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Writing a Chemistry Textbook that Supports Inquiry Based Learning

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WRITING A CHEMISTRY TEXTBOOK THAT SUPPORTS INQUIRY BASED LEARNING

by
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Sarah Jean Henning Toman
Abstract

The National Science Education Standards promote inquiry instruction. As teachers change how they teach, will textbooks follow suit? Is it even possible to have an inquiry-based chemistry textbook and if so, what would it look like and would students find it useful? This study conducted as part of the Target Inquiry Program at Grand Valley State University explored these questions by comparing student reactions to excerpts from a standard high school chemistry text to those of an inquiry-based chemistry text developed by the researcher. Reactions recorded in student interviews and achievement outcomes were analyzed to address the research questions. Results and implications for instruction are presented.
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Chapter 1: Thesis Proposal

Problem Statement

Traditional textbooks do not support inquiry learning (Mahaffy, 1995). Most textbooks in use today were written to accompany a more traditional approach to education (Bailar, 1993; Dunbar, 1938) not an approach based on student inquiry. This leaves high school chemistry teachers who tend to use inquiry-based instruction wondering what texts they should use to complement their teaching philosophy (Moore, 2003; Rice, Dudley, Williams, 2001).

Importance of the Problem and Rationale of the Study

Inquiry instruction has increased in popularity over the last several years (American Association for the Advancement of Science, 1993, National Research Council, 1996). It is now part of the state and national standards, C1.1 Scientific Inquiry (Michigan Merit Curriculum) and National Science Education Standards Rationale Science as Inquiry (NSES) for how high school chemistry teachers must teach; colleges and universities are training future teachers to use inquiry instruction in the classroom, and those already teaching are learning about inquiry instruction in their professional development and graduate studies programs (Roehrig & Luft, 2004; Yezierski and Herrington, 2010). With this new method of teaching, teachers are required to look at all facets of their instruction including assessment, laboratories, activities, and texts. Many teachers, however, are not applying this research to their classrooms and continue to teach in the traditional lecture style using verification laboratory activities (Smith, 2002). Target Inquiry (TI) through Grand Valley State
University has been testing chemistry students from a variety of high schools for several years. Teachers in the TI program give their students a pre- and post-test at the beginning and end of the chemistry course. Some of the teachers in the study use a traditional lecture style with verification activities, while others use a more inquiry-based approach. The teachers using an inquiry approach saw a greater increase in student scores over time than those students in the traditional courses (Yezierski & Herrington, 2010). Though high school chemistry teachers may see this evidence and want to reform their instructional approach, changing teaching styles can be very difficult and time consuming (Porter, Garet, Desimone, Yoon, & Birman, 2000). Often this involves professional development so that teachers can learn these new strategies and support one another as they begin to implement them in their classroom (Mertens & Flowers, 2004). This support plays an important role in this transformation of instructional practice. Professional development is strengthened when teachers are trained and grow together as colleagues (Porter et al, 2000).

Although teachers in the Eisenhower Professional Development Program (EPDP) varied in professional development experience, were at different stages in their career, taught various age levels, and were from different areas of the United States, they all had similar experiences with EPDP. Cochran-Smith (2002) agrees, saying,

Of particular importance is the opportunity to become part of an inquiry community that involves new and experienced teachers as well as teacher educators. Working as part of inquiry communities emphasizes that learning to teach is not a process that is ever completed but rather an ongoing project. (p. 17).
Background of the Problem

High School chemistry teachers have become dependent upon textbooks to determine the curriculum (McNaught, 2005). However, these chemistry textbooks are out-of-date by the time they arrive in classrooms (Griffin, 17) causing our students to fall behind students studying similar subjects in other countries. Many different organizations have been exploring why American science students continue to fall behind other industrialized nations (US Department of Education Institute of Education Sciences) and textbook use is one of the key features of these investigations. If all things go well, five years pass, from the time a text is written to the time it reaches schools (Rees, 2000). This means that brand-new textbooks today still reflect a more traditional teaching approach, although our national science standards are encouraging teachers to use an inquiry-based approach. One of the barriers to an inquiry-based approach is that most high school chemistry textbooks have looked the same for the past 40 years (Gillespie, 1997). Since textbook companies have been consolidating it would be an incredible risk for a publishing company to print a new type of book and, thus far, it has been a risk they are unwilling to take (Watt, 2007).

Historically, one of the difficulties with high school chemistry textbooks is that they are written with a “one size fits all” mentality. That is, one text should cover all a student needs to know for one course. However, when students in Portland Oregon at Portland State University reviewed six general organic chemistry textbooks they concluded that such a text does not exist. Although this was a college
chemistry textbook, the same concept applies to high school chemistry textbooks. Instead of a "one size fits all" text, some texts were superior in some areas while inferior in others (Lutz & Wamser, 2001). Lutz and Wamser found there was a benefit to having students take part in this process; generally only instructors take part in choosing texts (Nettels, 1929). In fact, Nettels describes several criteria to use when choosing a textbook, stating that all texts may have the required material, but not all are written equally. Some may include the latest scientific advances; some will include historical information about the scientists themselves, while others present new vocabulary and use it so that students are able to incorporate it into their learning.

Furthermore, not all teachers use high school chemistry textbooks in the same manner. For example, some expect students to pre-read in order to expose students to vocabulary and concepts prior to class, some expect students to read after class in order to review the topics previously covered, while others assign reading for concepts not covered in class at all (DiGisi, 1995). This can be quite a challenge for students, since chemistry textbooks are often written in a distinct style. In reading for other classes students are used to finding the main idea in the opening paragraph of a section, however, this may not be the case in a chemistry text (Barton, Heidema, & Jordan, 2002).

High school chemistry teachers using inquiry-based teaching methods expect students to come to class ready to learn in an inquiry method from a traditional textbook that may not mesh with inquiry-based teaching, may not have all of the
information necessary, and may be written in such a way that it is extremely difficult
for students using inquiry methods to understand.

Statement of Purpose

The goal of this study is to write part of an inquiry-based chemistry textbook,
pilot it in a classroom, and observe student reactions.

Research Question

Is it possible to write a chemistry textbook that does support inquiry-based
learning in a chemistry classroom?

Research Design

In order to compare traditional high school chemistry texts with an inquiry-
based chemistry text, an inquiry text must be written. The researcher designed a text
based on Boyle's, Charles', and Gay-Lussac's Laws. The Charles' and Gay-Lussac's
sections were piloted in the classroom. Both sections on Charles and Gay-Lussac
addressed the laws each discovered in this way: The opening piece of each section
discussed the historical context each scientist lived in, what he studied, the his
experimental design, some initial observations, and data similar to that which he
actually collected. The students will be asked these questions and observations
concerning the data: 1. Is there a relationship between the volume and temperature?
2. Graph any relationships found. 3. Is there a graphical relationship between volume
and temperature? 4. Is there a mathematical relationship between volume and
temperature?
In the initial data temperature is given in degrees Celsius. Then, a new (to Charles) Kelvin scale is given and the students will go through the series of questions again to see if there is a difference. The design of these sections fits the definition of inquiry-based teaching, since the students are able to experience data analysis and drawing conclusions similar to the practices of Charles and Gay-Lussac.

To examine the relationship between inquiry-based and traditional texts, all chemistry students will read seven chapters from four sources. The first source is called *Chemistry* by Addison Wesley (2002). This is a traditional textbook used in chemistry classrooms throughout the United States and is the text the study school has used for the past several years. The second is called *Introduction to Chemical Principles* by Peters and Kowalski (1994). This text is used at the college level in courses designed to prepare students who did not have high school chemistry for college level freshman chemistry. The third source is a one page handout on the Kinetic Molecular Theory (2008) written by Alice Putti, a high school chemistry teacher, as part of a laboratory activity. The final source is the one specifically written as part of the research to accompany inquiry-based teaching and is in Appendix A. Table 1 displays the chapters the students will read from each text.
Table 1

*Texts and Concepts read and indicated by Chapter*

<table>
<thead>
<tr>
<th>Text</th>
<th>Concept (Chapter)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Chemistry</em> by Addison-Wesley</td>
<td>Measurement (3), Problem Solving (4),</td>
</tr>
<tr>
<td></td>
<td>Atomic Structure (5), Stoichiometry (9),</td>
</tr>
<tr>
<td></td>
<td>Covalent Bonding (16), Solutions (18)</td>
</tr>
<tr>
<td><em>Introduction to Principles of Chemistry</em></td>
<td>Percent Composition (7)</td>
</tr>
<tr>
<td><em>Chemistry</em> by Peters and Kowerski</td>
<td>Kinetic Molecular Theory (10)</td>
</tr>
<tr>
<td><em>Kinetic Molecular Theory</em> Handout by Alice Putti</td>
<td>Kinetic Molecular Theory (10)</td>
</tr>
<tr>
<td><em>Inquiry Text</em> by Sarah Toman</td>
<td>Gas Laws (12)</td>
</tr>
</tbody>
</table>

For each chapter students will be given a reading guide to complete as homework as they read prior to attending class. They will be permitted to use this guide on a reading quiz administered in class the following day. Their scores will be recorded to compare the reading quizzes based on traditional and inquiry-based texts. Furthermore, pre- and post-tests will be given to compare the current class that reads the inquiry-based text to the class that used the traditional text the previous year. In order to examine the students’ thoughts on the inquiry-based text, six students will be selected as key informants. The informants will be interviewed three times.
Definition of Terms

Inquiry learning is a method of learning where students are experiencing science and constructing science knowledge based on those experiences (Llewellyn, 2005; Sanger, 2008). Using this definition, students have laboratory experiences where they perform experiments and activities and develop scientific theories based on their results. This definition of inquiry comes from the constructivist view that students learn by experience (Bodner, Klobucher, Geelan, 2001).

Delimitations of the Study

This study will not pilot an entire inquiry-based text in a classroom, and will therefore be limited in its conclusions. It will address the possibility of inquiry-based chemistry textbooks and their success in high school chemistry classrooms; however, it will not address every concept taught over the course of an entire high school chemistry program. This research may open the door for further studies involving inquiry-based chemistry textbooks in high school chemistry classrooms, and perhaps other disciplines and levels of instruction as well.

Limitations of the Study

This study will be performed in a small, private school over a two year period. Consequently the sample size is limited in both number and scope. The researcher should use caution when making conclusions that are beyond the scope of this study.
Organization of the Study

The chapters that follow will explore the theoretical framework, possible solutions to the inquiry-based textbook problem, the research design, implementation, results, and conclusion.
Chapter 2: Literature Review

Introduction

In traditional chemistry classrooms students are taught the name of a scientist, given a little insight into the historical context, and told what the scientist discovered: a mathematical equation, a phenomenon, or a new conceptual theory. The inquiry-based method, however, gives students a real-life scenario with a problem for them to solve and some information about the first scientist who studied the problem, and shows them some of the data the scientist collected. For example, Chiappetta and Koballa's (2002) book entitled *Science Instruction in the Middle and Secondary Schools* includes a chapter on the history of science education and discusses the results of the document put together by Science for All Americans in the 1980s. This document showed that the majority of science instruction focused on reading about science and memorizing answers rather than doing science and discussing the results. These two methods, one where students read about science and the other where students are expected to examine data and construct their own theories are very different.

This chapter will provide a glimpse into the research that has already been done to address the disconnect between traditional textbooks and inquiry-based learning. First the theoretical framework will be discussed followed by current research in the form of peer-reviewed journals and books and a summary to synthesize the information.
Theoretical Framework

The traditional teaching method dates back to the early twentieth century and Gerald Craig. Craig developed curriculum that focused on students reading scientific content, but was weak in hands-on activities (Chiappetta & Koballa, 2002, pg 24). Craig’s ideology which makes the teacher the giver of the information which the students later regurgitate without doing any science themselves still influences science teachers, textbooks, and curriculum today. In contrast, the inquiry-based method is based on the constructivist theory. “The constructivist teacher’s role is to create a context where the learner is motivated to learn, which includes providing content and resources, posing relevant problems and questions at appropriate times (Wheatley, 1991, p. 14; Windschitl, 2002, p. 137), and linking these resources and questions to the students’ prior knowledge.” (Baviskar, Hartley, & Whitney, 2009).

Looking at constructivism another way Llewellyn (2005) says it is a theory which proposes that people learn about the world around them based on their existing knowledge. Based on this understanding of constructivism the following articles were reviewed to help explore the relationship between traditional textbooks and inquiry-based learning.

Research

The textbook is just a part of the curriculum.

There are nine principles to guide a teacher’s design:

1. Identify desired results

2. Determine acceptable evidence of student learning
3. Plan learning experiences based on the first two principles
4. Regard learner differences as inevitable and valuable
5. Address learners’ needs to support their success
6. Periodically review and articulate learning goals
7. Continually assess progress and adapt when necessary
8. Employ flexibility to support learner success
9. Gather a variety of evidence to display learner success

Though these principles may include using a textbook, the text, however, is not the sole resource for the teacher. Rather, it plays a part in a much larger strategy for student learning which may include magazines, web resources, and laboratory experiences in addition to the textbook.

Though students are all required to read the same textbook, they do not all read it the same way. In fact, some students may need assistance in order to successfully read their textbook or other materials. Some students may need to have the material read to them; others may need a graphic organizer or web to help them concentrate on key concepts; while others may need to read out loud. Tomlinson and McTighe (2006) suggest that this is an important part of the curriculum and therefore, teachers should support their students in whatever way necessary to help maximize their success.

Sometimes students are required to do their own research in an area. Here they may read materials, not in the textbook, of varying reading levels, or conceptual knowledge, or both. In this case, Tomlinson and McTighe (2006) suggest the teacher
provide material at a variety of levels so that all students are able to do extended research and have the opportunity to succeed at some level.

**Literature reading in chemistry.**

Many students view chemistry textbooks as "a mass of facts" (Beall, 1993). In order to break students free of this thinking, Beall, a professor at Worcester Polytechnic Institute (WPI), had his students read chemical literature. This literature was chosen to demonstrate to students how chemistry is involved in practice as humans use scientific thinking to explore the world. In addition, these pieces were chosen to show students how the concepts learned in their chemistry course are applicable in real life situations beyond the classroom.

Another reason for this literature reading was to address the concern that students place too much emphasis on exams. Students believe the mathematical concepts are the most important part of the course because those ideas are emphasized on the homework, quizzes, and exams. Amaral and Shibley, Jr. (2010) agree saying that content is often stressed so much in chemistry courses that instructors neglect other valuable chemistry skills. To dispel this belief the assigned literature reading (containing very few mathematical calculations) made up 14% of each students’ overall grade.

In addition to reading the students were required to write. Accompanying each of the four assigned readings were questions for the students to consider and respond to. The goal of the writing was for the students to improve both their scientific communication and their understanding of how the topics covered in their
chemistry course applied to the actual practice of chemistry. Students were given two weeks to read each essay and write a response.

When polled, students had many negative reactions to the readings. They did not see the relevance of the assigned reading and how it fit into their chemistry coursework. Students did not find the assigned reading interesting; rather, many found it "boring." Furthermore, the students did not take adequate time to read and respond during the two weeks they were given. Many of them did their assigned reading and wrote their response the night before it was due.

WPI will continue to assign literature reading to its chemistry students, but may change to other literature reading assignments. In addition, to encourage students to take time and think about their writing, they may have a rough draft due after one week and the final draft due the second week. This may help students look at the reading and their writing at least twice, since they will be able to correct their drafts before turning them in for credit. Moreover, on the day the rough draft is due each class may discuss the reading. This would help students to hear what their peers are thinking, and may even promote thinking about chemistry in a deeper, more meaningful way.

**Teaching students how to read a chemistry textbook.**

Barton, Heidema, and Jordan (2002) say that chemistry textbooks are written differently from other texts. In fact, according to Holiday (1991) a high school chemistry textbook may include 3,000 new terms; even more than a foreign language textbook. Therefore, chemistry students need to develop a different set of skills to
read chemistry textbooks than they use in their other courses. One suggestion is to reacquaint students with their prior knowledge before the reading is assigned. Prior to a reading assignment teachers may engage the class in a discussion by asking questions covering material students have learned in prior courses. This brings to light any faulty ideas students may have about various concepts, or pinpoint areas where student understanding is weak. Teachers are then able to address those poorly or falsely understood ideas through activities before assigning the necessary reading.

Another strategy Barton, Heidema, and Jordan (2002) suggest teachers use is called webbing. In this case teachers may engage the class in a discussion by telling them the name of a new concept. The students then share any terms, theories, or ideas that this new concept brings to mind. Teachers construct a web on the board creating a visual representation tying these student thoughts together. Teachers will place the new concept in the middle of the board, and then connect it with other ideas suggested by the students creating a product visually similar to a spider’s web. During this process the class may suggest a misconception, and this gives the teacher the opportunity to discuss and clear up that misunderstanding with the class. The teacher may also suggest terms or ideas that the students have left out. Finally, the students each receive a copy of the web to use as they tackle the assigned reading.

A third approach suggested by Barton, Heidema, and Jordan (2002) is for the teacher to develop an anticipation guide to assist students with their assigned reading. This guide is a set of questions for students to answer both before and after they have completed the reading. The questions may address misconceptions students could
have about the new concept, or introduce and include key terms they will see. In addition to questions the teacher may write some statements for students to consider as they read. These statements may challenge students’ past experiences or knowledge or merely point students to the important concepts included in the assigned reading. The students fill out the anticipation guide individually, then come to class prepared to defend their answers in an all-class discussion prior to the reading. This gives the teacher an idea of student misconceptions to be addressed prior to the assigned reading. Students then read the textbook and fill out the anticipation guide again, noting any changes they have made based on the assigned reading.

Finally, Barton, Heidema, and Jordan (2002) point out chemistry teachers should recognize that a chemistry textbook is not necessarily written in the same style as other textbooks that students are used to reading. For example, main ideas are not always stated first; rather, they are often stated at the end of a paragraph or question. Teachers can aid students in their reading by making note of this different writing style so that students are aware of it prior to beginning the assigned reading.

Making science reading meaningful.

Students may do the assigned reading and yet have no idea what it was they actually read (Femsten & Loughran, 2007). In their article, Femsten and Loughran (2007) make several suggestions for how teachers can deal with this problem. The first one is the use of cooperative learning groups. Using this method the class is divided into groups of three to five depending on the number of tasks assigned to
each group. One possible scenario involving five tasks allows each student in the
group to contribute by doing a single task. One student may read for vocabulary and
develop a list of the most difficult new vocabulary terms. A second student may read
for the main ideas and create a short quiz. This quiz could include questions
requiring the understanding of the facts, questions requiring interpretation of the
material, and questions requiring students to give and support their opinion. A third
student could create a skit which includes factual information and the historical
context of the concept. A fourth student could create a song, rap, or rhyme using the
new vocabulary terms. The final student could find pictures relating to the concept
and new vocabulary words and use the pictures to quiz peers.

Fernsten and Loughran’s (2007) second suggestion also incorporates
cooperative groups. Each student is required to take an active role in the group, but in
this case once the roles are assigned the groups switch. For example, each group can
include one member who will become the expert in vocabulary, another in outlining,
a third in question writing, and a fourth in webbing. The original groups then disband
to form the expert groups. The vocabulary experts will produce a list from the
assigned reading. The students who are outlining will look for main ideas and
summarize the entire reading assignment. The students who are developing the
questions will also draw up a list of scientific concepts found in the assigned reading.
This list could contain concepts students already know, as well as a list of new
scientific concepts, followed by a few questions they think fellow students might
have about the reading assignment. Finally, the students in the webbing group will
create a visual representation on a piece of paper. This will include the main idea discussed in the assigned reading in the center of the page and connect the related topics back to it similar to the all class discussion that Barton, Heidema, and Jordan (2002) suggested. These new groups will work on their respective tasks together. When the working time is complete students will return to their original groups armed with their accomplished task and tell their fellow group members about the product they created.

Femsten and Loughran (2007) suggest that sometimes, independent work is necessary. In those cases, teachers may generate questions for students to consider and answer as they read. Some questions may focus on vocabulary and have students define key terms. Other questions may require students to explain the role of an idea as it relates to the main concept of the assigned reading. Finally, questions may ask students to incorporate new terms or concepts into their language. These types of questions will be challenging to various students at times. While some students may have difficulty picking out the vocabulary words, others will find relating key concepts difficult, yet others will find their challenge lies in the application questions.

Finally, Femsten and Loughran (2007) suggest a variation of “Think-Pair-Share.” First students individually write down all of the vocabulary and ideas that they remember from the assigned reading. Students then combine their list with a partner and use it to create questions which focus on the most important aspects of the assigned reading. Finally, students share these questions with the class as a tool for reviewing the reading assignment.
Truly comprehending science texts.

Best, Rowe, Ozuro, and McNamera (2005) assert that science textbooks are not all written the same way; some are high cohesion texts while others have low cohesion. The author's define cohesion as the degree to which the reader must make inferences to other knowledge based on the actually printed text. That is, high cohesion texts give the reader a lot of clues, references, and relationships between sentences in the text itself to assist the reader's understanding. On the other hand, low cohesion texts do not explicitly state connections, leaving readers on their own to make the inferences themselves.

Students do not all read textbooks the same way. Those with active working memory are able to read low cohesion texts successfully. Since these students are able to keep a lot of information in their active working memory they are able to remember what they have learned in other courses, or read earlier in the same text, and synthesize the information together into one idea. However, students with poor active working memory skills are not able to access as much information simultaneously and, therefore, do not comprehend a low cohesion text well. For these students, a high cohesion text is much more effective; rather than having to make all the connections between concepts on their own, it guides them in making the necessary inferences. Best et al (2005) note that though high cohesion texts seem to work best for all students, interestingly, some students with good active working memory do not always comprehend high cohesion texts well. This may be because such students are used to using those active working memory skills but do not need to
when reading a high cohesion textbook since it is all there for them. These students then do not read as carefully as they should, and, therefore, do not comprehend as deeply.

Another challenge to reading comprehension is student knowledge (Best, Rowe, Ozuro, & McNamera, 2005). Science textbooks are written in a style requiring students to make connections with their prior knowledge from other courses. However, if students do not understand the concepts from those courses, or have a misconception about a concept, they will not be able to understand their current text.

Furthermore, Best et al (2005) point out that science textbooks are written by scientific experts and there is extensive evidence showing that such experts have difficulty placing themselves in the role of a student who is not well versed in the world of science. Consequently, these experts leave out basic information based on their faulty assumptions that the reader is already knowledgeable in this area. These omissions leave it to the reader to make more inferences than they have the skills to make at their basic level of understanding.

Best et al (2005) suggest that high school science textbooks use a different measurement to evaluate the reading level of science texts than those currently in use. The methods used to evaluate most current textbooks use grade level reading formulas which are based on the length of words and sentences. This new tool could include sentence length and word frequency, but also examine conceptual overlap between sentences, cohesion and text features. These new methods in development
today may help future students to understand the science textbooks they are required to read.

Summary

In today's classroom all students are expected to be learning about the same concepts, but not necessarily in the same way. All students are expected to read at least some of the same textbook, but not all students read in the same way. The teacher is expected to change the curriculum to enhance student learning and success but not all students will define success the same way. Each article describes a slightly different approach to aid teachers as they seek to help all of their students read successfully. Tomlinson and McTighe (2006) suggest that teachers support their students in whatever way necessary to ensure successful reading at a level that challenges and stretches the student. Beall's (1993) study at WPI points out that students should be reading scientific material outside of their textbook and discussing what they learn with others. Barton, Heidema, and Jordan (2002) remind us that students may not be prepared to simply pick up their chemistry textbook and begin reading. They suggest a class discussion, an anticipation guide, and teaching students about how a chemistry textbook is constructed differently from textbooks they have read in other courses, before assigning the reading and expecting students to comprehend their chemistry textbook. Femsten and Loughran (2007) focus on student group work in a variety of ways in order for students to better understand their science textbook. For those times when independent work is better, Femsten and Loughran (2007) suggest teachers create a set of questions to guide students as
they read their textbook. Finally, Best et al (2005) point out that not all science textbooks are written the same way. Knowing this, teachers need to use different methods of evaluating science textbooks than teachers from other disciplines use. Furthermore, teachers should remember that not all students will read a science textbook in the same way and, therefore, may need varying degrees of support as they read their science textbook.

Conclusion

Though traditional science textbooks are not all the same, they are often difficult for students to read due to their large vocabulary, writing style, and cohesion level. In order to assist students with these science textbooks, several authors suggested webbing, reacquainting students with prior knowledge, and addressing student misconceptions, student discussion of the reading, and supporting students as they read. These thoughts may aid students in their reading comprehension; however, they still are influenced by Craig’s ideology of students reading about science as opposed to the constructivist theory of students learning about science based on their previous knowledge. A few authors encouraged all class discussions focusing on student prior knowledge and seeking to learn student misconceptions, these discussions were not supported by the science textbooks. In fact, none of these texts seem to support inquiry-based learning.

Though teachers today tend to be constructivist thinkers, the science textbooks currently in use are not supporting them in their quest to teach science by experiencing it. Despite the many suggestions to assist teachers as they teach
students how to read science textbooks, these textbooks are not designed to encourage inquiry-based learning. There appears to be a disconnect between the goals of today's classroom and the science textbooks that are available.
Chapter 3: Research Design

Introduction

Traditional textbooks do not support inquiry-based learning (Mahaffy, 1995). Most textbooks in use today were written to accompany a more traditional approach to education based on lecture and rote memorization (Bailar, 1993; Dunbar 1938), not an approach based on student inquiry. This leaves high school chemistry teachers who desire to use inquiry-based instruction wondering what text they should use to complement their teaching philosophy (Moore, 2003; Rice, Dudley, Williams 2001).

This raises the question, “Is it possible to write a chemistry textbook that supports inquiry-based learning in a chemistry classroom?” This chapter examines this question by discussing the key informants involved, the instruments used, the data collected, the data analysis, and the summary.

Participants/Subjects

Six key informants were chosen from two chemistry sections taught by the researcher: three students from each section. These six students were chosen four weeks into a 24 week course based on their sex, grades, and age. Three informants were male and three female. At the time they were chosen, two informants were earning an A, two informants were earning a B, and two informants were earning a C. One of the informants was a sophomore, four were juniors, and one was a senior. This is consistent with the distribution of sophomores, juniors, and seniors enrolled in the chemistry course. In addition to the informants, all students in the chemistry
course also had a role in the research. During the first week of the chemistry course all students were required to take an 80-question multiple-choice test. The test is an American Chemical Society (ACS) test designed by the ACS Division of Chemical Education to assess student content knowledge upon completing high school chemistry. Students took the 2003 Form version of the test. These same students then took the same test during the last week of the course to measure their content knowledge gain. In order to examine the content knowledge students gained from the traditional text in previous years to the content knowledge students gained from the inquiry-based text, these ACS test scores were collected and compared.

Instrumentation

In order to compare traditional texts with an inquiry-based text, an inquiry-based text had to be written. The inquiry-based text on Boyle’s, Charles’, and Gay-Lussac’s Laws was designed specifically for this study. The Charles and Gay-Lussac sections were piloted in the classroom. Each section addressed the laws in this way: the opening piece discussed the historical situation, what the scientist was interested in, his experimental design, and some initial observations. Finally, data similar to what Charles and Gay-Lussac actually collected was presented in table form. The students were then asked questions about the data and required to make conclusions based on their analysis. This design fits the definition of inquiry, as the students were able to experience data analysis and drawing conclusions, similar to the practices of Charles and Gay-Lussac. Furthermore, this idea is consistent with constructivist
thinking in that the students developed their own thoughts and beliefs about the topics as they read and experienced the situations in the text (Cobern, Tobin, 1993).

As part of the research to accompany inquiry-based teaching each student had their own copy of the inquiry-based text written by the researcher. In addition to the inquiry-based text, the students read three additional texts. The researcher chose three additional texts in order to eliminate any bias students may have when comparing the textbook they use regularly to a different one. The first text was *Chemistry* published by Addison Wesley (2002). This is a traditional textbook used in chemistry classrooms throughout the United States, and is the text the researcher’s school has used for the past several years; each student had their own copy. The second text was called *Introduction to Chemical Principles* by Peters and Kowalski (1994). This text is used at the college level in courses designed to prepare students who did not have high school chemistry for college level freshman chemistry; each student had a copy to read in class. The third text was a one-page handout (2008) written by Alice Putti as part of a laboratory activity; each student had their own copy. Table 1 displays the chapters the students read from each text. For each chapter students were given a reading guide to fill out as they read. They were permitted to use this guide on a reading quiz administered in class the following day. Student scores were recorded to compare the quiz scores from traditional texts to those scores from the inquiry-based text.
Table 1

*Texts and Concepts read and indicated by Chapter*

<table>
<thead>
<tr>
<th>Text</th>
<th>Concept (Chapter)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Chemistry</em> by Addison-Wesley</td>
<td>Measurement (3), Problem Solving (4),</td>
</tr>
<tr>
<td></td>
<td>Atomic Structure (5), Stoichiometry (9),</td>
</tr>
<tr>
<td></td>
<td>Covalent Bonding (16), Solutions (18)</td>
</tr>
<tr>
<td><em>Introduction to Principles of Chemistry</em> by Peters and Kowerski</td>
<td>Percent Composition (7)</td>
</tr>
<tr>
<td><em>Kinetic Molecular Theory</em> Handout by Alice Putti</td>
<td>Kinetic Molecular Theory (10)</td>
</tr>
<tr>
<td><em>Inquiry Text</em> by Sarah Toman</td>
<td>Gas Laws (12)</td>
</tr>
</tbody>
</table>

*Data Collection*

The six informants were interviewed by the researcher three times. The first interview took place after reading Chapters 3, 4, 5, and 7. Chapters 3, 4, and 5 were from the *Chemistry* (2002) textbook while Chapter 7 was from *Introduction to Principles of Chemistry* (1994). The second interview took place after reading Chapters 9 and 10. Chapter 9 was from the *Chemistry* (2002) textbook while Chapter 10 was from the *Kinetic Molecular Theory* Handout (2008). The final interview took place after reading Chapter 12 which was from the inquiry-based piloted text. The students continued to read the *Chemistry* (2002) textbook after the interviews were
students had completed. Students were interviewed each time they read a text other than the *Chemistry* (2002) textbook.

These interviews took place either in the lecture classroom or the laboratory classroom, before or after school or during lunch. They took place one-on-one with the researcher and the informant (McNiff & Whitehead, 2006) and were recorded; interview transcripts were made from each recorded interview. Although interview lengths varied, they were all between three and six minutes long.

The interviews required the informants to examine several key points. Questions focused on the reading guides, on mathematical versus non-mathematical concepts, and comparing the textbooks to one another. The reading guides were developed to help students focus on particular areas of the text as they read. Duffelmeyer, Baum, and Merkley (1987) suggest that an expository text is more difficult for students to understand than a narrative text, and they recommend an anticipation guide to improve student comprehension. Hence, students were given reading guides prior to each reading assignment. Students were allowed to use these reading guides the following day in class on their reading quizzes, and in the interviews the informants were asked if they actually used their reading guide on their reading quiz.

Some reading quizzes were more conceptual in nature, while others were more mathematical. In order to see if there was a relationship between student perception of the material and its difficulty and how their perception related to mathematics, during the interviews the informants were asked to separate their
reading quizzes into “math” and “non-math” piles, and then asked if one pile of reading quizzes was easier for them. Finally, informants were always asked if they preferred their standard textbook or the new text they had read. After each text was read and the informants were re-interviewed, the informants listed all the texts in order of preference.

Data Analysis

The data was analyzed in several ways. First, the class pre- and post-tests were analyzed to see how the amount of knowledge gained from Chapter 12 of the Chemistry (2002) textbook compared to the inquiry-based text. Before the tests were analyzed, an independent-samples $t$ test was conducted to determine any differences in the classes during the 2006-2007 school year compared to the 2007-2008 school year. The $t$ test shows whether or not two different groups of student test scores are comparable. Another statistical analysis, called a univariate analysis, was performed to confirm the $t$ test results.

A second form of analysis compared the reading quiz scores for each text the students read. The reading quizzes were graded on a five point scale. Generally, the concepts covered in the traditional texts were not as conceptually rich as those in the inquiry-based text. The inquiry-based text material required a lot of synthetic thinking; students had to put several different ideas together to form a new idea.

The third analysis focused on the student answers in the interviews. Each YES or NO answer was numerically coded: YES = 1, NO = 2. The further explanations then were analyzed for common threads. In addition, the informants...
were asked to make a distinction between the "math" and "non-math" reading quizzes to explore any relationship between the perceived difficulty of a reading quiz and its mathematical content.

Summary

Is it possible to write a chemistry textbook that does support inquiry-based learning in a chemistry classroom? In order to explore the answer to this question an inquiry-based text needed to be written. This text was piloted in the researcher's chemistry courses and compared with three other standard texts. Every student in the researcher's chemistry course had a role in this research, completing the reading guides, doing the assigned reading, taking the reading quizzes, and taking the pre- and post-tests. Every student read all four texts and took the reading quizzes as part of their chemistry course. Comparing the student scores on the pre- and post-tests from one year to another, students did not learn less from the inquiry-based textbook than the students in the previous class learned from the traditional Chemistry (2002) textbook.

Six key informants from the chemistry course were chosen to take a more in-depth part in the study. These informants participated in three interviews with the researcher to examine the reading quizzes and texts more closely. Although the mean of the student scores on the reading quizzes based on the Chemistry (2002) textbook were higher, not all of the informants favored that text. In fact, three of the informants preferred the inquiry-based text above all the others. Furthermore, all of
the informants agreed that the inquiry-based textbook was more engaging, and they were more likely to read it above the other three texts they had read.
Chapter 4: Results

Demographic Information

The students were in a general, one-year college preparatory chemistry course at a private school of 220 students in the mid-west. There were two sections of chemistry taught by the same teacher. The chemistry courses were made up of 35% sophomores, 55% juniors, and 10% seniors. All 42 students read all four of the texts. The number of students is convenient since most parametric statistical techniques require a minimum of 30 for their sample size (Green, 2008). In order to examine the students' thoughts on the piloted inquiry-based text, six students were selected as key informants. Six key informants are sufficient for purposeful sampling (Patton, 2002). The informants were interviewed three times throughout the trimester and asked to compare the texts in a variety of ways.

The one-on-one interviews between each informant and the researcher took place before or after school or during lunch in either the lecture or laboratory classrooms. Each interview was recorded and later transcripts were made for each interview. Although interview lengths varied, all were between three and six minutes long.

Findings

Answering the research question, "Is it possible to write a chemistry textbook that supports inquiry-based learning in a chemistry classroom?" took several forms.
Statistical analysis.

The data was analyzed in several ways. First, the class pre- and post-test scores were analyzed to see how the amount of knowledge gained from Chapter 12 of the Chemistry (2002) textbook compared to the piloted inquiry-based text. Before the test scores were analyzed, an independent-samples $t$ test was conducted to determine any differences in the classes during the 2006-2007 school year compared to the 2007-2008 school year (Table 2.). The $t$ test shows whether or not two different groups of student test scores are comparable. The test was not significant: $t(42)=0.95$, $p=0.35$. Students in the 2006-2007 school year ($M=2.1$, $SD=1.6$) compared to the students during the 2007-2008 school year ($M=1.8$, $SD=1.1$). Therefore, these student test scores are comparable and there does not seem to be a change in the student content knowledge as measured by this test. In addition a univariate analysis was performed on the student test scores and the significance of the year was 0.90, further showing there is no evidence for a change in student knowledge on the Gas Law assessment portion of the ACS test.

Table 2

*Student Pre-Post Gas-Law Scores $t$ test results*

<table>
<thead>
<tr>
<th>School Year</th>
<th>Pre-Post Mean</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006-2007</td>
<td>1.1</td>
<td>2.2</td>
</tr>
<tr>
<td>2007-2008</td>
<td>1.0</td>
<td>2.1</td>
</tr>
</tbody>
</table>
**Reading quiz score analysis.**

A second form of analysis compared the students' reading quiz scores for each text they read. The students' reading quizzes were graded on a five point scale. The mean and standard deviation for each quiz is listed in Table 3.

Table 3

*Reading Quiz Scores by Text and Chapter*

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Text</th>
<th>Chemistry</th>
<th>Introduction to Principals of Chemistry</th>
<th>Kinetic Molecular Theory Handout</th>
<th>Inquiry-Based Text</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measurement (3)</td>
<td></td>
<td>Mean = 4.2</td>
<td>SD = 0.67</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Problem Solving (4)</td>
<td></td>
<td>Mean = 4.4</td>
<td>SD = 0.54</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Atomic Structure (5)</td>
<td></td>
<td>Mean = 4.4</td>
<td>SD = 0.87</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percent Composition (7)</td>
<td></td>
<td>Mean = 4.5</td>
<td>SD = 0.66</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stoichiometry (9)</td>
<td></td>
<td>Mean = 4.0</td>
<td>SD = 0.59</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kinetic Molecular Theory (10)</td>
<td></td>
<td>Mean = 3.8</td>
<td>SD = 0.98</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gas Laws (12)</td>
<td></td>
<td>Mean = 3.5</td>
<td>SD = 1.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Covalent Bonding (16)</td>
<td></td>
<td>Mean = 4.3</td>
<td>SD = 0.63</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solutions (18)</td>
<td></td>
<td>Mean = 4.3</td>
<td>SD = 0.72</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
required a lot of synthetic thinking; students had to put several different ideas together to form a new idea. Since this type of thinking is new to students it is possible that with more training their skills would improve, and thus increase their reading quiz scores as well.

**Interview analysis.**

The third analysis focused on the student answers in the interviews. Each YES or NO answer was numerically coded: YES = 1, NO = 2. In order to see if there was a relationship between student perception of the material and its difficulty and how their perception related to mathematics, during each interview the informants were asked to separate their reading quizzes into “math” and “non-math” piles, and then asked if one pile of reading quizzes was easier for them. Over the course of the three interviews, the informants did not always choose the same reading quizzes for the “math” and “non-math” piles, with two exceptions, nor were the choices for any particular quiz very consistent (Table 4.).
Table 4

*Informants' Mathematical Interpretations according to Chapter*

<table>
<thead>
<tr>
<th>Informant</th>
<th>Interview 1</th>
<th>Interview 2</th>
<th>Interview 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Math</td>
<td>Non-math</td>
<td>Math</td>
</tr>
<tr>
<td>1</td>
<td>3, 4, 5, 7</td>
<td>0</td>
<td>4, 5, 7, 9</td>
</tr>
<tr>
<td>2</td>
<td>3, 4, 7</td>
<td>5</td>
<td>3, 4, 7, 9</td>
</tr>
<tr>
<td>3</td>
<td>3, 4, 7</td>
<td>5</td>
<td>3, 4, 7</td>
</tr>
<tr>
<td>4</td>
<td>3, 4, 7</td>
<td>5</td>
<td>3, 4, 7</td>
</tr>
<tr>
<td>5</td>
<td>3, 4, 7</td>
<td>5</td>
<td>3, 4, 9</td>
</tr>
<tr>
<td>6</td>
<td>3, 4, 7</td>
<td>5</td>
<td>3, 4, 7, 9</td>
</tr>
</tbody>
</table>

All of the informants were consistent in choosing Chapter 4 as a "math" reading quiz, and Chapter 10 as a "non-math" reading quiz; however, they were not consistent with the other five reading quizzes. In fact, the informants did not always choose the same reading quizzes from interview to interview. In some cases informants were unable to decide in which category a reading quiz belonged and placed it in both. In the first interview when the informants were asked which category was "harder" for them, five of the six informants responded the "math" reading quizzes because the quizzes required them to think. In the second interview the informants were asked again, and this time only three of the six informants responded that the "math" reading quizzes were "harder," but their reasoning was nearly the opposite. In this case two of those three said the "math" reading quizzes were more difficult because they were not required to think. In the third interview the
were more difficult because they were not required to think. In the third interview the informants were asked the question differently. The informants were asked how often they actually used their reading guides on their reading quizzes, and if it made a difference if it was a “math” or a “non-math” quiz. Five of the six informants said it did make a difference, and three of those five said they used their reading guides more on the “non-math” reading quizzes.

The further explanations then were analyzed for common threads. During the interviews, the informants often stated that their science books in general, and specifically the chemistry books they were studying, were not fun to read, not memorable, too long, and did not have enough real-life examples. The informants were told that the final text was written to address those issues, so that students would be more engaged and more likely to read it. All six of the informants agreed that the Chapter 12 text addressed their concerns. Although they did not all agree that it was their favorite text (Table 5.), due to the amount of work involved, they did all agree that the text helped them learn the material better. The inquiry-based text forced them to read deeply in order to find the answers to address the questions on the reading guide.
Table 5

Informants' Text preference

<table>
<thead>
<tr>
<th>Informant Preference</th>
<th>Chemistry by Addison-Wesley</th>
<th>Introduction to Principles of Chemistry by Peters and by Handout by Kowerski</th>
<th>Kinetic Theory by Sarah Toman</th>
<th>Inquiry Text by Alice Putti</th>
</tr>
</thead>
<tbody>
<tr>
<td>Informant 1, 5, 6, 2, 3, 4</td>
<td>5, 6</td>
<td>2, 3, 4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Favorite</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Informant 2, 4, 6</td>
<td>3</td>
<td>1, 5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Least Favorite</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In the third and final interview, five of the six informants said they liked the fact that the Chapter 12 text showed direct relationships, graphs, examples, and visuals. When asked what they did not like about the Chapter 12 text one informant responded, “I guess all of the questions seemed kind of the same to me.” Another informant, when asked if she would like to have an entire textbook like the Chapter 12 text replied, “Yes, because it might be good to get the examples, like, pounded into you. No, because it would be time consuming.” Finally, in response to the question probing what the informants did like about the Chapter 12 text, one replied, “I like it ‘cause, like, you kind of have to read the material to understand the answers, ‘cause you don’t know where the question is.”
Summary

The t test and univariate analysis confirm that the student ACS test scores from the 2006-2007 school year may be compared to the student ACS test scores from the 2007-2008 school year. These latter student ACS test scores had comparable scores on the Gas Laws assessment, so at the very least the inquiry-based text did not hinder student learning. The reading quiz scores from the inquiry-based text had the lowest mean; however, the concepts covered were highly conceptual and involved extensive synthetic thinking. There does not appear to be a relationship between “math” and “non-math” reading quizzes. The key informants were inconsistent in categorizing these quizzes and inconsistent in their reasons for the choices they made.

The final analysis really addresses the question “Is it possible to write a chemistry textbook that does support inquiry-based learning in a chemistry classroom?” The key informants’ answers clearly support the definition of inquiry, meaning they are constructing knowledge through their own experience with the text (Cobern & Tobin, 1993). The informants stated the Chapter 12 text showed direct relationships, graphs, and visuals. The text did display visuals, but the key informants constructed the graphs and drew their own conclusions about the relationships displayed on the graphs that they created themselves.

Now that the analysis and findings have been explored, the final chapter will discuss the conclusions concerning textbooks that support inquiry-based learning in today’s chemistry classrooms.
Chapter 5: Conclusion

Summary

The purpose of this study was to write part of an inquiry-based chemistry textbook, pilot it in a classroom, and observe and record student reactions. This was accomplished by the researcher writing an inquiry-based text and comparing it with three other texts in a high school chemistry classroom. Each time the students read one of the four texts they were given a reading guide to complete as they read. The following day they were allowed to use that reading guide during an in-class reading quiz. In order to determine if the researcher’s text was truly inquiry-based, key informants were interviewed and asked to compare that text with the three other texts. The informants used their reading quizzes to help answer questions about the difficulty level of each text, how much mathematics each involved, which text they preferred, and how the inquiry-based text was different from the other three texts.

Conclusions

Following these interviews it does seem possible to write a textbook that supports inquiry-based learning in a chemistry classroom. The informants clearly stated that the inquiry-based text addressed the issue that their science books in general, and the chemistry books they were studying in particular, were not fun to read, not memorable, too long, and did not have enough real-life examples. All six of the informants agreed that the inquiry-based text was more engaging and they were more likely to read it. Furthermore, the informants stated that they were forced to read the inquiry-based text on a deeper level than the other three texts in order to answer the questions on the reading guides.
Discussion

Key principles.

The piloted inquiry-based text required the students to construct their own graphs and make conclusions based on these graphical results. In their chapter on curriculum instruction and design in *Integrating Differentiated Instruction and Understanding by Design*, Tomlinson and McTighe, (2006) give nine principles to guide a teacher’s curriculum instructional design. Several of these principles were included in this pilot inquiry-based text. First of all the goal was clear. Students were to learn the relationships between pressure, temperature, and volume as stated in Charles’ and Gay-Lussac’s Gas Laws. Second, students would show that they had learned these relationships by performing well on their reading quiz in class. Finally, the reading guide was designed based on these first two principles. The reading guide included data similar to what Charles and Gay-Lussac had actually collected, was presented in table form, and the reading guide asked the students to graph that information and draw conclusions based on their graphs.

Relationships.

Another way previous research was included in the piloted inquiry-based text was to place the reader within the historical context of the original scientists. Beall (1993) encouraged his students to read chemical literature in order to see where the chemistry they were studying in class was applied. Furthermore, he wanted to demonstrate that chemistry was not simply another mathematics course; therefore, he required his students to write about the literature they had read. In the piloted inquiry-based text the students read about the background of Charles and Gay-Lussac and what real-life experiences got
them involved in studying the relationships between the pressure, volume, and temperature of gasses. Although the students were asked about the mathematical relationships, they were also asked both about physical relationships between pressure, volume, and temperature and required to make predictions prior to exploring the mathematics involved.

**Reading guides and reading quizzes.**

The literature highly recommends the use of anticipatory guides. Barton, Heidema, and Jordan (2002) suggest that students have questions to answer both before and after their assigned reading. These questions could challenge common student misconceptions and should be answered by the students individually. Femsten and Loughran (2007) suggest that students should have a list of questions generated by their teacher to answer and consider as they read. These questions may simply address vocabulary, or go a bit deeper and ask students to explain the role of a concept as it relates to the main idea of the assigned reading. Furthermore, Best et al (2005) suggest that because science texts are often written by science experts and, therefore, leave out a lot of basic information assuming that the reader is already aware of these facts. However, the typical high school student is not a science expert and needs these basic facts included in the text. In addition, Best et al (2005) state that students with low active working memory often have difficulty reading science texts due to the amount of information they are required to acquire at one time. Thus, these students are not able to comprehend the information beyond a surface level of understanding.

Based on all of this prior research, the reading guides were developed to accompany each text. They were teacher generated and given to students to complete as
they read each text. In particular, the inquiry-based text’s reading guide carefully asked the same question several times in different ways. For those students with low active working memory, these questions led them step-by-step. For those students with excellent active working memory skills these questions appeared redundant. Both results were apparent in the interviews. All of the informants agreed that the questions probed deeply into their understanding of the material, but some stated, “The questions seemed kind of the same to me.” Furthermore, the students took ownership of their learning. This was apparent when an informant said this kind of textbook may be helpful because, “It might be good to get the examples, like, pounded into you.”

**Findings.**

The results of this classroom research are consistent with the literature. Students understood that they were responsible for their learning. In the interviews the informants understood that they were constructing their own graphs and drawing their own conclusions based on the graphs. They had reading guides written in accordance with the literature, and thus were able to understand the information at a deep level and construct their own ideas based on the concepts in the reading. It does appear that writing a chemistry textbook that is inquiry-based is not only possible, but the results are recognized by students as a different type of text.

**Recommendations**

This study should open the door to exploring the idea of inquiry-based chemistry textbooks. The researcher is repeating the study to see if the results are similar. The study could also be piloted in other schools to see if the evidence is similar. Further studies could explore inquiry-based chemistry texts covering other concepts in high
school chemistry classrooms. These texts could be mathematical or non-mathematical and researchers could see if there is a difference in student understanding. In addition, these other texts could focus on either very simple or highly synthetic concepts to see if the students are able to construct their own ideas in basic or more complex situations. At this point the students in the study did not perform any better on the standardized ACS exam. However, as more and more inquiry-based chemistry texts are piloted and students learn how to construct their own knowledge from these texts, it would be interesting to see how this affected their pre- and post-ACS test scores.
References


We have discussed Boyle’s Law, published in the 1600s, let’s fast forward a bit to the late 1700s.

You may have heard of the Hindenburg, the hydrogen gas filled balloon that exploded over New Jersey in 1937, but do you know who made the first hydrogen filled balloon? Jacques Alexandre Cesar Charles in 1783, he flew the balloon over Paris and sadly, the peasants were so scared they destroyed the balloon. Yet, Charles continued to study gases, particularly the relationship between temperature and volume.

Charles wanted to see what would happen to the volume of a gas as the temperature rose. For example, he noticed if there was water in a glass bulb and the bulb was heated the liquid water became a gas and filled the bulb. When cooled the gaseous water returned to its liquid form taking up only part of the container. Charles wondered what would happen to the volume of the gas as it was heated to various temperatures. Like Boyle, Charles used a barometer to perform his experiments. By placing the barometer into a water bath he was able to change the temperature of the gas in the tube and observe any changes in the volume of the gas this may cause.
Below is some data similar to what Charles would have collected.

<table>
<thead>
<tr>
<th>Volume (mL)</th>
<th>Temperature (°C)</th>
<th>Temperature (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>440</td>
<td>2</td>
<td>275</td>
</tr>
<tr>
<td>500</td>
<td>42</td>
<td>315</td>
</tr>
<tr>
<td>610</td>
<td>108</td>
<td>382</td>
</tr>
<tr>
<td>675</td>
<td>150</td>
<td>423</td>
</tr>
</tbody>
</table>

1. Is there a relationship between the volume of air in the tube and its temperature?

2. Graph the relationship between volume and temperature.

3. Is there a graphical relationship between volume and temperature?

4. Is there a mathematical relationship between volume and temperature?

At this point in history, the Kelvin temperature scale was in use. Since intuitively, it seems that there should be a relationship between volume and temperature, let's see if converting the Celsius data to Kelvin makes a difference.
5. Is there a relationship between the volume of air in the tube and its temperature?

Graph the relationship between volume and temperature.

6. Is there a graphical relationship between volume and temperature?

7. Is there a mathematical relationship between volume and temperature?

Though Charles completed these experiments in 1787, it wasn't published until 1802 when another scientist, Joseph Louis Gay-Lussac, published his experiments confirming Charles' conclusions. In fact, instead of taking credit for the law himself, Gay-Lussac credited Charles' earlier work and that is why the relationship between volume and temperature is known as Charles Law.
Gay-Lussac continued his experiments with gases. In 1804 he took ballooning to new heights and traveled up to 7,000 meters above the earth in hydrogen balloons. This was over double the height that Charles achieved over 20 years earlier. During his balloon rides, Gay-Lussac collected data on air samples at various heights and analyzed them in his lab. He is most famous for his 1808 announcement combining data from several scientists called the (gas) law of combining volumes. For now, we will focus on his study of the relationship between pressure and temperature.

One way we could examine this relationship, an advantage Gay-Lussac never had, is to look at a bottle of hairspray (Figure 12.8). Have you ever wondered why hair spray, bug spray, and other similar products that are packaged in spray bottles have warnings?

1. If you heated such a bottle, what would happen? (CAUTION: DO NOT TRY THIS, JUST MAKE A PREDICTION.)

2. Why does it happen?
Gay-Lussac explored this relationship in a safer manner in his lab using a bulb connected to a pressure gauge (Figure 12.9). He then placed this bulb filled with air into water of various temperatures and read the gauge to see if the temperature changes affected the pressure in the bulb.

Figure 12.9

3. What variable that Boyle and Charles studied did Gay-Lussac have to hold constant? Why did it need to be held constant?

Here is some data similar to what Gay-Lussac may have collected. You may choose to look at the relationships between pressure and temperature using the Celsius or Kelvin data or both.

4. Can you predict which data may be more likely to show a relationship? Explain your choice then try it.

<table>
<thead>
<tr>
<th>Pressure (kPa)</th>
<th>Temperature (°C)</th>
<th>Temperature (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100.</td>
<td>39</td>
<td>312</td>
</tr>
<tr>
<td>103</td>
<td>48</td>
<td>321</td>
</tr>
<tr>
<td>120</td>
<td>101</td>
<td>374</td>
</tr>
<tr>
<td>145</td>
<td>180</td>
<td>453</td>
</tr>
</tbody>
</table>

5. Is there a relationship between the pressure of air in the bulb and its temperature?

6. Graph the relationship between pressure and temperature.
7. Is there a graphical relationship between pressure and temperature?

8. Is there a mathematical relationship between pressure and temperature?

Gay-Lussac continued his studies and though he is most famous for his law relating the relationship between pressure and temperature, he also studied electrochemistry and participated in debates with his colleagues about Lavoisier's definition of acids.
Appendix B: Interview Protocol

Interview # 1

~ We are here with . . .

<table>
<thead>
<tr>
<th>Date</th>
<th>Student</th>
<th>Start Time</th>
<th>End Time</th>
<th>Completed RG/RQ</th>
</tr>
</thead>
</table>

I am going to ask you several questions and may have you explain them further.

Please be honest, these do not reflect on your grade in any way. I am going to take notes and also record our time together so I can listen to it later. ~

Interview Questions

1. Do you read your chemistry textbook more often than in your past science courses?
3. Would you have read your chemistry textbook if there were no reading quizzes?
4. Did you actually read your textbook or just look for the answers to the reading guide questions?
5. Did you read parts of your textbook that were not covered on the reading guides? Why?
6. We have read two different textbooks so far. Which one was your favorite? Explain.
7. Which one was your least favorite? Explain.
8. Do you think the reading guides help you on your quizzes? Explain.

9. Are the reading guides and quizzes easier when they are about concepts, when they are about math, or does it matter?

~ Thank you for your time, I look forward to talking with you again soon. ~
Interview # 2

~ We are here with . . .

<table>
<thead>
<tr>
<th>Date</th>
<th>Student</th>
<th>Start Time</th>
<th>End Time</th>
<th>Completed RG/RQ</th>
</tr>
</thead>
</table>

I am going to ask you several questions and may have you explain them further.

Please be honest, these do not reflect on your grade in any way. I am going to take notes and also record our time together so I can listen to it later. ~

Interview Questions

1. Some of the information in your reading guides/quizzes is not covered in class notes, do you use your reading guide/quiz to study? If so, how?

2. How well do you remember the material covered on the reading guides and quizzes compared to the notes in class? Explain why you think that is.

3. Last time you put the guides/quizzes into a “math” and a “non-math” pile. Does this affect how well you remember the material? For example, is it easier to remember the “non-math” material?

4. If the “math” material were covered in a different way, would it help you remember the material better?

5. What would help to make your textbook more “memorable”?

6. What would help make your textbook more interesting?

7. Have you ever had a textbook that you wanted to read? Why did you want to read it?
8. We have read three different textbooks so far. Which one was your favorite? Explain.

9. Which one was your least favorite? Explain.

10. Separate the reading guides/quizzes into “math” and “non-math” piles.

Are the reading guides and quizzes easier when they are about concepts, when they are about math, or does it matter?

~ Thank you for your time, I look forward to talking with you again soon. ~
Interview # 3

~ We are here with . . .

<table>
<thead>
<tr>
<th>Date</th>
<th>Student</th>
<th>Start Time</th>
<th>End Time</th>
<th>Completed RG/RQ</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

I am going to ask you several questions and may have you explain them further.

Please be honest, these do not reflect on your grade in any way. I am going to take notes and also record our time together so I can listen to it later. ~

Interview Questions

1. Last time you put the guides/quizzes into a “math” and a “non-math” pile, please do that again.

2. You were allowed to use your reading guides on your reading quizzes, how often did you actually use them?

3. Did it make a difference if it was a “math” quiz vs a “non-math” quiz?

4. We read four different textbooks. Which one was your favorite? Explain.

5. Which one was your least favorite? Explain.

6. Did you think the Ch # 12 reading text was any different from the others? Explain.

7. What did you like about the Ch # 12 text?

8. What didn’t you like about it?

9. Would you like to have an entire textbook in this workbook format? Why/not?
10. Students often do not read their book, it's boring, their teacher covers every-thing in class, it's too long, etc. The Ch # 12 text was written to address these issues if students will be more engaged when reading the book, or more likely to read it. Do you think it does that? Explain.

~ Thank you for your time and help throughout my research! ~
Appendix C: Permission Forms
Human Research Review Committee Application Form

GRAND VALLEY STATE UNIVERSITY

HUMAN RESEARCH REVIEW COMMITTEE
‘see attached’ is not acceptable as a fill-in on this form

Principal Investigator(s): Deborah Herrington and Ellen Yezierski

Contact email address: _herringd@gvsu.edu and yezierse@gvsu.edu

Address and Telephone
Number of Principal Investigator(s): Deborah Herrington: 373 PAD 331-3809; Ellen Yezierski: 368 PAD 331-3808

GVSU Department or School: __Chemistry

Department __________________________________________

Title of the Project: _Target Inquiry: How do Students Respond to Inquiry Instruction? __________________________

Date(s) and Location(s) of Subject Enrollment: _College and high school instructor participants will be enrolled in the study spring and summer 2007. Student participants will be enrolled in the study beginning in September, 2007. Voluntary student participants will be recruited from the high school chemistry classes of the teacher researchers at the following area high schools: Allendale High School, Holland High School, West Ottawa High School, Black River Public School, North Muskegon High School, Muskegon High School, Western Michigan Christian High School, Kelloggsville High School, Jenison High School, and Hudsonville High School. _____________________________

Summary of the Project: ‘see attached’ is not acceptable
The teacher researchers for this project will be involved in the development teaching materials that appropriately model the process of scientific inquiry in their classrooms. During the 2007-2008 school year, the teachers will implement their new materials in their classrooms and use action research to evaluate the impact of these materials on their students. The research questions that will guide the teacher researchers’ evaluation of their materials are:

(1) How do inquiry activities impact students’ conceptual understanding of chemistry?
(2) How do inquiry activities impact students’ science processing skills?
(3) How do inquiry activities impact students’ attitudes towards chemistry?
In what capacity does this project involve human subject? (E.g., surveys, interviews, clinical trial, use of medical records, etc.) Participants will complete surveys and content tests linked to the teachers’ curriculum materials. Course materials such as lab notebooks, test or quiz answers, homework problems, group activities, and projects may also be collected. Many of the participants in this study will be minors; therefore, we request an expedited review as described in 46.110 of the Federal Register under research category (7) “Research on individual or group characteristics or behavior.”

Check one:

This is a request for exemption from HRRC approval requirements as specified by 46.101 of the Federal Register 4616:8336, January 26, 1981. (Refer to instructions on the reverse of this form.)

X This is a request for expedited review as described in 46.110 of the Federal Register 46(16):8336, January 26, 1981. (Refer to instructions on the reverse of this form.)

This is a request for full review. (Refer to instructions on the reverse of this form.)

________________________________________________________

Principal Investigator (s)                      Signature of Unit
(Original must be signed in ink)         Head/Department Chair
(I have reviewed the attached protocol and determined that the principal investigator is competent to conduct the study as described.)

To the best of my knowledge adequate subject protections have been provided).

Date Signed

SUPPORTING MATERIALS

A. Investigators
   Deborah Herrington: Grand Valley State University Department of Chemistry
   Ellen Yezierski: Grand Valley State University Department of Chemistry
   Brian Brethauer: Allendale High School
Kevin Conkel: Hudsonville High School
Tim Ewald: Black River Public School
Deborah Johnson: North Muskegon High School
Alice Putti: Jenison High School
Gretchen Ludeman: Kelloggsville High School
Peter Larsen: Holland High School
Susan Munster: Muskegon High School
Brian Vanzanten: West Ottawa High School
Sarah Toman: Western Michigan Christian High School

B. Location
The inquiry materials will be developed at Grand Valley State University during Summer 2007. Teacher researchers may solicit information from local high school and college instructors to assist in the development of their inquiry materials. The evaluation data including chemistry content tests, surveys, and coursework materials will be collected at the 10 area high schools previously specified. Permission will be obtained from each of the high school principals and the parents prior to any data collection. Student assent will also be obtained. (A copy of the principal permission letter, parent consent, and student assent letters are in Appendix A.)

C. Methods
During spring and summer 2007, local high school and college instructors will be sent a voluntary survey to ascertain the chemistry content and process skill expectations for students entering college level chemistry courses. As these surveys will be anonymous, completion of the survey will imply participant consent. Data from these surveys will assist in the development of the inquiry materials. At the beginning of the 2007-2008 school year, informed consent will be obtained from the parents and assent from the students for the use of classroom content tests, survey, and course materials to evaluate the impact of new inquiry instructional materials on students’ conceptual understanding of chemistry, science processing skills, and attitudes towards chemistry. The goal of collecting this data is to allow teachers to further improve their instructional materials for themselves as well as other teachers who may wish to use their materials. Parents and students will be assured that any data obtained through tests, surveys, and course materials will be kept strictly confidential. Teachers will distribute the parent consent and child assent letters and will oversee their collection. To ensure confidentiality, all data from tests, surveys, and course materials will be viewed only by the investigators and the individual participant. Names will be removed from any of the materials and a code number will be used to track each participant’s data. Any materials used for publication will either be aggregate data from a class or use a pseudonym to protect the identity of the participants. All paper records will be kept in a locked filing cabinet in the teachers’ locked offices.
during the academic year to allow the teachers access for data analysis purposes. At the conclusion of the academic year, paper records will be stored in a locked file cabinet in a locked GVSU office (PAD 373 or PAD 368). Any computer data will be stored in password protected computer files. The records will be kept for a period of 3 years following the study to allow for completion of the evaluation and then destroyed. All tests, surveys, and course assignments that are part of the standard course work will be required of all students; however, data for analysis will not be included for any student whose parent does not want them involved with the study.

Teachers will be videotaped up to 4 times per academic year during lessons that they identify as inquiry based and invite us to observe. At this time, any student who has not returned a signed permission form will be situated in the room so that image is not captured on tape. At the beginning of the class the person videotaping will remind the students that if at any time they wish to have videotaping terminated it will in no way influence their grade or relationship with their teacher. The videotapes will not be released or published and will only be viewed by the researchers, their undergraduate or graduate student working on the TI project, and the classroom teacher that was videotaped. The PIs and their graduate or undergraduate student will code each of the videotapes using the Reformed Teaching Observation Protocol. At the end of the TI program the teachers will be asked to watch their classroom videotapes to reflect on the development of their teachers over the course of TI. The videotapes will be kept in a locked filing cabinet in PAD 373 or PAD 368 for 3 year following completion of the TI program to allow for data analysis. They will then be erased.

D. Potential Risks and Benefits

There are no risks to students participating in this study. The majority of data collected from the students will be standard course work. Additional surveys or content tests may help students think differently about the process of science or provide them with additional practice in taking standardized tests. There are several expected benefits from students engaging in the new inquiry instructional activities.

(6) Students may improve their problem solving and data analysis skills.

The videotapes will in no way affect a student’s success in the course or their relationship with their teachers. The teachers will not view the videotapes until after their participation in TI has concluded. Although there are not any direct benefits to the students from being videotaped, the videotapes have potential benefits for teachers and their future classes.

(1) Teachers’ classroom practices will be documented over a 3-5 year period allowing them to critically reflect on and improve their teaching.
(2) Teachers will be able to identify strengths and weaknesses in their teaching that will allow them to better facilitate activities for future classes.

E. Drug or Devices to be Used

No drugs or devices will be used on TI teachers.

F. Granting Agencies

The previously mentioned 10 area high schools have each been $500 to support the teachers’ implementation of the new inquiry instructional activities. This funding has been provided by the Camille and Henry Dreyfus Foundation’s Special Grant for Chemical Sciences. This grant proposal can be found in Appendix B.

APPENDIX A

1. Principal Permission Letter
2. Parent Permission and Student Assent Letter

APPENDIX B

1. Grant Proposal for Camille and Henry Dreyfus Foundation’s Special Grant for Chemical Sciences
Human Research Review Committee Approval

GRAND VALLEY STATE UNIVERSITY

July 12, 2007

Proposal No.: 07-243-H
Expedited
Approval Date: 7/11/2007
Expiration Date: 7/10/2008

Title: Target Inquiry: How do Students Respond to Inquiry Instruction?

Dear Professors Herrington and Yezierski:

Grand Valley State University, Human Research Review Committee (HRRC), has completed its review of the revisions and clarifications submitted for this proposal. The HRRC serves as the Institutional Review Board (IRB) for Grand Valley State University. The rights and welfare of the human subjects appear to be adequately protected and the methods used to obtain informed consent are appropriate. Your project has been APPROVED as EXPEDITED. Please include your proposal number in all future correspondence. The first principal investigator will be sent all correspondence from the University unless otherwise requested.

Revisions: The HRRC must review and approve any change in protocol procedures involving human subjects, prior to the initiation of the change. To revise an approved protocol including a protocol that was initially exempt from the federal regulations, send a written request along with both the original and revised protocols including the protocol consent form, to the Chair of HRRC. When requesting approval of revisions both the project’s HRRC number and title must be referenced.

Problems/Changes: The HRRC must be informed promptly if any of the following arises during the course of your project. 1) Problems (unexpected side effects, complaints, etc.) involving the subjects. 2) Changes in the research environment or new information that indicates greater risk to the subjects than existed when the protocol was previously reviewed and approved. 3) Changes in personnel listed on the initial protocol, e.g. principal investigator, co-investigator(s) or secondary personnel.

Renewals: The HRRC approval is valid until the expiration date listed above. For this project to continue beyond the expiration date listed above a Continuing Review form must be submitted at least ten (10) business days prior to the protocol expiration date listed above. You can find this document at http://www.gvsu.edu/forms/research_dev/FORMS. A maximum of 4 renewals are
possible. If you need to continue a proposal beyond that time, you are required to submit a new application for a complete review.

**Closed:** When the project is closed to further enrollment and all data analysis has been completed, a close protocol form must be submitted to the HRRC. You can find this document at http://www.gvsu.edu/forms/research_dev/FORMS.

If I can be of further assistance, please contact me at 616-331-3417 or via e-mail: reitemep@gvsu.edu. You can also contact the Graduate Assistant in Faculty Research and Development Office at 616-331-3197.

Sincerely,

Paul J. Reitemeier, Ph.D.s
Human Research Review Committee Chair
301C DeVos Center
Grand Rapids, MI 49504
Phone: (616) 331-2281

Human Research Review Committee
Faculty Research and Development Center
301C DeVos • 401 Fulton Street West Grand Rapids, MI 49504-6405
www.gvsu.edu/hrrc
Office: (616) 331-3197. Fax: (616) 331-7317
Principal Permission Form

Dear

We are assistant professors in the Department of Chemistry at Grand Valley State University (GVSU). We are conducting a research study to determine how Target Inquiry* (a new professional development program) affects teachers, their teaching, and student achievement. Your chemistry teacher, ____________________________, would like to participate. This study will take place in his/her classroom and at GVSU (Padnos Hall). S/he will be videotaped while teaching for a maximum of 4 times during each school year for a maximum of 5 years.

Additionally, as part of this program, ________, has developed new inquiry teaching materials that he/she will be implementing in his/her classroom. These materials are aligned with the new Michigan High School Chemistry Content Expectations. To further improve his/her teaching, ________ would like to collect data to evaluate the impact of these materials for students. This may include student surveys, test results, or other classroom artifacts such as lab reports. The items that ________ collects and the data analysis methods will depend on his/her student focus (e.g. motivation, conceptual understanding, data analysis skills, etc.).

We are requesting your permission to conduct classroom observations and request student participation in the study. The GVSU Human Research Review Board has approved this study and the attached teacher, student assent, and parent permission forms. Attached is documentation of approval by the GVSU HRRC.

The results of the research study will be submitted for publication at professional meetings and in research journals. ________’s new inquiry materials along with the results of their evaluation may be presented at conferences and/or published in educational journals such as the Science Teacher. To maintain confidentiality, teachers and students will be assigned codes and their names will not be used. Video will be used for data analysis only and will not be released or published. Records, data, and video will be stored in a locked cabinet in Padnos Hall at GVSU for 3 years after the close of the study and then destroyed. Furthermore, any student data used in the evaluation of the inquiry materials will be presented anonymously or as aggregate class data.
If you have any questions concerning the research study or your participation, please call us at (616) 331-3317.

Sincerely,

Deborah G. Herrington, Ph.D.  Ellen J. Yezierski, Ph.D.
Target Inquiry Principal Investigator  Target Inquiry Principal Investigator

I give consent to participate in the study described above.

______________________________  ________________________________
School                                                                 Name

______________________________  ________________________________
Signature                    Date

If you have any questions that have not been answered by the investigator, you may contact the Grand Valley State University Human Research Review Committee Chair as follows:
Paul J. Reitemeier, Ph.D., Chair, HRRC  Office phone: (616) 331-3197  E-Mail: Reitemep@gvsu.edu

*Target Inquiry is funded by the National Science Foundation and the Camille and Henry Dreyfus Foundation
Parent Permission and Student Assent letter

Dear Parent,

Your child’s chemistry teacher, _________, is a part of the Target Inquiry* program at Grand Valley State University (GVSU). This program is designed to help teachers increase the quantity and quality of inquiry instruction in their chemistry classrooms. Research has shown that inquiry instruction can help students learn and retain chemistry concepts more effectively. We are conducting a study to determine how a new teacher professional development program affects teachers and student achievement in chemistry. Additionally, as part of this program, _____, has developed new inquiry teaching materials that he/she will be using in the classroom. These materials are aligned with the new Michigan High School Chemistry Content Expectations. To further improve his/her teaching, _____ would like to collect data to evaluate the impact of these materials on students. These data may include student surveys, test results, or other classroom artifacts such as lab reports. The items that _____ collects and the data analysis methods will depend on his/her student focus (e.g. motivation, conceptual understanding, data analysis skills, etc.).

We are requesting your child’s participation. Your child’s participation in this study is voluntary. You (or your child) are free to decide not to participate in this study or to withdraw at any time without adversely affecting your relationship with you teacher, the investigators, or GVSU. Your decision will not result in any loss of benefits to which your child is otherwise entitled. Specifically, your choice or your child’s choice to participate (or not) will not affect your child’s grade in the course.

Participation involves allowing the data from surveys, test results, or other classroom artifacts such as lab reports to be used in the analysis of the new classroom materials. Please note, that if you and your child choose for him/her not to participate, s/he is still responsible for completing the tests, assignments, or lab reports required for this course. However, his/her scores on such assignments will not be included in the data analysis. Additionally, as part of the TI study, your child’s teacher will be videotaped during regular instruction, and it is possible that your child’s likeness may be captured on video. Your child has the right to request that taping be stopped at any time. Video will be used for teacher data analysis only and will not be released or published. The results of the research study may be published at professional meetings and in research journals. To maintain confidentiality, your child will be assigned a code and his/her name will not be used. Records, data, and video will be stored in a locked cabinet in Padnos Hall at GVSU for 3 years after the close of the study and then destroyed. Furthermore, any student data used in publications or presentations will be anonymous or reported as class aggregate data.
The study has possible benefits to your child. First, it will provide them with added practice taking standardized chemistry exams. Second, your child will be engaged in learning activities that have been shown to improve student conceptual understanding and retention. The study also has possible benefits to educators who design professional development programs for teachers, researchers who study teacher professional development, and high school chemistry teachers who use the materials generated by this project.

If you have any questions concerning the research study or your participation, please call us at (616) 331-3317.

Sincerely,

Deborah G. Herrington, Ph.D. Ellen J. Yezierski, Ph.D.
Target Inquiry Principal Investigator Target Inquiry Principal Investigator

I give consent for my child ____________________________ to participate in the above study.

________________________________________________
Parent/Guardian Name

_________________________________________  __________
Signature Date

If you have any questions about your rights as a research participant that have not been answered by the investigator, you may contact the Grand Valley State University Human Research Review Committee Chair as follows:
Paul J. Reitemeier, Ph.D., Chair, HRRC Office phone: (616) 331-3197 E-Mail: Reitemep@gvsu.edu

*Target Inquiry is funded by the National Science Foundation and the Camille and Henry Dreyfus Foundation

I have been informed that my parent(s) has given permission for me to participate in a study that is investigating how a new teacher professional development program impacts student achievement and how new inquiry teaching materials impact students. The study involves completing required surveys and/or course materials such as tests, assignments, or lab reports. I understand that my teacher will be videotaped during regular instruction, and it is possible that my likeness be captured on video. I also understand that I have the right to request that taping be stopped at any time.
My participation in this project is voluntary and I have been told that I may stop my participation in this study at any time. If I choose not to participate, it will not affect my grade in any way.

________________________________________
Printed Name

________________________________________
Signature

________________________________________
School