similar about these two objects?

M: They're both absorbing a color of light [PA system interrupts]

I: What is different about these objects?

M: They're absorbing different kinds of light.

I: O.K. Is visible light the only form of radiation that involves waves?

M: No.

I: O.K. What are some others?

M: Non-visible light [giggle]

I: O.K. such as…

M: Um…ultraviolet light.

I: O.K. Do you know of any others?

M: [pause] not off the top of my head.

I: You seem a little nervous, M, and that's fine. But understand that none of this is going to affect your grade.

M: I know.

I: …in a positive or negative way. So, I just want you to give me the best possible answers you can. I think you're doing a wonderful job so far. Ah, let's talk about two forms of radiation. Suppose I have something giving off green light and something giving off microwaves. Can you tell me how those two things would be similar?

M: Can you explain that again?

I: Alright, sure. Alright, we have two objects and one object is giving off green light and another object is giving off microwaves. How are those two items similar?

M: They're both giving off energy.

I: O.K. and how are they different?

M: They're giving off different kinds of energy like a microwaves is giving off more, like microwave energy is a lot higher.

I: O.K. and what cause microwave energy to be a lot higher?

M: Because smaller molecules, they have, they're more excited.

I: O.K., um, what does the term "Wave Particle Duality" means to you?

M: That there's more than one way of like, dual means like two or more and then, um….well, I'd just go by what else I learned like microwaves and crap, stuff like that, so….I would think that there's more than one wave going through.

I: O.K. Here I have a common CD, M. Alright, so I'll let you look at that. What phenomenon do you observe on the surface of the CD?

M: The colors.

I: What colors? Go ahead

M: That it gives off orange, green, and blue.

I: Alright, so those are the colors you see on there? Um, where else have you seen this phenomenon in your everyday life?

M: On crystals and stuff.

I: Crystals? O.K. …where else?

M: with water when you spray like your hose or something and you see a rainbow come out.

I: mmmK What does the term diffraction have to do with this phenomenon?

M: [pause] When you move something in the light, like it reflects off and you can see the color.

I: O.K. Um... I'm going to shift gears now and I'm going to ask you some questions about guided inquiry. Do you know what guided inquiry is, M?

M: No.

I: Let me take the CD. Guided inquiry is when you're sent to the laboratory to learn about something on your own. Rather than the teacher standing up in the front of the room and lecturing about it, the teacher sends you to observe and to be familiar with the phenomenon and try to explain it on your own. An example of a guided inquiry activity would have been Module 4 in your, um, folder there….Construction of a Spectroscope. So, take that out. Turn to Module 4. [pause while M found it] O.K. if you look at it real quickly there…before you did this, um, if you turn the page there…you had no idea what a continuous spectrum or line spectrum was. Did you know what they were after you did the experiment?

M: Yea

I: O.K. So, that's an example of guided inquiry. I didn't stand in front of the room and tell you what those items were. You went into the laboratory and you observed them and you had an opportunity to figure out what they were. Also, another guided inquiry activity was Module #3. [pause while M found it] Diffraction Simulation. Do you remember doing that?

M: Yea

I: I took the laser and I pointed the laser at the wall and you had the discovery slides you looked through and you saw the diffraction patterns.

M: Yea

I: O.K., um. So, now I refreshed your memory. Do you remember what we did in all of these activities? Now, suppose that we just got a new student in our chemistry class and I asked you, I said "M, I'm really busy right now, could you ….let's say the new student's name is Robbie. Could you take a few minutes and describe the process of guided inquiry laboratories to Robbie? Let's take some time to think about what you would say to him. I'm going to give you about 3 minutes or so to write on this blank sheet of paper what you would say to Robbie about guided inquiry assuming that Robbie's never done guided inquiry before.

I: Our time period is over and I'd like for you to share with me what you've written.

M: I said you are given a task you are going to do, and as you do the lab, you are asked questions. And as you do the lab you write down what you think the answers are. Then we go over them as a group. So, if you, you know if your answer is right or not.

I: Now, what would this student be expected to do ahead of time before they come to class?

M: You would have to make sure that you had all the materials to, before the class before you got there like your book, your experiments, the lab information. Um, you have to make sure that you had the right kind of clothes on. Like you don't want to wear shorts and stuff in the lab. And if you wear contacts you want to make sure that you take them out if you're working with chemicals and stuff.

I: Alright, now, what do you do during class time when you are preparing a guided inquiry, performing a guided inquiry experience?

M: What do we do in class time?

I: Right. So, if I give you a guided inquiry experience, what do you do?

M: Well, you, um, read the procedure to find out what you have to do in the experiment. And then you just go through it step by step. And as you go through it, you go ahead a little bit to see what your questions were. And you always make sure you've done your objectives and everything.

I: Where are the people located in the lab setting? When somebody's doing guided inquiry, where are your classmates? Where is everyone located?

M: Well, they're usually nearby. They're at their own section of the table. If you have a question you can ask somebody who's over on the other side of the table who is next to her or something. It's all pretty much in the same room environment.

I: Would you characterize this guided inquiry as noisy or quiet?

M: It's pretty noisy.

I: Why do you suppose it's noisy?

M: Cause you have a different ideas going around the room all the time. And you have people thinking out loud and talking to each other.

I: Ah, what do you think is the teacher's role in guided inquiry?

M: Just to help you along with like the lab and everything and the procedure and to actually make you, give you some more background and everything about what is going on and not tell you the answer.

I: O.K. Ah, what do you see me doing during our guided inquiry activities?

M: Well, you're walking around to make sure that everything's safe in the lab and to make sure that we're doing things right, or otherwise you're pretty much just let us do our own thing and make sure that you're doing it.

I: How do I assist students without actually giving out answers?

M: Well, you help us along by telling us to read more or to read a certain part, or if we are having trouble with things you ask us questions that would make us think differently or motivate us to do other things.

I: What don't I do?

M: I don't know..

I: Yea, O.K. As a student doing a guided inquiry experience, what do you wish that I did? Is there something that I won't do that you wish I did?

M: I've, I never really had a problem with it.

I: O.K. Have you seen my role change any since we started guided inquiry way back in the beginning of the year 'til now?

M: Yea, you had to explain a lot more in the beginning about what was going on because people didn't really understand. So, it was all real new to them. And, after a while, you just came off more and more and just kept like backing off more and more. And then everybody just kinda went on their own and learned how to do it on their own and everything. So, you made us a little more independent.

I: O.K. What do you do during our guided inquiry experiences?

M: Well, I'm always discussing things with my partner to make sure that we both know, that we're on track. And we discuss and throw ideas back and forth to see, um, what sounds the best to us or to like what might be the answer or what we saw and what we did.

I: How does the student go about getting proper assistance during guided inquiry?

M: Well, it depends on like the question. If the question's real tough like we ask each other first, and then if nobody else knows, we'll ask you. [M laughs]

I: What are some important things a student must do to get the most out of a guided inquiry experience?

M: Well, you need to pay attention to your observations. Because if you don't write down observations and everything, you can't compare to the question being asked.

I: O.K. Now, suppose again that a student just joined our chemistry class, and I ask you again…the student's name's Mary….I ask you again to sit down and describe to Mary how we learn chemistry concepts in a lecture, rather than guided inquiry. I'm going to give you again 3 minutes to write down what you would say to Mary.

I: Alright, M, I'd like you to share with me what you have to say about lectures.

M: Well, sometimes we read out of science magazines and we watch videos about science, and there's a lot of questions asked like lots of people ask questions. And a lot of them, all of them are answered. And we do work out of books with partners, and we take some notes, but things are always explained.

I: O.K. Along the same lines what would the new student be expected to do ahead of time before class?

M: Well, you'd have to make sure you had your book and your binder and all of your materials that you need like the notes you took the previous day, or, um, like a pencil or something so you can write. Like the basic materials you need for every class.

I: What do you do during class time when you're, um, participating in a lecture?

M: I like to listen to what everybody else has to say, because usually they have the same questions I do. And if I don't understand something, I'll ask, but usually I get it right away. I don't have to ask.

I: Where are the people located in the classroom setting during a lecture?

M: In their assigned seat.

I: Assigned seat…O.K. Is it noisy or quiet?

M: Well, it depends on what the questions ask. If we're doing work usually it's really if we're doing work. Sometimes if we work alone, but a lot of times we're working with a partner. So, it gets pretty noisy. But, um, when we're asking questions there's a lot of ideas flying around the room at that time. So, it's pretty noisy too.

I: Um, if you were to compare it to guided inquiry, which do you think would be more noisy?

M: Guided inquiry.

I: O.K. Why do you suppose?

M: Because you're actually working at science a hands-on thing and you're, you're ideas are being put out and you're asking questions about "Am I doing this right?". And you just kinda want your thinking about what you're supposed to do next instead of listening to somebody talk.

I: What do you think is the teacher's role in a lecture while chemistry?

M: To explain to us what's going on, but to have us think for ourselves a little bit. Like when people ask questions and everything you explain it, but you don't, you let them think about it more in depth than just to tell them the answer straight out.

I: And how do I assistant students during a lecture?

M: Well, you ask them to like read further or, um, if there's notes on the board go over and write down examples and stuff.

I: What do you think is a student's role in lecture while learning?

M: Well, you pay attention and to, um, take things down as they're given out because more than likely you'll have the same question some day. And, um, well, think about what's going on in case you have a question. And to take down stuff a lot.

I: What do you do personally during our lectures?

M: Well, I like to listen to everything that's going on around me. I listen to what's going on and whenever something's being put on the board, I take it down.

I: So, if you need help during a lecture, what do you do?

M: Well, I'd usually just ask you…or if it's a real simple question like what page we're on or something, I'll just ask the person sitting next to me.

I: Alright, now, M, we're going to look at the two types of learning: guided inquiry and lectures, and I want you to compare these two. Um, how do you see these two types of learning experiences being different?

M: Well, the, um, labs and everything are hands-on and you're doing it yourself and you're seeing things that are happening. When you're doing, talking, people we're talking about what's going on. You're not really seeing what's going on. So, you're just kinda hearing everybody talk about it. And you're reading it out of a book. So, it's not like you're actually doing it. I, I'd prefer to learn out of by doing than rather listening.

I: How are they physically different in terms of what the people are physically doing?

M: People are more active in the lab. They're doing, um, more things like moving around and making sure things they're being careful and everything. And they're awake and everything and people are like they tend to get lazy and tired when they are sitting for a long period of time.

I: As far as experiences, um, when a student leaves a guided inquiry lesson versus a student leaving a lecture, how do you think those experiences are different for a student?

M: More people will talk about what happened with the lab. They…the labs are a lot more fun. The, um, lectures like you'll talk about it, but you're kinda getting out of a seat like not like it's another day. When you're doing a lab, it's more like a hands-on thing and you're having fun, cause you're with your friends, you get to talk to your friends, you're pretty much learning with them at the same time.

I: M, do you see any pros or cons of using one method of learning versus the other?

M: Yea, I like the lab more. I think the lab was better. There's the pro. You're doing it as hands-on then.

I: When you say lab, do you mean the guided inquiry right?

M: Yea.

I: O.K.

M: That's hands-on work and you're doing that. That's the pro of it. The con against it is people goof off sometimes and it gets dangerous. The lectures, you're learning things, that's the good thing, but the con is that you're just kinda sitting there and sometimes you get bored if it's like an off day or something and you're getting real bored and you're not really paying attention as you would if you were in the lab and you were doing something more physical

I: Good. Now, we did our first discovery inquiry back when we were talking about states of matter. And what I'd like to do is to have you take out the activity on physical and chemical changes. And I'm going to give you a minute to look through it and refresh you're memory. Then I'll have a few questions for you.

I: What were you thinking when we did this activity?

M: Well, when I heard of physical change I knew that that meant something you could see it when it changed when it was actually turning into something different. Like it physically changed. It chemically changes you can't, it's something you can't see what's going on. You can see what's going on, but it doesn't actually take a complete form. When I was doing the demonstration, I knew what the physical change was, but I was kinda like rolling over in my mind what the chemical would because you don't really think of it as much when you can't physically do it or something or change something.

I: What was your level of comfort as we did this activity?

M: I felt pretty comfortable with it. I, um, I like to I really like to learn about stuff that involves chem because I like to, I like to play with fire. [M laughs] I like to do stuff like that. So, when I'm working with fire and everything, I'm safe, I just like to learn more about it.

I: Um, did your comfort level change at all throughout the activity, either get lower or higher?

M: As I went further and further, I kept gaining more confidence because I, because it was actually processing as I went further in the demonstration, so.

I: Did you have any anxiety in the beginning of this experience?

M: No.

I: No, it didn't…O.K. Did you feel comfortable with the activity?

M: Yea. I like, I like activities. I like to do things with my peers. I kinda like to have fun.

I: Did you feel comfortable with the questions that were asked at the end of the activity?

M: Yea.

I: Alright, now, we just had a lecture not too long ago. So, we're changing gears again. Um, on the electromagnetic spectrum. Do you remember there was a day when I talked about the electromagnetic spectrum?

M: Yea

I: And I had it up on the laserdisc. We also did some problems, some math problems associated with that. You don't have to dig those out, but just think about that and if you want to you can.

M: I want to.

I: O.K. [pause while M found those] Good. What were you thinking during this lecture?

M: Well, I was, I was following everything that was going on, but I was kind of wondering how it all tied together. Once everything was, once you were done explaining it, it finally clicked. But when, especially the math part, I'm not that great at math. So, it has to be explained a lot more to me. But when it comes to like logic and everything, I'm like "Oh, O.K., that's good enough." The math part is…I don't do math that well.

I: That's O.K. We all have our own talents. Now, how would you describe your comfort level during this lecture?

M: I was alright with it. Like, everything was pretty self-explanatory. Again, the math, I kinda got a little off track. Like I had to write more things down and that kinda made me fall behind a little bit more. But, other than that, I felt pretty good about it.

I: Were you frustrated when you had to do the math?

M: A little bit, but not as much as an actual math class. It was just some simple things, if like I got like a wrong calculation or something, it wouldn't frustrate me to the point to where I wouldn't know where to start. I actually knew where to start and where to get, but sometimes I came up with the wrong thing, I got frustrated.

I: Now, what doing this lecture, what, what made you, um, change your comfort level at all. What made your comfort level high, what made your comfort level low?

M: Well, my comfort level, when my, well, I was really comfortable with when we were taking definitions and everything cause I remember things pretty well when it comes to wording and everything. And when I know color and everything, but if you put numbers to it and percentages and everything, that's when I start to fall back and like I wanna slow down a little more and I'm like "Wait! Whoa!" it has to catch up a little more with that.

I: What did you like most about this lecture?

M: Well, I like all the symbols and everything cause I like to draw [M laughs] and, um, when I kept reading it over it made me feel a little smarter like with all the terminology and definitions and all the stuff. It made me feel a little smarter to look at it and actually understand what was going on.

I: So, you say you enjoyed being challenged?

M: Yea.

I: Ah, what did you like least about this lecture?

M: Well, um, drawing. I can't draw either. So, my drawings come out really crappy. [M and I laugh] So, I don't like to do things where I have to draw because if like if

I'm sitting there drawing I try to make it look right and neat. And people continue and I tend to fall behind because I have to make it look right.

I: O.K. Good. Now, we're going back to guided inquiry again and do you remember the lab we did on polymers where we made the superball?

M: Yea

I: And we made the slime

M: the slime and the glue thing

I: Yep. What were some things you were thinking while we did that activity, that guided inquiry activity?

M: I wondered what the ball would be like. Would it be actually round, would it be colorful, would it actually bounce? And with the glue I actually wondered like "What do you mean by glue? Is it going to make things stick to each other? We already have glue, why do we have to make it?" [M laughs] Why do you have to have glue to make glue. But it was actually something really cool I played with a lot.

I: How did your comfort level change as we completed that activity?

M: I really thought it was fun. My comfort level was real high at the end of the activity cause I like to play with things and I like to get messy and everything, so. As I kept going I got more and more comfortable with the activity cause I thought it was fun.

I: What made the experience more comfortable as time went on?

M: Well, the fact that a lot of my peers were getting more comfortable with it. Not only that, but understanding it. I actually understood what was going on. And, I'm not that great when it comes to remembering things, especially in science. But I remembered a lot of what was going on and I actually knew what was going on for a change and I was getting real excited that I was in on it. I was like "Yea, I know what I'm doing!"

I: What did you like most about this activity?

M: I got to make toys.

I: O.K. And what did you like least about this activity?

M: That it got things really messy and I'm not the big type who likes to clean up.

I: Did your role in discovery experiences change between when we started at the beginning of the year and when we did polymers?

M: Yea, because in the beginning of the year, I liked it when my partner would do most of the hands-on work and I would watch. I like to watch more than I like to do. When I got to the polymers, I actually wanted to do it because I liked to get into the goop and everything. It's like "Wow, I want to do that! Oh, no, wait! My turn!" And, um, I think ever since then, I've always wanted to get involved, especially when we went and did and worked with fire and stuff. I don't know…I like fire. [M laughs]

I: Do you think you participated more or less as the year went on.

M: I think I participated a lot more cause I got more comfortable with the surroundings and everything that was going on. And it was pretty much a given that we were going to do an experiment like once a week or maybe even twice a week if we were lucky. We did a lot of experiments. I liked that a lot because I learned more with hands-on. And I like the fact that when I got involved, I had fun. So, I, after one experience, I wanted to keep going cause I though it was a lot more fun than.

I: Good. Did you feel more confident as we did more guided inquiry?

M: Yea, I felt that I was learning more on my own than somebody telling me what was going on. So, I felt that, you know, my opinion actually matters. So, I got more confident with what I was doing. I was like "My answer can't be wrong here. It can't be wrong!" [M laugh]

I: Now, I want you to think about a recent activity that we did that was guided inquiry. Do you remember we did when atoms get excited? We took the nichrome wire and heated them and looked at the flame color as we heated the barium nitrate and the copper nitrate and so on. Alright, do you remember that lab?

M: Yes

I: It's pretty recent. Ah, what were some things you were thinking while you did that activity?

M: I was thinking about what the colors were going to turn out to be cause and also, um, how was things, how were things going to actually react, what was going to be the same. Like what would be the same colors. How do they compare? How do they differ? And, um, was Christine going to get burned or not? [M and I laugh]

I: Had she been burned before in the year?

M: Well, she, she touched the nichrome wire when it was a little hot. Like it, she felt the heat and everything. She really didn't get burnt, but like…when we would always play with fire and everything she usually…[M laughs]….she gets kinda clutsy. I do too, so….

I: Did anything make you anxious? How was your comfort level as you did this experiment?

M: I liked it. I liked the fact that I could just…people rushing around to get it done…but when I'm doing a lab, I just do it because I like to have fun and I really don't want to quit and do more work. I'd rather just work back there and have fun with it.

I: What made the experience more comfortable as time went on.

M: My partner…I think my other partners, they liked to take control a lot. They didn't really let, they let me in on it, but they like to do more of it themselves. And I think that when I switched partners I had a lot more fun. They actually let me do and be a part of what was going on instead of worrying that I was going to mess things up.

I: What did you like most about that activity?

M: That I got to see an actual change about what was going on and how things react in heat and a fire and stuff and how energy and light and everything is in together, how everything corresponds.

I: What did you like least about this activity?

M: Um, I constantly worried about like, I like to play with fire, but I constantly worry about getting burnt or catching my clothes on fire and stuff. So, I was constantly worrying about that.

I: Did your role in guided inquiry, um, become even greater with the last lab?

M: Yea, because it was more of our ideas put together instead of somebody's ideas didn't really want to work with me. They just wanted to get things done instead of , you know, "let's work together and be partners. No, I just want to get it done and get it out of the way."

I: So, you feel you participated more or less?

M: I think I participated a lot more.

I: And do you feel very confident at all by the end of the year doing guided inquiry?

M: Yea, I liked doing the labs and stuff like that. I enjoy that

I: As far as confidence and comfort level, which type of learning experience do you feel more comfortable with, guided inquiry or lecture?

M: Guided inquiry

I: And why?

M: Because I'm doing it myself. I can see what was going on and I can be a part of what's going on.

I: O.K.

M: And I'm learning it on my own instead of it being told to me.

I: Now, we're on the home stretch. At the end of the unit on light, you were asked to identify the white powder thief who stole the precious hologram. That was your final. Tell me how you applied the scientific method to solving this problem.

M: Well, my partner and I, we, well when we came up with the procedure we took, ah, two modules, Module 5 and Module 4, and combined them together. We figured that we could, um, get the, we find, we used the one product, the unknown and find out what color it was when it burned [bells ring] the light. And then we'd take the other, ah, chemicals that were similar to that that also burned the orange and red light because they'd all be similar then. And, um, we just did the process of elimination after that which one it was.

I: Um, what's the first thing a scientist should do when they're setting up to, um, find an answer to some particular question?

M: Well, they should, um, devise a process of how they're going to do it, and they should, um, ask themselves questions on what's going on. "Do I…what do I need for this experiment? What do I need to find in this experiment? What are some of the things I can compare this chemical to after I'm done to find what the answer is" or, um, also, they, um, they could do things like basically process of elimination and find out if it was like this or was it like this.

I: Now, did you, you and Christine, have a hypothesis?

M: Um, no…we really wanted to find out what it was without guessing. We decided that it would have been better if we just wanted to go ahead and do the experiment and find out rather than guess because we didn't really want to guess. We really wanted to find out more what it was.

I: What kind of data did you collect?

M: Well, we collected, um, the what the colors were, the similar colors and how they, how they all burned, how they burnt like the color orange, what color was brighter, if it was lighter, the redness of it and everything. And then we decided that we were going to use a spectroscope to see what colors turned up in there?

I: And what colors ended up turning up in there?

M: Well, with each chemical it was different. We got a lot of the darker colors like the greens and the blues and the purples. Um, we got a lot of orange, especially when there was orange light. And we got red and there was red light. And there was a lot of green and blue in there. So, when they all, when some of, two of them actually showed up and the rest didn't, we figured that those were the ones that compared. Since those compared that must of been it.

I: So, how did you come to your conclusion?

M: When, um, when we did the experiment, we went through and we decided which one worked the best and which one...which ones compares. Did they, what was orange and the other one was the same color of orange. Cause the other colors came out red or dark red or light green or light orange and so on, so forth. When they came out two the same color of red and the same colors in the spectroscope, we then did the process of elimination, it had of been that one.

I: O.K., um, I'd like to thank you for participating in this interview. I want to go over the informed consent again. Um, do you understand that everything will be kept confidential and that this tape will be destroyed when I'm finished collecting data?

M: Yes

I: O.K., ah, do you have any questions for me either about the interview process or about any the questions that I asked you.

M: No

I: Do you have any comments either about lecture or guided inquiry that you would have liked to have said that I didn't bring out?

M: No

I: O.K. I'd like to thank you, M, for participating in this interview. It's going to be a big help to me because I can use your data now to get my research finished. O.K.?

M: O.K.

I: Thank you.

Appendix M:

Category and Coding System for Qualitative Data

Category and Coding System for Qualitative Data

Factual Knowledge about Waves and Light Category

The responses in this category were coded using the same coding scheme as the second tier of the two-tiered multiple choice questions. However, these codes were used for making generalizations about the data, rather than quantifying the data and making interpretations based on statistics.

Feelings/Perceptions of Guided Inquiry

Code 1:	Located in the lab
Code 2:	Students active and moving about
Code 3:	Making and recording many observations
Code 4:	Students discussing observations with partners
Code 5:	Hands-on type of learning
Code 6:	Learn for yourself
Code 7:	Teacher monitoring safety
Code 8:	Teacher guiding, rather than answering questions
Code 9:	Teacher directing students where to find answers
Code 10:	Class reconvening after activity

Feelings/Perceptions of Lecture Category

Code 11:	Located up front in seats
Code 12:	Students sitting in seats taking notes
Code 13:	Students working in groups or with partners
Code 14:	Getting assistance by asking the teacher
Code 15:	Teacher talking and writing notes on board
Code 16:	Teacher providing answers to questions
Code 17:	Teacher providing examples to further understanding

Guided Inquiry vs. Lecture Category

Code 18:	Viewed guided inquiry as more active
Code 19:	Viewed lecture as more passive
Code 20:	Viewed guided inquiry as nosier
Code 21:	Viewed lecture as noisier
Code 22:	Pro for guided inquiry
Code 23:	Con for using guided inquiry
Code 24:	Prefers guided inquiry
Code 25:	Prefers lecture
Code 26:	Better understanding/learn more with guided inquiry

Comfort/Anxiety Levels with Guided Inquiry Category

Code 27:	Frustrated at first because not familiar with process
Code 28:	Concerned at first with grade
Code 29:	Comfort level rose with more exposure to guided inquiry process
Code 30:	Working with partners and discussing increase comfort level
Code 31:	Active and hands-on increased comfort level
Code 32:	Fact that activities were fun and entertaining increased comfort
Code 33:	Did not like cleaning up
Code 34:	Level of student participation increased over time

Comfort/Anxiety Levels with Lecture Category

Code 35:	Overwhelmed, frustrated, uncomfortable
Code 36:	Too much information/ went too fast made anxious
Code 37:	Anxiety over understanding the material
Code 38:	Comfortable with being told what need to know/all the answers to questions
Code 39:	Comfortable with students going to the board to help with questions
Code 40:	Frustrated with additional work necessary to understand
Code 41:	Difficulty in remaining focused/staying awake caused later frustrations

Factual Knowledge about Acids and Bases Category

The responses in this category were coded using the same coding scheme as the second tier of the two-tiered multiple choice questions. However, these codes were used for making generalizations about the data, rather than quantifying the data and making interpretations based on statistics.

Scientific Method Category

Code 42:	Made initial observations of the unknown
Code 43:	Wrote a hypothesis before collecting data
Code 44:	Compared unknown to known standards

Comfort/Anxiety Levels with Guided Inquiry Category

Code 27:	Frustrated at first because not familiar with process
Code 28:	Concerned at first with grade
Code 29:	Comfort level rose with more exposure to guided inquiry process
Code 30:	Working with partners and discussing increase comfort level
Code 31:	Active and hands-on increased comfort level
Code 32:	Fact that activities were fun and entertaining increased comfort
Code 33:	Did not like cleaning up
Code 34:	Level of student participation increased over time

Comfort/Anxiety Levels with Lecture Category

Code 35:	Overwhelmed, frustrated, uncomfortable
Code 36:	Too much information/ went too fast made anxious
Code 37:	Anxiety over understanding the material
Code 38:	Comfortable with being told what need to know/all the answers to questions
Code 39:	Comfortable with students going to the board to help with questions
Code 40:	Frustrated with additional work necessary to understand
Code 41:	Difficulty in remaining focused/staying awake caused later frustrations

Factual Knowledge about Acids and Bases Category

The responses in this category were coded using the same coding scheme as the second tier of the two-tiered multiple choice questions. However, these codes were used for making generalizations about the data, rather than quantifying the data and making interpretations based on statistics.

Scientific Method Category

Code 42:	Made initial observations of the unknown
Code 43:	Wrote a hypothesis before collecting data
Code 44:	Compared unknown to known standards

Appendix N:

Sample Field Notes from Qualitative Interviews

Fieldnote for MM Interview

LOG:

*Date: May 27, 2004
*Site: Semi-rural high school in northwestern Pennsylvania
*Respondent: M.M. is a "C" student in Conceptual Chemistry
*Data Collector: Mr. Les McSparrin – researcher and M's Conceptual Chemistry teacher
*Purpose of Data Collection: To assess M's understanding of waves and light.
To assess M's perceptions of and attitudes toward both guided inquiry and lecture and to compare and contrast both.
To assess M's comfort levels with guided inquiry and lecture.
To assess M's view of the role of the teacher and student in both guided inquiry and lecture.
To assess M's understanding of the scientific method.

DATA: - Refer to verbatim transcript of interview data.

SUMMARY/HIGHLIGHTS

M.M. was confused on the terms related to waves and light. Many of her responses were either too general or were nebulous as to what she meant and would be marked as incorrect in quantitative scoring. Although there were a few correct responses, they were brief and were missing the details necessary to place the answer beyond basic understanding.

M.M. viewed guided inquiry as being given a task to complete with specific objectives. She stated that it was necessary for her to follow a procedure, pay careful attention to observations, and to answer guiding questions while completing the task. Her perception of the teacher's role during guided inquiry was for the teacher to walk around and make sure that everyone was safe and to make sure that everyone was doing the skill components of the task correctly. M.M. reported that the teacher's role became less intrusive over time. The teacher became more of the consultant for questions, and the students became more independent and worked on their own. M.M. indicated that guided inquiry was noisy as people consulted with their partners about the phenomenon they were observing.

M.M. viewed lecture as a time for listening because things were always explained and questions were always answered during this time. She described the activities of reading science magazines, watching videos, working with partners, taking notes, and answering questions as occurring during lecture. Her perception of the teacher's role during lecture was to explain what was going on but to have the students think for themselves. She indicated the teacher often asked the students to read further and helped them by providing examples. She described the student's role during lecture was to listen to everything going on and to take notes off the board. M.M. indicated that lecture was noisy also because the students tended to work in groups, but guided inquiry was noisier.

M.M. reported seeing people more active during guided inquiry. She viewed guided inquiry as doing it for yourself and being able to see things as they happened. She indicated that the students did not have the same opportunity in lecture. She viewed guided inquiry as more hands-on, and that was better. However, she did recognize the dangers of students goofing off in lab and the safety issues associated with that. M.M. stated that she preferred learning by doing rather than listening.

M.M. indicated that she was comfortable with guided inquiry and her confidence levels increased with more exposure to the process. She indicated that she tended to follow concepts in lecture, but she grew uncomfortable as math became involved. M.M. expressed that her comfort level increased as she had more interaction with her partners and she participated more. She felt that her opinions mattered and was comfortable with learning on her own rather than somebody telling her. However, worrying about her partner's safety with fire and disliking the process of cleaning up raised her anxiety levels at times.

M.M was able to explain how she and her lab partner completed the task in the culminating assessment. She was able to explain, in general terms, how they compared their unknown with known standards to identify the thief. Although, they had some good ideas about how to complete the task, it was unfortunate that they didn't write a hypothesis before experimenting and collecting data.

METHODOLOGICAL COMMENTS:

Doing the interviews during open finals was a good time to complete the process. In the afternoon, most students had left for home, and there were no interruptions during the interview process except for the bell system tones sounding at scheduled times. It was also helpful to conduct the interviews in the classroom setting where guided inquiry and lecture occurred so that the respondent could reactivate her memory. In addition, it was helpful for the respondent to have access to her folder of activities to refer to during the interview. In future interviews, I may have students point things out to me in the lab to help illustrate what equipment they are specifically referring to.

ANALYTIC COMMENTS:

It was surprising how confused M.M. was on the factual knowledge about waves and light. It appeared as though she was nervous and still hung up on the one right answer, and this may have confused her and made it difficult to explain her answers. M.M. was a hard worker in class who participated and worked well with her peers. Therefore, it is no surprise that she indicated that she enjoyed being able to solve problems on her own, and that she enjoyed the interaction with her peers. She often asked questions for guidance during our inquiry activities, so that is more than likely why she viewed the teacher more as the guide on the side. M.M. was always very attentive during lectures and wrote many notes and asked questions when she didn't understand. This is consistent with her description of the activities she reported doing during lecture and the student's role at that time. M.M. was always willing to complete any task assigned during class, whether it was time for guided inquiry or for lecture. She didn't ever indicate her preference between the two during class. Therefore, it was very informative data to know that she preferred the hands-on active form of learning. There is so much more we can glean from students by sitting down and discussing our day to day classroom activities. It was apparent that M.M. did have an understanding of how to compare unknowns to a set of known standards; however, she had steps missing from her scientific method – particularly the hypothesis. She is not unique in this behavior. Most students in the conceptual level were anxious to get the task under way. Researching and writing out a plan with a clear hypothesis may have seemed to them as too analytical and "bookwork" like, and they preferred to be active and experience hands-on activities as quickly as possible.

Appendix O:
Output Tables for Wilcoxon Signed-Ranks and Mann-Whitney U Tests

Table 6: Wilcoxon Signed-Ranks Test on Pre/Post Scores for AP Chemistry Light Unit

Ranks

		N	Mean Rank	Sum of Ranks
POSTSCOR - PRESCORE	Negative Ranks	7(a)	5.93	41.50
	Positive Ranks	6(b)	8.25	49.50
	Ties	0(c)		
	Total	13		

a POSTSCOR < PRESCORE
b POSTSCOR > PRESCORE
c POSTSCOR = PRESCORE

Test Statistics(b)

	POSTSCOR - PRESCORE
Z	-.280(a)
Asymp. Sig. (2-tailed)	.780

a Based on negative ranks.
b Wilcoxon Signed-Ranks Test

Table 7: Wilcoxon Signed-Ranks Test on Pre/Post Scores for Chemistry I Light Unit

Ranks

		N	Mean Rank	Sum of Ranks
POSTSCOR - PRESCORE	Negative Ranks	1(a)	3.00	3.00
	Positive Ranks	17(b)	9.88	168.00
	Ties	0(c)		
	Total	18		

a POSTSCOR < PRESCORE
b POSTSCOR > PRESCORE
c POSTSCOR = PRESCORE

Test Statistics(b)

	POSTSCOR - PRESCORE
Z	-3.594(a)
Asymp. Sig. (2-tailed)	.000

a Based on negative ranks.
b Wilcoxon Signed-Ranks Test

Table 8: Wilcoxon Signed-Ranks Test on Pre/Post Scores for Conceptual Chemistry Light Unit

Ranks

		N	Mean Rank	Sum of Ranks
POSTSCOR - PRESCORE	Negative Ranks	4(a)	6.13	24.50
	Positive Ranks	24(b)	15.90	381.50
	Ties	1(c)		
	Total	29		

a POSTSCOR < PRESCORE
b POSTSCOR > PRESCORE
c POSTSCOR = PRESCORE

Test Statistics(b)

	POSTSCOR - PRESCORE
Z	-4.068(a)
Asymp. Sig. (2-tailed)	.000

a Based on negative ranks.
b Wilcoxon Signed-Ranks Test

Table 9: Mann-Whitney U Test Done on Conceptual Chemistry Prescores vs. Chemistry I Prescores

Ranks

	Class Level	N	Mean Rank	Sum of Ranks
PRESCORE	Chemistry I	19	30.05	571.00
	Conceptual Chemistry	30	21.80	654.00
	Total	49		

Test Statistics(a)

	PRESCORE
Mann-Whitney U	189.000
Wilcoxon W	654.000
Z	-1.972
Asymp. Sig. (2-tailed)	.049

a Grouping Variable: Class Level

Table 10: Mann-Whitney U Test Done on Conceptual Chemistry Postscores vs. Chemistry I Postscores

Ranks

	Class Level	N	Mean Rank	Sum of Ranks
POSTSCOR	Chemistry I	19	33.29	632.50
	Conceptual Chemistry	30	19.75	592.50
	Total	49		

Test Statistics(a)

	POSTSCOR
Mann-Whitney U	127.500
Wilcoxon W	592.500
Z	-3.233
Asymp. Sig. (2-tailed)	.001

a Grouping Variable: Class Level

Table 11: Mann-Whitney U Test Done on Conceptual Chemistry Postscores vs. Chemistry I Prescores

Ranks

	Class Level	N	Mean Rank	Sum of Ranks
PREPOST2	Chemistry I	19	21.18	402.50
	Conceptual Chemistry	30	27.42	822.50
	Total	49		

Test Statistics(a)

	PREPOST2
Mann-Whitney U	212.500
Wilcoxon W	402.500
Z	-1.488
Asymp. Sig. (2-tailed)	.137

a Grouping Variable: Class Level

Table 12: Mann-Whitney U Test Done on Advanced Placement Chemistry Prescores vs. Chemistry I Prescores

Ranks

	Class Level	N	Mean Rank	Sum of Ranks
PRESCORE	Advanced Placement	13	23.46	305.00
	Chemistry I	19	11.74	223.00
	Total	32		

Test Statistics(b)

	PRESCORE
Mann-Whitney U	33.000
Wilcoxon W	223.000
Z	-3.474
Asymp. Sig. (2-tailed)	.001
Exact Sig. [2*(1-tailed Sig.)]	.000(a)

a Not corrected for ties.
b Grouping Variable: Class Level

Table 13: Mann-Whitney U Test Done on Advanced Placement Chemistry Postscores vs. Chemistry I Postscores

Ranks

	Class Level	N	Mean Rank	Sum of Ranks
POSTSCOR	Advanced Placement	13	21.19	275.50
	Chemistry I	19	13.29	252.50
	Total	32		

Test Statistics(b)

	POSTSCOR
Mann-Whitney U	62.500
Wilcoxon W	252.500
Z	-2.342
Asymp. Sig. (2-tailed)	.019
Exact Sig. [2*(1-tailed Sig.)]	.018(a)

a Not corrected for ties.
b Grouping Variable: Class Level

Table 14: Mann-Whitney U Test Done on Advanced Placement Chemistry Prescores vs. Chemistry I Postscores

Ranks

	Class Level	N	Mean Rank	Sum of Ranks
PREPOST1	Advanced Placement	13	18.46	240.00
	Chemistry I	19	15.16	288.00
	Total	32		

Test Statistics(b)

	PREPOST1
Mann-Whitney U	98.000
Wilcoxon W	288.000
Z	-.979
Asymp. Sig. (2-tailed)	.328
Exact Sig. [2*(1-tailed Sig.)]	.343(a)

a Not corrected for ties.
b Grouping Variable: Class Level

Table 15: Wilcoxon Signed-Ranks Test on Pre/Post Scores for Chemistry I Acid/Base Unit

Ranks

		N	Mean Rank	Sum of Ranks
POSTSCOR - prescore	Negative Ranks	1(a)	1.00	1.00
	Positive Ranks	19(b)	11.00	209.00
	Ties	0(c)		
	Total	20		

a POSTSCOR < prescore
b POSTSCOR > prescore
c POSTSCOR = prescore

Test Statistics(b)

	POSTSCOR - prescore
Z	-3.884(a)
Asymp. Sig. (2-tailed)	.000

a Based on negative ranks.
b Wilcoxon Signed-Ranks Test