From Verification to Guided-Inquiry: What Happens When a Chemistry Laboratory Curriculum
Changes?

Pamela Sue Scott

A Thesis Submitted to the Graduate Faculty of

GRAND VALLEY STATE UNIVERSITY

In

Partial Fulfillment of the Requirements

For the Degree of

Master of Education

Advanced Content Specialization - Chemistry

August 2014

Acknowledgments

I have benefited from the support, guidance, and reassurance of several professors within the Chemistry Department, as well as professors from the College of Education (COE) at Grand Valley State University (GVSU). From the Chemistry Department, I want to expressly thank Dr. Debbie Herrington and Dr. Tom Pentecost for their enduring support, guidance, friendship, and educational application of inquiry instruction in the chemistry classroom and for their help and assistance with this research. Additionally, I want to thank, Dr. Ellen Yezierski, Dr. Julie Henderleiter, Dr. Sherril Soman, and the 2nd Target Inquiry (TI) Cohort for their collaboration, feedback, advice and motivation throughout the TI program. From the COE, I want to thank Dr. Doug Busman and Mrs. Jacque Melin for their guidance and assistance throughout the ED695 thesis process.

I want to express my gratitude to Mr. Bill Faber, the Grand Rapids Community College (GRCC) general chemistry laboratory instructor who enabled this research to be conducted, and to Leah Engemann, GRCC's Physical Science Laboratory Assistant, for working pro bono as my editor-in-chief.

A special thank you is reserved for one remarkable chemistry professor at GRCC who has influenced my life in many ways. She is Dr. Jennifer Batten. I want to thank Jennifer for being an awesome friend, an amazing colleague and an extraordinary role model, educator and leader.

Last but not least, I wish to thank my Mother, Marcia Brewer, and family members, Tracy, Jeff, Sydney, and Chase Darling for their love, support and encouragement. Most of all, however, I sincerely appreciate and am thankful for the love, support and inspiration that my son, Myles, and husband, Chad, have given to me throughout this educational journey – thank you!

Pamela S. Scott

Abstract

How does the degree or level of inquiry-based laboratory instruction impact student performance and student perseverance in the laboratory portion of a first-semester general chemistry course? In 2008, a two-year community college sought to answer this question by replacing the traditional verification laboratory curriculum with a guided-inquiry laboratory curriculum. This change provided a case study of the 'new' guided-inquiry curriculum vs. the 'old' traditional verification curriculum. Researchers used a modified for college instruction version of The Continuum of Scientific Inquiry Rubric (Fay, Grove, Towns, & Bretz, 2007) to assess both laboratory curricula, to determine the level of inquiry incorporated into each laboratory experiment as well as the inquiry levels of both laboratory curricula overall. Student performance was evaluated via laboratory report average final grades and individual laboratory report scores, while student perseverance was measured by comparing overall completion rates of laboratory reports and student withdrawal rates for each laboratory curriculum to determine if any relationships exist between level(s) of inquiry and student performance and student perseverance.

Table of Contents

Chapter One: Introduction

Problem Statement

Increasing the use of inquiry-based science instructional activities in both lecture and laboratory classrooms has been at the heart of most calls for curriculum reform at all levels of education (Bransford, Brown & Cocking, 2000; Lederman, 2004). While many studies have been conducted on the effectiveness of inquiry-based science instruction techniques with respect to student performance and outcomes in the chemistry laboratory, literature reveals that the definition of inquiry-based science instruction lacks consistency, and a common standardized performance measure for assessing the value of inquiry-based laboratory instruction remains variable. Furthermore, it is difficult to compare studies that investigate the effectiveness of inquiry-based teaching in the laboratory because the degree or level of inquiry present is most often overlooked and seldom characterized or reported.

Importance and Rationale

Science education is in the midst of a crucial transition, as an inquiry-based approach to instruction improves student achievement (Blanchard et al., 2010) and allows students to make connections and correlations between science and their own lives, which can be particularly important for culturally diverse learners (Adamson et al., 2003). Inquiry-based laboratory instruction promotes the development of students' scientific processing skills and can advance critical thinking capabilities, problem-solving skills, and an overall understanding of the nature of science (Hofstein & Lunetta, 2004). The National Science Teachers Association asserts "understanding science content is significantly enhanced when ideas are anchored to inquiry experiences." Therefore, "scientific inquiry is an effective and powerful way of understanding science content" (National Science Teachers Association, 2004).

The National Science Education Standards (National Research Council, 2000) and the Benchmarks for Science Literacy (American Association for the Advancement of Science, 2009) emphasize the importance of inquiry-based instruction, where classrooms are student-centered, and laboratory activities are hands-on and minds-on, allowing students to engage in the processes that scientists use in constructing knowledge. Inquiry-based science instruction should not be an isolated occurrence, but a comprehensive and ongoing pedagogical approach.

Background

In 1986, the National Science Board (NSB) reported that laboratory instruction "has deteriorated to the point where it is often uninspired, tedious and dull," and courses and curricula "fail to reflect advances in the understanding of teaching and learning" (National Science Board, 1986, p. 2). Even so, the predominant type of laboratory instruction in today's chemistry curriculum is still the traditional verification style, also known as cookbook chemistry. Within the verification laboratory environment the teacher presents a study topic, the students follow a structured procedure, or recipe, in order to collect data and the final outcome is predetermined known results. The students are involved in neither the planning of the scientific investigation nor the interpretation of the results; hence the traditional method of laboratory instruction has limited opportunities for students to understand science content. Furthermore, most textbooks are filled with information and terminology that students are expected to memorize, and most exams assess students' abilities to recall the facts. This type of instruction places very little emphasis on critical thinking and is an unrealistic representation of scientific experimentation (Domin, 1999).

The Inquiry Process

Inquiry-based instruction is not a new technique, but it does stand in stark contrast to the more structured, traditional lecture-and-test instruction and verification centered laboratory curriculum framework of today's schools. Brunner (2012) of the Center for Children and Technology classifies the inquiry process into four stages, as illustrated in Figure 1.0.

Figure 1.0 The Inquiry Process.
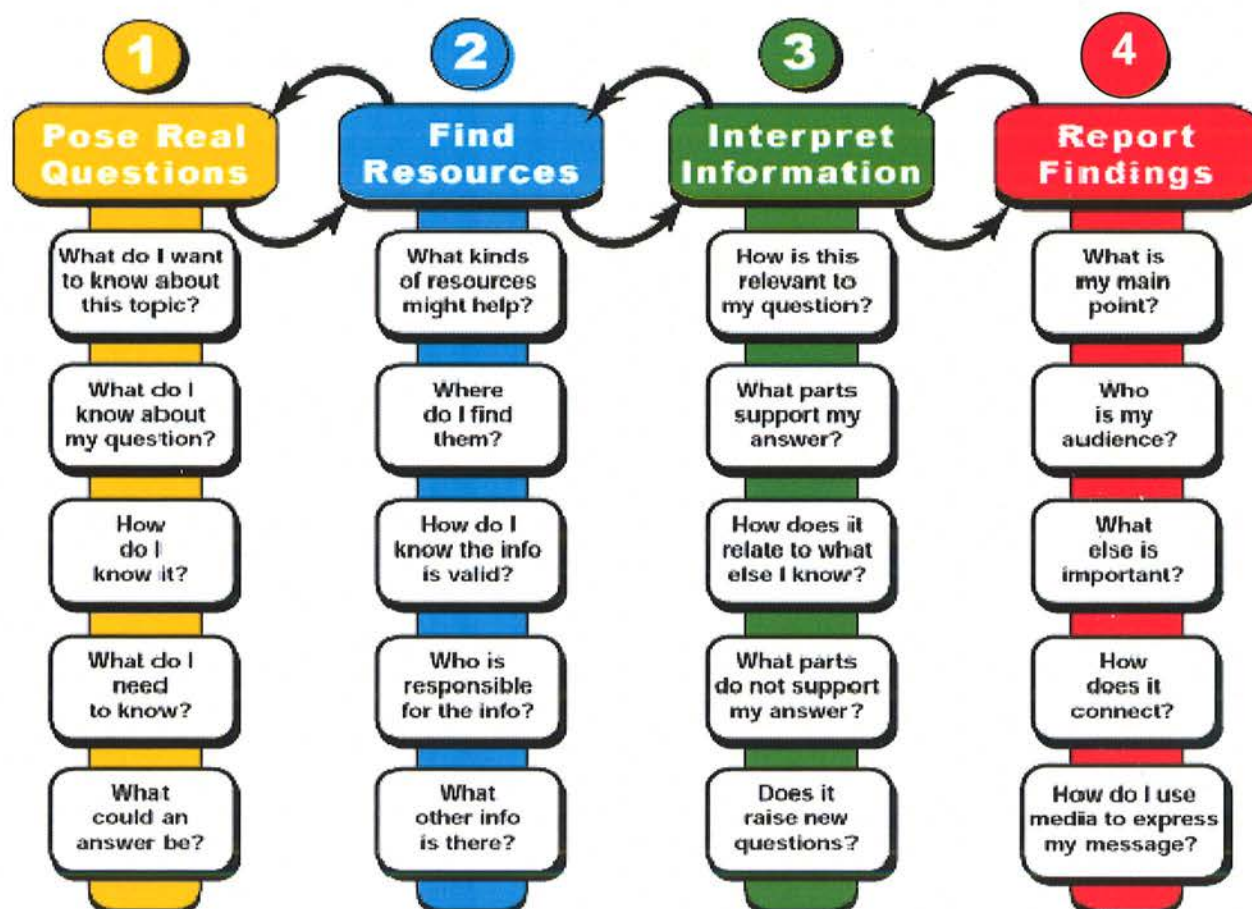
1 Pose Real Questions	**2** Find Resources	**3** Interpret Information	**4** Report Findings
What do I want to know about this topic?	What kinds of resources might help?	How is this relevant to my question?	What is my main point?
What do I know about my question?	Where do I find them?	What parts support my answer?	Who is my audience?
How do I know it?	How do I know the info is valid?	How does it relate to what else I know?	What else is important?
What do I need to know?	Who is responsible for the info?	What parts do not support my answer?	How does it connect?
What could an answer be?	What other info is there?	Does it raise new questions?	How do I use media to express my message?

Stage (1) Formulation (pose real questions). Inquiry-based instruction requires a classroom teacher to play a much different role than that of a teacher in a traditional classroom. Instead of providing direct chalk-and-talk instruction to students, teachers help students create

10

their own content related questions. Thinking is not driven by answers but by questions; thus, teaching students to ask the right questions is one of the greatest skills a teacher can impart.

Stage (2) Exploration (find resources). Teachers facilitate students as they develop skills and learn how to filter the vast resources (i.e. internet, books, journals, people, media) to find the information they need.

Stage (3) Collection (interpret information). Teachers assist students in evaluating the resources for accuracy and validity, and in processing the information to form conclusions.

Stage (4) Assessment (report findings). Teachers support and encourage students as they learn to create meaningful representations of their research findings and transfer information skills and knowledge to solve problems and make decisions (Brunner, 2012).

Likewise, the National Science Education Standards describe inquiry-based science instruction as involving students in active learning that emphasizes questioning, data analysis, and critical thinking.

Students at all grade levels and in every domain of science should have the opportunity to use scientific inquiry and develop the ability to think and act in ways associated with inquiry, including asking questions, planning and conducting investigations, using appropriate tools and techniques to gather data, thinking critically and logically about relationships between evidence and explanations, constructing and analyzing alternative explanations, and communicating scientific arguments. (National Research Council, 1996, p. 105)

Although a considerable body of literature supports inquiry-based science instruction, little progress has been made to integrate inquiry-based teaching in the science laboratory, particularly at the college and university levels (Bruck, Bretz & Towns, 2008). Today, the vast

majority of higher education institutions continue to use a more structured, traditional verification laboratory curriculum as the primary means of educating students in the science laboratory (Abraham et al., 1997). College faculty often resist inquiry-based instruction because they view inquiry as costly, time consuming, student-directed, and as such, potentially chaotic. In addition, they often perceive significant obstacles (i.e. class sizes, limited resources, student competencies) when incorporating inquiry into laboratory activities (Brown, Abell, Demir & Schmidt, 2006).

Analysis of the literature indicates that the effectiveness of inquiry-based laboratory instruction has been measured by many different performance measures, such as interviews, observations, surveys, and questionnaires which are designed to capture changes in student attitudes, beliefs and perceptions with respect to the laboratory environment. In addition, few studies report quantitative comparisons of exam scores that have been used to evaluate student achievement in the laboratory.

Further complicating the assortment of performance measures and student outcomes is the fact that it is difficult to compare studies that investigate the effectiveness of inquiry-based instruction, because the degree or level of inquiry present in a particular activity, laboratory experiment or curriculum is most often not characterized. As if in answer to this limitation, a Continuum of Scientific Inquiry Rubric, has been developed. The rubric was first described by Schwab (1960) as "three levels of openness and permissiveness," and later amended by Herron (1971) into "Herron's scale: a four-point scale describing four levels of inquiry." Subsequently, the rubric was adapted and used by Lederman (2004) for high school instruction, and more recently, the rubric has been modified for college instruction (Fay, Grove, Towns, & Bretz, 2007). Rather than seeking to answer the question of whether inquiry-based instruction had

value in laboratory application, Fay et al. (2007) focused on showing that the inquiry content of a laboratory curriculum could be quantitatively measured. Their study confirms that a modified, for college instruction, rubric (Table 1.0) and rubric companion (Table 1.1), depicting a visual comparison of inquiry characteristics, can be consistently used to evaluate the level of inquiry in laboratory activities by multiple different raters, and thus can aid instructors in making laboratory curricula choices. In addition, an article by Bruck et al. (2008) suggests that the rubric can be used to standardize the means of communication with respect to inquiry-based science instruction and learning in future higher education research literature.

Table 1.0 The Continuum of Scientific Inquiry Rubric (Fay et al., 2007).

Level of Inquiry	Description
Level-0	The problem, procedure and methods to solutions are provided to the student. The student performs the experiment and verifies the results with the manual.
Level-1	The problem and procedure are provided to the student. The student interprets the data in order to propose viable solutions.
Level-2	The problem is provided to the student. The student develops a procedure for investigating the problem, decides what data to gather, and interprets the data in order to propose viable solutions.
Level-3	A 'raw' phenomenon is provided to the student. The student chooses the problem to explore, develops a procedure for investigating the problem, decides what data to gather, and interprets the data in order to propose viable solutions.

Table 1.1 Rubric Companion: Visual Comparison of Inquiry Characteristics (Fay et al., 2007).

Level	Problem/Question	Procedure/Method	Solution
0	Provided to student	Provided to student	Provided to student
1	Provided to student	Provided to student	Constructed by student
2	Provided to student	Constructed by student	Constructed by student
3	Constructed by student	Constructed by student	Constructed by student

Grand Rapids Community College

Grand Rapids Community College (GRCC) always used a traditional laboratory curriculum in the general chemistry two-semester sequence (CM103/104), which consisted of a

collection of verification experiments written in house by the chemistry faculty. However, in 2008 the chemistry department actively engaged in a laboratory curriculum evaluation of the two-semester general chemistry course. In an effort to provide a more dynamic learning environment, the faculty decided to implement a commercially published guided-inquiry curriculum. The inquiry-based laboratory curriculum that is the focus of this research is *Guided Inquiry Experiments for General Chemistry: Practical Problems and Applications* (Kerner & Lamba, 2008).

Statement of Purpose

The research presented in this thesis makes use of Fay et al.'s (2007) modified for college instruction rubric (Table 1.0) to characterize the level of inquiry present in both the traditional and inquiry-based laboratory curricula, to examine the relationship between the level of inquiry present in a laboratory experience and student outcomes, and to use a standard means of communication with respect to inquiry-based science instruction. In addition, this investigation documents the changes observed when a laboratory program is transitioned from a structured traditional laboratory curriculum to a more inquiry-based instructional laboratory curriculum, thus informing and providing quantitative data and evidence to chemistry instructors, science educators, schools and institutions as they contemplate inquiry-based science curriculum reform.

Research Question

How does the degree or level of inquiry-based science laboratory instruction impact student performance and student perseverance in the first-semester general chemistry course (CM103) at Grand Rapids Community College (GRCC)? In 2008, a commercially published guided-inquiry laboratory curriculum (Kerner & Lamba, 2008) was implemented for the first-semester general chemistry course (CM103) at Grand Rapids Community College in Michigan.

This curriculum change provided a case study of the new guided-inquiry laboratory curriculum versus the old traditional laboratory curriculum.

Hypothesis

The implementation of a more inquiry-based instructional laboratory curriculum will positively impact student performance and student perseverance in the laboratory portion of the first-semester general chemistry course (CM103) designed to educate students majoring in science and engineering programs.

Design, Data Collection, and Analysis

A quasi-experimental design and nonrandom sampling procedure was used to establish two student test groups from intact laboratory sections. Comparison of ACT test scores was used to ascertain that the two samples of students were drawn from the same population. The student performance data set consisted of students' individual laboratory report scores and overall laboratory report final grades, three semesters from the old traditional curriculum (Fall 2006, Winter 2007 and Fall 2007) and three semesters from the new guided-inquiry curriculum (Fall 2008, Winter 2009 and Fall 2009). Additionally, a comparison of laboratory report completion rates between the two laboratory curricula provided a measure of student perseverance in the laboratory portion of the course. In an effort to minimize instructor effect, student data was provided by the same laboratory instructor for all six semesters.

The level of inquiry present in each experiment for both laboratory curricula was determined using the modified version of The Continuum of Scientific Inquiry Rubric (Fay et al., 2007) for college instruction (Table 1.0).
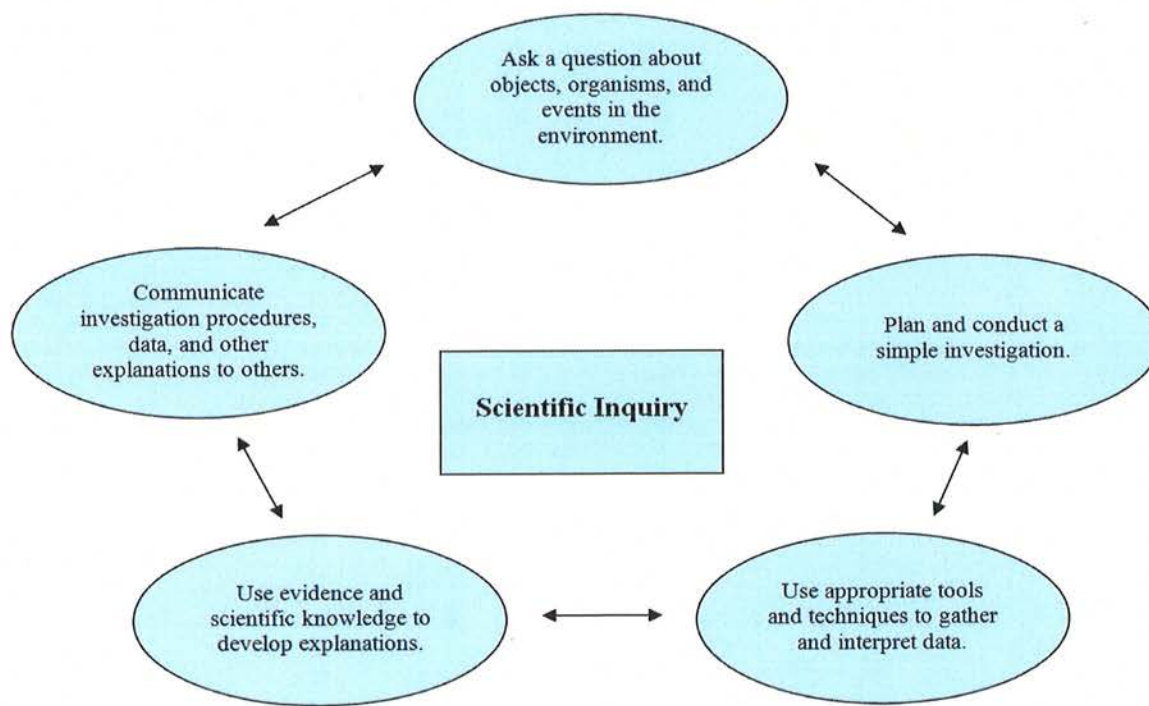
Statistical analysis was done using nonparametric versions of the *t*-test and Analysis of Variance procedures to determine the difference in levels of inquiry present in each laboratory

15

curriculum, effect of level of inquiry on student performance, a comparison of laboratory report completions rates and a comparison of withdrawal grades as a measure of student perseverance in the laboratory portion of the course. A Kolmogorov-Smirnov test (Field, 2005) was used to check for normality of data and determined that nonparametric statistical techniques were necessary because these data did not exhibit normal distribution.

Definitions

Inquiry-based science instruction, also known as teaching science through inquiry, active learning, discovery learning, or simply as scientific inquiry, combines the curiosity of students with the application of scientific processes to enhance the development of critical thinking skills (Figure 1.1). As students encounter problems they do not understand, they develop questions, make observations, collect and interpret data, and apply new information to propose possible solutions (National Research Council, 2000).

Figure 1.1 Inquiry-Based Learning Cycle (Carin, Bass & Contant, 2004, p. 21).

Ask a question about objects, organisms, and events in the environment.

Communicate investigation procedures, data, and other explanations to others.

Plan and conduct a simple investigation.

Scientific Inquiry

Use evidence and scientific knowledge to develop explanations.

Use appropriate tools and techniques to gather and interpret data.

Inquiry-based science instruction is a pedagogical approach that gives students opportunities to take ownership of their own learning, a skill necessary to succeed in society. Moreover, scientific inquiry is the process used by scientists to investigate the nature of science, and it is at the core of how students learn or create knowledge. The National Science Education Standards define scientific inquiry as,

> The diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Inquiry also refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world. (National Research Council, 1996, p. 23)

Delimitations of the Study

Student performance was evaluated via laboratory report average final grades and individual laboratory report scores. A comparison of laboratory report completion rates between the two laboratory curricula provided a measure of student perseverance. Thus, in an effort to minimize instructor effect, laboratory report data was accumulated and provided by the same laboratory instructor throughout the data collection segment of this study.

Limitations of the Study

This research was unable to correlate the changes in the laboratory format to improvements in student learning in chemistry because of institutional course grading limitations. Without external, course objective-related measures of learning, claims about the impact on student learning due to the implementation of the inquiry-based laboratory curriculum could not be rendered. Therefore, this research used and compared students' individual

laboratory report scores and laboratory report average final grades as a measure of student performance in the two curricula.

Organization of the Thesis

Chapter Two provides an interpretation of the theoretical framework and presents an analysis of current research concerned with inquiry-based laboratory instruction. Chapter Three focuses on the key features (participants, instrumentation, data collection and analysis) with respect to this study's research method. Chapter Four reports the findings and interprets the student performance and student perseverance results in terms of the research question, "How does the degree or level of inquiry-based science laboratory instruction impact student performance and student perseverance in the first-semester general chemistry course (CM103) at GRCC?" and hypothesis, "The implementation of a more inquiry-based instructional laboratory curriculum will positively impact student performance and student perseverance in the laboratory portion of the first-semester general chemistry course (CM103) designed to educate students majoring in science and engineering programs." Chapter Five brings this study to a close with an explanation, recommendation, and articulation of the results.

Chapter Two: Literature Review

Introduction

This chapter considers the research question, "How does the degree or level of inquiry-based science laboratory instruction impact student performance and student perseverance in the first-semester general chemistry course (CM103) at GRCC?" and provides a synthesis of current research with respect to inquiry-based laboratory instruction. Thus, Chapter Two comprehensively explores a variety of studies that use a number of different descriptions with respect to inquiry-based science instruction and reviews an assortment of performance measures used by researchers to assess student outcomes and the value of inquiry-based science instruction in the chemistry laboratory. As a result, this chapter (1) provides a description of the theoretical framework, (2) presents several peer-reviewed research studies, (3) summarizes the findings, and (4) closes with a brief conclusion.

Theoretical Framework

The postpositivist philosophy is consistent with the approach of traditional instruction and verification laboratory curriculum, in which it is assumed that as long as the classroom material is presented; the students will learn. In this case, the instruction is the cause and the learning is the effect. The students have a responsibility to learn, but it is the presentation of information by the teacher that leads to the learning (Creswell, 2009).

By contrast, the social constructivist perspective holds that individuals construct meaning via interacting with each other and the objects in the environment, and meaningful learning or understanding occurs when individuals are engaged in social activities. This philosophy is in alignment with the approach of inquiry-based science instruction, where students engage in hands-on and minds-on activities, thus placing them at the center of the learning process. In a

social constructivist classroom, rather than acting as the providers of knowledge, the role of the teacher is to provide facilitation, support and encouragement; imparting the skill of how-to-learn becomes more important than any particular information being presented. Thus, provided with proper coaching, in this type of classroom students are not receivers of knowledge but instead students construct their own understandings as they seek answers to questions (Creswell, 2009).

In recent decades, social constructivists have shifted the focus from individual learning to address collaborative and social dimensions of learning, thus bringing together the work of Jean Piaget, Jerome Bruner, and Lev Vygotsky. Both Piaget and Bruner alleged that learning occurs as a result of experience and the process of social interaction. In addition, both Bruner and Vygotsky placed language and collaborative communication, and hence instruction and learning, at the core of intellectual development (Wood, 1998). Therefore, Piaget, Bruner and Vygotsky have all substantially influenced and enhanced the collaborative development (teacher-student), group work (student-student) and overall nature of inquiry-based laboratory instruction and laboratory classroom environments.

In the last decade, chemistry educators have begun to develop and apply innovative teaching strategies adapted to the physical conditions of the learning environment founded on the social constructivists' perspective. These include modifying lecture and laboratory activities to promote student-student group work and teacher-student collaborations, and to implement more inquiry-based science instruction in both lecture and laboratory classrooms (Gabel, 2000).

Synthesis of the Research Literature

Although inquiry-based instruction can be incorporated into all aspects of a science course, educational researchers and science instructors alike would agree that the most obvious choice for implementation is the laboratory classroom. Clearly, the science laboratory, if

structured correctly, provides an authentic research experience and opportunity to promote cognitive learning skills such as asking relevant questions, observing phenomena, developing critical thinking and formulating arguments in a scientific context (Hofstein, Shore & Kipnis, 2004). In addition, the construct of inquiry-based laboratory classrooms provides students with group work opportunities to collaborate, deliberate and communicate with classmates. Thus, students learn science by doing science. Research indicates that students who engage in active inquiry-based instructional and learning environments learn practical, useful approaches to solving problems and answering questions, demonstrate improved conceptual science understanding and research skills, and exhibit improved perceptions and more positive attitudes toward science (Hofstein et al., 2004).

Guided/Open-Inquiry Laboratory Instruction

> [Inquiry] an activity consisting of three phases: (1) exploration, in which the students collect data on system for which no theoretical background is provided; (2) invention, in which the students analyze their data and draw conclusions from it, and the excepted scientific terminology is placed on the observed behavior; (3) discovery, further student experimentation and data analysis designed to enlarge on the invented concept.
>
> (Renner's definition, as cited in Pavelich & Abraham, 1977, p. 24)

A four-year study by Pavelich and Abraham (1979) evaluated a guided/open-inquiry laboratory format (test group) compared to a traditional laboratory format (control group) in a two-semester sequence general chemistry course. The characteristics of three different laboratory formats are summarized in (Table 2.0) and differentiated by the nature of the information provided or not provided by the teacher. In this early study, the researchers employed a two-phase laboratory format consisting of (1) a guided-inquiry laboratory session scheduled prior to a lecture topic,

followed by (2) one or two open-inquiry laboratory sessions scheduled to coincide with the lecture topic. The two-phase laboratory format was essential for first-year chemistry students to develop the fundamental laboratory skills required to perform open-inquiry experiments.

Table 2.0 Characteristics of Laboratory Types* (Pavelich & Abraham, 1979).

	Verification	Guided-Inquiry	Open-Inquiry
Order	$C \rightarrow D$	$D \rightarrow C$	$D \rightarrow C$
Choice of Problem	T	T	S
Experiment Design	T	T	S
Data Analysis	T	S	S
Data Explanation	T	S	S

*C: Concepts   D: Data   T: Teacher   S: Student

Observational assessment of in-class laboratory activities was used by researchers to informally establish that both group of students developed laboratory skills, techniques and procedures equivalently. A more formal Piagetian-type paper and pencil tasks test was used to measure the effect of laboratory format on intellectual development. The tasks were administered to both student populations, at the beginning of the first-semester (~600/group), at the end of the first-semester (N = 133 for both groups) and at the end of the second-semester (N = 91 for each group). The researchers reported that after one semester the test group displayed significant gains in abstract thinking or growth in intellectual development (t = 4.71, $p < 0.001$); however, those results were lost after two semesters. An additional instrument, The *Laboratory Program Variables Inventory* (LPVI) survey, developed by the authors and validated by Abraham (1982), was used to survey the students about their laboratory experiences. The LPVI consisted of twenty five statements concerned with various operational aspects of the laboratory formats. Students were asked to rank the statements in order, from those statements that were most descriptive of their laboratory experience, to those statements which were least descriptive. By comparing the student statement rankings, the researchers found exceptional differences between the operational aspects (e.g., the instructor lectures to the whole class) of the two laboratory

formats. Additionally, the guided/open-inquiry laboratory format was determined to be substantially better than the traditional laboratory format at encouraging scientific inquiry processes.

Inquiry-Based Laboratory Instruction

"Students work cooperatively in small groups to investigate scientific phenomenon" (Hofstein, Nahum & Shore, 2001, p. 195). Over a period of four years (1997-2000), Hofstein et al. (2001) conducted research, on 11th grade high school chemistry students using non-inquiry (control group) and inquiry-type (test group) laboratory instruction, seeking to apply a measure similar to LPVI. The *Science Laboratory Environment Inventory* (SLEI) survey, developed and validated by Fraser, McRobbie and Giddings (1993), was used to assess students' perceptions of the chemistry laboratory learning environment. The SLEI consisted of sixty eight items inside eight learning factors or scales: Student Cohesiveness, Open-Endedness, Integration, Rule Clarity, Material Environment, Teacher Supportiveness, Involvement and Organization. Student interviews and feedback questionnaires provided other sources of information regarding students' attitudes and perceptions of the inquiry-type (test group) laboratory environment, and served as a method for validating the sensitivity of SLEI for different instructional approaches used in the science laboratory classroom. The study concluded that the students in the inquiry-type (test group) laboratory, as a result of their laboratory experiences, attained a significant improvement in perceptions of the chemistry laboratory learning environment. Students perceived that they were more involved, as measured by the Involvement scale (Mean = 3.94 vs. Mean = 3.42, t = 9.99, $p < 0.000$), and responsible for their own learning, Open-endedness scale (Mean = 3.27 vs. Mean = 2.20, t = 20.43, $p < 0.000$), and preferred the inquiry-type (test group) laboratory curriculum as compared with the non-inquiry (control group) laboratory.

Kipnis and Hofstein (2007) followed up this study with a direct comparison of inquiry-type and traditional chemistry laboratory environments over a period of six years (1999-2005). The researchers expanded their study to over 3500 high school chemistry students and added a practical test to assess the development of inquiry skills as well as an *Attitude Towards Science Laboratory* (ATSL) questionnaire to capture student attitude towards laboratory work. The ATSL questionnaire, developed and validated by Hofstein, Ben-Zvi and Samual (1976), included 62 items that were divided into eight factors or scales: (I) Learning in the chemistry lab, (II) Amount of laboratory work, (III) Value of laboratory work, (IV) The place of laboratory work within the framework of chemistry teaching and its value as a mean for learning chemistry, (V) Students' enthusiasm for practical work and their enjoyment in working in the lab, (VI) Students' assessment of their own experimentation versus teacher's demonstration, (VII) Immediate and future benefits students gain from experimentation, and (VIII) The advantage of laboratory work. This measure was administered at the start of the 11th grade and the end of the 12th grade. The practical test revealed that students in the inquiry-type (test group) curriculum asked significantly more questions (Mean = 5.19 vs. Mean = 3.05, t = 10.55, $p \leq 0.0001$) and that those questions were more high-level, quantitative inquiry-type questions than the non-inquiry (control group), suggesting that the teaching technique had a positive impact on the development of inquiry skills. Analysis of the SLEI survey yielded similar results as the Hofstein et al. (2001) study. Analysis of the ATSL questionnaire revealed no significant difference between the inquiry-type (test group) and non-inquiry (control group) in the 11th grade. However, the comparison conducted at the end of the 12th grade revealed the inquiry-type (test group) demonstrated a more positive attitude towards chemistry laboratory work compared to the non-inquiry (control group) on five (III, IV, V, VI and VII) dimensions of attitude. The researchers

concluded that the inquiry-type program provided the students with the opportunity to be involved in a worthwhile (student-centered) learning process that the chemistry laboratory provided.

Inquiry-Discovery Laboratory Instruction

"The experiments used in this study were written to assist the student in discovering some of the important laws of chemistry for himself. The experiments utilized the inquiry approach to learning" (Richardson & Renner, 1970, p. 77). A three-year study led by Richardson and Renner (1970) used control and experimental student groups measured against each other to investigate the effects of inquiry-discovery laboratory instruction on student laboratory final exams during three consecutive years (Fall 1966, Fall 1967 and Spring 1968) and laboratory pre- and post-tests (Spring 1968) for the beginning college chemistry laboratory. The experimental variables became more controlled as the study progressed, yielding the third-year (Spring 1968), with the most consistent experimental controls. For example, the third-year controls involved (1) one experimental group and one control group, (2) the eight laboratory experiments performed by each group were matched for content, (3) eight pre- and post-tests were administered at the time each experiment was performed, (4) both groups of students had the same lab instructor, lecture instructor and lab assistant. Therefore, the only experimental variable was the difference in laboratory format, thus the data set from 1968 was considered the most reliable. Likewise, the authors stated "the superiority of the inquiry method of laboratory instruction over that of the conventional method is probably best provided by the interpretation of the data collected during the Spring semester 1968" (Richardson & Renner, 1970, p. 78). With that said, the authors reported that the students in the inquiry-discovery laboratory

(experimental group) performed significantly better on the final laboratory exam for all three

semesters when compared to the students in the conventional laboratory method (Table 2.1).

Table 2.1 Final Laboratory Exam Mean Scores by Laboratory Method.

Year (Semester)	Verification Lab (Control Group)	Inquiry-Discovery Lab (Experimental Group)
1966 (Fall)	*20.90	*25.90
1967 (Fall)	*17.06	*20.48a, *21.00b
1968 (Spring)	*18.44	*21.58

$*p < 0.05$, a: first independent experimental group, b: second independent experimental group

In addition, statistical analysis of the pre- and post-test data (Spring 1968) showed that the

inquiry-discovery laboratory students (experimental group) achieved significantly better (at the

0.05 level of significance) over the conventional laboratory student (control group) on all eight

of the pre- and post-tests.

The next study describes inquiry-discovery laboratory instruction as "a sequence of

events designed by the students under the guidance of a teacher in which students construct

meaningful knowledge about phenomena in the laboratory setting" (Bodner, Hunter & Lamba,

1998. p. 6). In a extensive implementation of inquiry-based discovery laboratories into the first

half of a two-semester general chemistry curriculum, Bodner et al. (1998) utilized an Action

Research method where all of the students (~400), working in the laboratory in groups of three,

were treated to the same intervention. The researchers used laboratory observations and

interviews to report that both students and teaching assistants expressed overall contentment with

their laboratory experiences despite frustrations caused by the non-prescriptive nature of the

inquiry-discovery laboratory format. Additionally, the use of a Likert-scale survey indicated that

86% students would recommend or strongly recommend the inquiry instruction in the laboratory

and 74% either agreed or strongly agreed that working in groups helped them understand course

material, implying that the inquiry teaching approach had a significant and favorable effect on student attitude and disposition.

Inquiry-Based, Cooperative Learning, Laboratory Instruction

"Laboratory format for general chemistry that exposes students to the process of scientific problem solving, emphasizes collaborative work, and requires the students to communicate their results both orally and in writing" (Cooper, 1994, p. 307). In a large-scale general chemistry experiment conducted by Cooper (1994) involving 2000 students per semester, student surveys indicated that the inquiry-based cooperative learning (4 students per group) laboratory setting offered a more positive laboratory experience, and the students believed they learned more from their laboratory experience. Cooper (1994) also indicated that the combination of cooperative learning inside an inquiry laboratory curriculum impacted student performance in lecture. All students, regardless of laboratory type, take the same lecture exams; therefore analysis of lecture grades showed a gender difference and revealed that female students enrolled in the inquiry-based cooperative learning (test group) laboratory curriculum outperformed their female counterparts enrolled in the traditional (control group) laboratory curriculum by as much as 10%. Despite the positive outcome shown for female students, a similar correlation was not found for male students. Moreover, an examination of drop rates also corroborated a gender difference. The drop rate for females in the inquiry-based cooperative learning (test group) laboratory was found to be 13% compared to 21% for the traditional (control group) laboratory and male students dropped the course 9% regardless of laboratory type.

"[Guided-inquiry] experiments are designed to lead students to hypothesis formation and testing. This approach is based on the learning cycle, which consists of three phases: data

collection, concept invention, and application" (Farrell, Moog & Spencer, 1999, p. 572). A

four–year study by Farrell et al. (1999) presents a case study with respect to the implementation

of guided-inquiry laboratory instruction in a two-semester sequence general chemistry course for

science majors. The researchers evaluated final exams, course grades, which consisted of

quizzes (10% of overall course grade), group participation (5% of overall course grade), lecture

exams (65% of the overall course grade) and laboratory reports (20% of the overall course

grade), and withdrawal grades (W-grades) as performance measures to investigate the effects of

the guided-inquiry cooperative learning curriculum on student achievement. The authors

reported a grade distribution (Table 2.2) that demonstrates an increase in 'A' (4.9%) and 'B'

(7.5%) overall course grades, a decrease in 'D' (1.9%) and 'F' (3.4%) overall course grades and

a decrease in course withdrawal 'W' (7.0%) grades for students enrolled in the guide inquiry

laboratory curriculum. In addition, the final exams of the guided-inquiry (test group) students

scored as high as or higher than the students in the traditional (control group) curriculum. These

results indicated that the percentage of students successfully completing the chemistry course

substantially increased (12.3%) as a result of the new approach. In addition, the authors stated

that they intended to continue using the guided-inquiry cooperative learning instructional

technique because they had not discovered any negative attributes that would lead them to

abandon it.

Table 2.2 Grade Distribution for Authors' Sections of General Chemistry (Farrell et al., 1999).

Period	Curriculum	Percentage of Students Earning Grade						
		A	B	C	D	W	F	D+W+F
F90-S94	Traditional	19.3	33.1	25.7	9.0	9.3	3.6	21.9
F94-F97	Guided Inquiry	24.2	40.6	25.6	7.1	2.3	0.2	9.6

Guided-Inquiry, Collaborative, Science Writing Heuristic (SWH), Laboratory Instruction

"When using SWH, the role of the instructor changes. [The instructor] serves as a facilitator and helps guide students to design an experiment to answer the student's questions" (Greenbowe & Hand, 2005). A study by Greenbowe and Hand (2005) investigated the effects of a guided-inquiry, group work laboratory format in conjunction with the SWS laboratory report writing technique in the first-semester general chemistry by comparing American Chemical Society (ACS) standardized exam scores administered at the beginning of the semester against ACS exam scores administered at the end of the semester. At the beginning of the semester, there was a significant difference ($F(1, 285) = 14.5298, p < 0.001$) in favor of male students (62.7%), over female students (56.5%), on the American Chemical Society (ACS) California Diagnostic Test scores; however, by the end of the semester, there was no significant difference ($F(1, 236) = 0.0822, p = 0.775$) between male students (78.3%) and female students (76.5%) on the ACS First-Semester General Chemistry Examination scores. The study indicated that female students made significant improvements in their level of chemistry knowledge, and substantial gains in the gender gap, which was reduced from 0.45 at the beginning of the semester to 0.04 at the end of the semester.

Poock, Burke, Greenbowe and Hand (2007) extended this study to encompass a two-semester longitudinal study involving 78 science and engineering students during their first-semester and second-semester in both the lecture and laboratory segments of a general chemistry course. The researchers reported a clear statistically significant difference ($F = 4.298, p = 0.0074$) in students' lecture academic performance (average total points in the lecture portion of the course) at the end of the first-semester between students (Mean = 83.1%) having a teaching assistant (TA) rated high in implementing the SWH practices in the laboratory compared to

students (Mean = 74.8%) having a TA rated low. Similarly the researchers reported a

statistically significant difference ($F = 6.071$, $p = 0.0010$) in students' lecture academic

performance (average total points in the lecture portion of the course) at the end of the second-

semester between students (Mean = 83.7%) having a teaching assistant (TA) rated high in

implementing the SWH practices in the laboratory compared to students (Mean = 67.8%) having

a TA rated low. The researchers concluded that students benefit when an instructor or TA

proficiently utilizes the guided-inquiry, collaborative, SWH laboratory approach and engages

their students in the laboratory portion of the course.

Summary

An account of the research study (year), a brief description of the type of chemistry

course (interval of study), the featured laboratory format (group size), performance measure data

collection methods (E: exams, I: interviews, O: observations, P: pre-/post-test &/or practical test,

V: surveys, Q: questionnaires) and results in terms of student outcomes with respect to each

research study considered in the previous section is summarized and presented below in

chronological order (Table 2.3).

Table 2.3   Summary of Research Literature Results.

Research Study (year)	Course Type	Laboratory Format (group size)	Performance Measure(s)						Student Outcomes
			E	I	O	P	Q	V	
Richardson & Renner (1970)	Beginning College Chemistry	Inquiry-Discovery	X			X			Significantly ↑ students' scores on lab final exam & pre-/post-tests
Pavalich & Abraham (1979)	General Chemistry (1ˢᵗ year)	Guided/Open-Inquiry (student pairs)			X	X		X	Significant gain in intellectual development & substantially better at encouraging scientific inquiry processes

Research Study (year)	Course Type	Laboratory Format (group size)	Performance Measure(s)						Student Outcomes
			E	I	O	P	Q	V	
Cooper (1994)	General Chemistry (1 semester)	Inquiry-Based Cooperative Learning (4 students)	X					X	↑(+) attitudes, ↑ lecture exam & ↑ retention rate (particularly for female students)
Bodner et al. (1998)	General Chemistry (1st semester)	Inquiry-Discovery (3 students)	X	X				X	Inspired (+) lab climates & (+) student attitudes
Farrell et al. (1999)	General Chemistry (1st semester)	Guided-Inquiry Discovery (4 students)	X						↑ in final course grades & ↓ in withdrawal rates = ↑ students success completing the course
Hofstein et al. (2001)	High School Chemistry (11th grade)	Inquiry-Type (3-4 students)		X			X	X	Students preferred the inquiry-type laboratory & perceptions of the lab significantly improved
Greenbowe & Hand (2005)	General Chemistry (1st semester)	Guided-Inquiry, Collaborative, SWH	X						Female students made significant improvements in their level of chemistry knowledge
Kipnis & Hofstein (2007)	High School Chemistry (11th & 12th grades)	Inquiry-Type (3-4 students)				X	X	X	Students developed inquiry skills & a more (+) attitude toward chemistry work in12th grade
Poock et al. (2007)	General Chemistry (1st year, 2 semesters)	Guided-Inquiry, Collaborative, SWH	X		X				↑ Students' mean total points in the lecture portion of the course for both 1st and 2nd semester

Instruments (E: Exams, I: Interviews, O: Observations, P: Pre-/Post-test &/or Practical Test, Q: Questionnaires, V: Surveys)

Conclusion

The literature review presents several research studies (quantitative and qualitative) that

were conducted on the effectiveness of inquiry-based laboratory instruction in a variety of

chemistry (high school and general chemistry) laboratory courses. However, it is problematic to compare these studies because (1) the definition of inquiry-based laboratory instruction is extensive and lacks consistency; (2) these studies used several different performance measures (exams, interviews, observations, tests, questionnaires and surveys); to (3) assess many different student outcomes (improvement in student intellectual gains, attitudes, encouraging inquiry, laboratory perceptions and student achievement). Furthermore, it is most difficult to compare these studies because the degree or level of inquiry present in the laboratory experiences was not evaluated and characterized. Hence, this thesis will add to the literature base by evaluating the effect of inquiry-based laboratory instruction as a function of the level of inquiry present in the new guided-inquiry laboratory curriculum.

Chapter Three: Research Design

Introduction

Chapter Three considers the research question, "How does the degree or level of inquiry-based science laboratory instruction impact student performance and student perseverance in the first-semester general chemistry course (CM103) at GRCC?" and addresses a variety of essential research design features. As a result, this chapter (1) provides a description of the two student test groups, (2) considers the method used to establish the reliability of the modified for college instruction rubric, (3) discusses the data collection and statistical analysis techniques, and (4) concludes with a brief summary.

Participants/Subjects

A quasi-experimental design and nonrandom sampling procedure was used to establish two student test groups from intact laboratory sections, three semesters from the old traditional laboratory curriculum (Fall 2006, Winter 2007 and Fall 2007) and three semesters from the new guided-inquiry laboratory curriculum (Fall 2008, Winter 2009 and Fall 2009). In order to minimize instructor effect, data was collected and provided by the same laboratory instructor throughout the data collection segment of the study for all six semesters.

ACT test scores of the two student test groups were compared to establish population equivalency. There were a total of 183 students with allocated laboratory grades in the original data set. ACT scores were only available for 128 of these students. This smaller, n = 128, sample was used for statistical analysis. The control group consisted of 58 students who performed traditional verification laboratory experiments, while the experimental group consisted of 70 students who performed the guided-inquiry laboratory experiments.

Instrumentation: The Continuum of Scientific Inquiry Rubric

The Continuum of Scientific Inquiry Rubric: Inter-Rater Reliability

The researchers in this study used the modified rubric for college instruction advanced by Fay et al. (2007) to characterize the level of inquiry present in each laboratory experiment and both laboratory curricula overall. As such, Fay et al. (2007) established the dependability of the modified for college instruction Continuum of Scientific Inquiry Rubric (Table 3.0) to distinguish between levels of inquiry present in a wide spectrum of chemistry laboratory activities covering a comprehensive selection of chemistry concepts. Included within the selection of chemistry concepts were chemically similar activities as well. Fay et al. (2007) commissioned a team of three researchers to evaluate all 27 individual chemistry experiments section-by-section: (1) pre-lab, (2) procedure, and (3) post-lab calculations and conclusions, across 12 different resources, twice over. The first set of 18 general chemistry/environmental chemistry laboratory experiments were chosen from three commercially published laboratory curricula and the second set consisted of 9 organic chemistry laboratory experiments that were selected from the *Journal of Chemical Education* by searching the terms 'inquiry' and 'discovery-based learning.' Upon completion of the second evaluation by researchers, an inter-rater reliability (IRR) value was calculated separately for each category of experiments (general/environmental chemistry = 18 individual experiments = 0.89), (organic chemistry = 9 individual experiments= 0.78) and overall for the entire collection of all 27 experiments (overall = 0.85). Since the lowest acceptable value for establishing reliability is 0.70, the high overall 0.85 IRR rendered the modified rubric as robust and the reliability of the modified rubric to characterize the level of inquiry present in college chemistry laboratory experiments and overall laboratory curricula is considered good (Fay, et al., 2007).

Table 3.0 The Continuum of Scientific Inquiry Rubric (Fay et al., 2007).

Level of Inquiry	Description
Level-0	The problem, procedure and methods to solutions are provided to the student. The student performs the experiment and verifies the results with the manual.
Level-1	The problem and procedure are provided to the student. The student interprets the data in order to propose viable solutions.
Level-2	The problem is provided to the student. The student develops a procedure for investigating the problem, decides what data to gather, and interprets the data in order to propose viable solutions.
Level-3	A "raw" phenomenon is provided to the student. The student chooses the problem to explore, develops a procedure for investigating the problem, decides what data to gather, and interprets the data in order to propose viable solutions.

Data Collection and Statistical Analysis

Inter-Rater Reliability and Level(s) of Inquiry

Given the robust nature and good reliability of the modified rubric (Table 3.0), the level of inquiry present in the 14 laboratory experiments from both of GRCC's general chemistry laboratory curricula (traditional and guided-inquiry) were analyzed and characterized independently by two researchers, and an IRR was calculated. Laboratory experiments comprised of multiple sections were assigned a single inquiry-level, which was determined by the highest level of inquiry present in any of the sections of the experiment. A Spearman's Rho (Field, 2005) correlation coefficient was used to assess the inter-rater reliability of the level of inquiry classification for each (14 experiment) laboratory curricula and overall (28 experiments). A graphic distribution of experiments with respect to levels of inquiry across laboratory curricula was developed.

A statistical comparison of the levels of inquiry in the two curricula was done using a Mann-Whitney (U) test (Field, 2005), which is the non-parametric equivalent of a t-test. This more conservative comparison was warranted because the inquiry levels were not normally distributed.

Student Performance: Effect of Curriculum

The first student performance data set consisted of students' overall laboratory report average final grades from intact laboratory sections, three semesters from the old traditional laboratory curriculum (Fall 2006, Winter 2007 and Fall 2007) and three semesters from the new guided-inquiry laboratory curriculum (Fall 2008, Winter 2009 and Fall 2009). Initially, the student performance evaluation compared the Laboratory Report Average Final Grade (LRAFG) and an Adjusted Laboratory Report Average Final Grade (ALRAFG) of both student groups for both laboratory curricula. The LRAFG was calculated by using all of the 14 possible laboratory report scores per semester and included any/all zero scores assessed for laboratory reports that were not submitted to the instructor for grading. The ALRAFG was derived solely from those laboratory reports that were completed and submitted to the instructor for grading, thus the ALRAFG excluded any/all laboratory report scores of zero. The LRAFG and ALRAFG for both student test groups were statistically compared using a Mann-Whitney (U) test, because the grades were not normally distributed.

Student Performance: Effect of Level of Inquiry

The second student performance data set consisted of students' individual laboratory report scores from intact laboratory sections, three semesters from the old traditional laboratory curriculum (Fall 2006, Winter 2007 and Fall 2007) and three semesters from the new guided-inquiry laboratory curriculum (Fall 2008, Winter 2009 and Fall 2009). This performance evaluation pooled all students into one group, omitted the type of laboratory curriculum, and compared individual laboratory report scores by the level of inquiry assigned to the laboratory experiment. For ease of comparison, the scores for each laboratory report were converted to a 10.00-point scale. Ideally, had every student submitted each laboratory report for instructor

grading, there would have been a total of 1792 individual laboratory report scores produced. However, scores were only available for 1564 laboratory reports; consequently the comparison was made using these. The laboratory report scores were not normally distributed so the comparison was done using the Kruskal-Wallis (H) test (Field, 2005), a non-parametric Analysis of Variance. In addition, Mann-Whitney (U) tests with a Bonferroni correction (Field, 2005) were used to determine which levels of inquiry (Level-1, Level-2 and/or Level-3) were different from the others.

Student Perseverance

The student perseverance data set consisted of completed student laboratory reports and student withdrawal grades (W-grades) from intact laboratory sections, three semesters from the old traditional laboratory curriculum (Fall 2006, Winter 2007 and Fall 2007) and three semesters from the new guided-inquiry laboratory curriculum (Fall 2008, Winter 2009 and Fall 2009). The student perseverance evaluation compared the percentage of completed laboratory reports and the percentage of withdrawal grades of both student test groups for both laboratory curricula. The comparisons were made via Mann-Whitney (U) tests, because the data were not normally distributed. In addition, a subgroup statistical analysis of student perseverance for students that did not complete all fourteen laboratory reports was used to capture the effect of curriculum on students that might be in danger of not completing the course.

Summary

A quasi-experimental design and nonrandom sampling procedure was used to establish two student test groups from intact laboratory sections. The work of Fay et al. (2007) provided a robust measuring instrument and a reliable rubric to use for the purpose of assessing and establishing the level(s) of inquiry present in college level chemistry laboratory activities,

experiments and curriculum. Thus, this study used the modified for college instruction version of The Continuum of Scientific Inquiry Rubric (Fay et al., 2007) to assess and establish the level of inquiry integrated into each laboratory experiment and both laboratory curricula overall.

In addition, instructor effect was minimized by analyzing only those data that were collected and provided by the same laboratory instructor throughout the data collection segment of the study for all six semesters. Furthermore, student performance and perseverance assessments feature the creation of a product (laboratory reports) on an ordinal scale of unequal scale intervals. Student performance was evaluated and statistically analyzed via laboratory report average final grades (LRAFG) and individual laboratory report scores, whereas student perseverance was measured and statistically analyzed by comparing the overall percentage of completion rates for laboratory reports by curriculum to ascertain if any relationships exist between level(s) of inquiry and student performance and student perseverance in the laboratory portion of the course.

Chapter Four: Results

Context

This study was conducted at GRCC, a two-year community college located in the Great Lakes region of the United States. GRCC practices an open admission policy and serves 30,000 students annually. The student population involved in this research, n = 128, was composed of students enrolled in CM103, which is the first sequence of a two-semester general chemistry course intended to educate students majoring in science and engineering programs. CM103 was a five-credit course comprised of 4 hours of lecture (~70-80% of course grade) and three hours of laboratory (~20-30% course of grade) each week. The laboratory component of CM103 was taught by the same chemistry laboratory instructor throughout the data collection segment of this research and featured a pre-laboratory quiz (~15 minutes), a pre-laboratory lecture (~15 minutes) followed by a laboratory exercise (~2.5 hours). In the laboratory classroom students enrolled in the traditional laboratory curriculum (Fall semester 2006 - Fall semester 2007) worked in pairs, while the students enrolled in the inquiry-based laboratory curriculum (Fall semester 2008 – Fall semester 2009) worked in groups of (2-4 students). Each student was required to write his or her own laboratory report for each laboratory exercise that was completed in both laboratory curricula. Laboratory reports that were submitted to the instructor for grading during the traditional laboratory curriculum were scored on a 10.00-point scale. However, laboratory reports submitted to the instructor for grading during the inquiry-based laboratory curriculum were scored on a 15.00-point scale and later converted to a 10.00-point scale for comparison via statistical analysis.

Findings

In an effort to answer the research question, "How does the degree or level of inquiry-based science laboratory instruction impact student performance and student perseverance in the first-semester general chemistry course (CM103) at GRCC?" and address the hypothesis, "The implementation of a more inquiry-based instructional laboratory curriculum will positively impact student performance and student perseverance in the laboratory portion of the first-semester general chemistry course (CM103) designed to educate students majoring in science and engineering programs" statistical analysis of data took many forms. As a result, this chapter (1) describes the analysis of students' ACT scores used to establish that the two student test groups were from the same population, (2) considers the level(s) of inquiry present in laboratory experiments and curricula, (3) discusses the student performance and perseverance data, and (4) concludes with a summary of the results.

Participants/Subjects

A comparison of mean ACT scores for each test group of students (Table 4.0) shows that the scores were normally distributed and have equivalent variances, both of which are requirements for comparison of the groups using a t-test. On average, there was no difference in the ACT comprehensive score of the students in the traditional laboratory curriculum and the guided-inquiry laboratory curriculum, $t(126) = -0.12, p > 0.05$. The same was true for the students' ACT science scores, $t(126) = -0.21, p > 0.05$. Therefore, the two student test groups, those completing the old traditional verification laboratory activities and those completing the new guided-inquiry laboratory activities, were treated as equivalent samples drawn from the same population this allows comparison of student performance and student perseverance.

Table 4.0 Comparison of Average ACT Scores by Student Group.

Students (Curriculum Type)	Mean ACT Comp. Score (SD)	Mean ACT Science Score (SD)
Control, N = 58 (Traditional Laboratory)	21.2 (4.0)	22.2 (3.7)
Experimental, N = 70 (Guided-Inquiry Laboratory)	21.3 (3.4)	22.3 (3.3)

Significant, $p < 0.05$

Inter-Rater Reliability and Level(s) of Inquiry

To establish the level of inquiry found in each laboratory experiment and laboratory

curriculum, the modified rubric for college instruction described in Chapter's One (Table 1.0)

and Three (Table 3.0) was used by two evaluators. A Spearman's Rho correlation coefficient

was used to establish inter-rater reliability (Table 4.1). Given the fairly strong agreement,

indicated by the IRR value ($0.85, p < 0.01$), the level of inquiry assigned to each experiment in

both laboratory curricula was determined (Table 4.2). When the initial level of inquiry assessed

for any given experiment resulted in disagreement, discussions between the two researchers

negotiated the final level of inquiry assigned to that experiment. Furthermore, it's important to

note that any initial disagreement with respect to an assessed inquiry-level between the two

researchers was never more than one level away from each other.

Table 4.1 Inter-Rater Reliability Values for Laboratory Curricula.

Laboratory Curriculum	Number of Experiments with Agreement	Total Number of Experiments	Inter-Rater Reliability (Spearman's Rho)
Traditional	12	14	0.73[*]
Guided-Inquiry	12	14	0.74[*]
Overall	24	28	0.85[*]

*Reliability significant, $p < 0.01$

Table 4.2 Laboratory Curricula: Level of Inquiry.

Experiment: Traditional Laboratory Curriculum *(Chemistry Concepts)*	Level of Inquiry
1. Introduction to the Chemistry Lab	0
2. Determination of Density	**0**
3. Separation of a Mixture *(extraction using acid/base properties)*	0
4. Electrons & Light *(atomic spectra & unknown identification)*	1
5. Chemicals & Reactions *(observe, describe & identify chemical changes)*	1
6. Solution Chemistry *(concentration of a solution determination)*	0
7. Molecular Modeling *(Lewis dot structures & molecular geometries)*	0
8. Separation of Compounds *(intermolecular forces)*	1
9. A Cycle of Copper Reactions *(reaction types)*	0
10. Stoichiometry	0
11. Determining Concentration *(Beer's law)*	0
12. Enthalpy Changes & Hess's Law *(calorimetry-heat of solution)*	0
13. Signs of ΔH, ΔS & ΔG (qualitative thermodynamics)	**1**
14. Ten Unknowns *(experimental design & unknown identification)*	1
Experiment: Guided-Inquiry Laboratory Curriculum *(Concepts)*	**Level of Inquiry**
1. Introduction to the Chemistry Lab.	0
2. How Long Can a Bubble Last? *(experimental design)*	2
3. Are All Pennies the Same? *(density)*	1
4. What Makes a Solution Colored or Colorless? *(absorbance, color & periodic tends)*	1
5. What Factors Affect Color Intensity? *(solution prep & Beer's law)*	1
6. Are There Property Patterns? *(reactivity & periodic properties)*	1
7. What Factors Affect the Solubility of Ions? *(double replacement reactions)*	2
8. Can Toxic Ions be Removed from Water by Precipitation? *(separation of compounds by solubility)*	2
9. Do Like Repel or Attract? (intermolecular forces & solubility)	**1**
10. How Much Hydrogen? *(stoichiometry & reactivity of metals with acid)*	1
11. How Much is Too Much? *(stoichiometry & limiting reagents)*	1
12. Which Salts Make Good Cold Packs & Hot Packs? *(calorimetry-heat of solution)*	1
13. How is Heat Measured Indirectly? *(calorimetry-Hess's law)*	1
14. Thermodynamic Signs (qualitative thermodynamics)	**1**

Bold italicized text denotes initial disagreement, and the value posted is the agreed-on level.

A distribution of the 14 laboratory experiments with respect to levels of inquiry across each curriculum was developed (Figure 4.0). The majority of the experiments in the traditional laboratory curriculum were rated Level-0 (64.3%) with the remainder rated Level-1 (35.7%);

conversely, the experiments in the guided-inquiry laboratory curriculum were rated Level-0 (7.1%), Level-1 (71.4%) and Level-2 (21.4%), respectively.

Figure 4.0 Distribution of Levels of Inquiry Across Laboratory Curriculum.
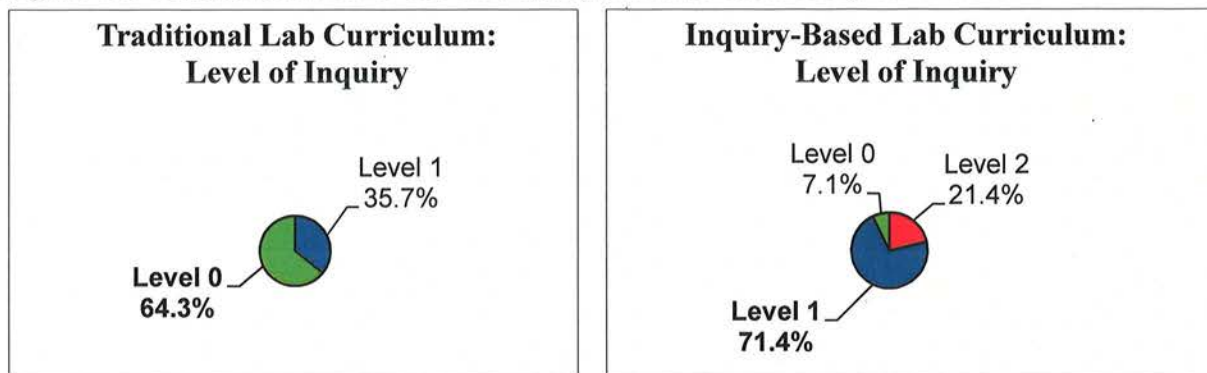
A Mann-Whitney (U) test, found that the level of inquiry in the guided-inquiry curriculum (Median = Level-1) was significantly higher than that that of the traditional curriculum (Median = Level-0), U = 34.50, $p < 0.005$, r = -0.62.

Before comparing student performance, it is important to note that the new inquiry-based laboratory experiments were determined to be suitable replacements for the old traditional laboratory experiments by the chemistry department at GRCC. Therefore, the inquiry-based laboratory experiments should have a comparable level of course rigor and expectations of the students.

Student Performance: Effect of Curriculum

The LRAFG and ALRAFG for both student test groups were statistically compared (Table 4.3) using the Mann-Whitney (U) test because they were not normally distributed. Data analysis revealed that the LRAFG for the students in the guided-inquiry curriculum (Median = 85.00%) was not significantly lower than that that of the students in the traditional curriculum (Median = 89.93%). On the other hand, the ALRAFG for the students in the guided-inquiry

curriculum (Median = 90.07%) was significantly lower than that of the students in the traditional

curriculum (Median = 94.74%), U = 925.00, $p < 0.005$, r = -0.47.

Table 4.3 Comparisons of LRAFG and ALRAFG by Student Test Group.

Student Test Group (Lab Curriculum)	Median/Mean LRAFG (SD) [%]	Median/Mean ALRAFG (SD) [%]
Control, N = 58 (Traditional)	89.93/77.59 (27.25)	94.74/93.89 (3.83)
Experimental, N = 70 (Guided-Inquiry)	85.00/81.00 (15.29)	90.07/88.75 (7.01)

Note: LRAFG= laboratory report average final grade; ALRAFG= adjusted laboratory report average final grade

Given that both types of laboratory curricula were instructed and graded by the same

instructor, and covered similar topics, these data may indicate that expectations of the students in

the guided-inquiry curriculum were greater and that the inquiry laboratory reports might be

better probes of student understanding than the traditional laboratory reports.

Student Performance: Effect of Level of Inquiry

A Kruskal-Wallis (H) test, a non-parametric equivalent of an analysis of variance,

revealed a significant effect with respect to level of inquiry on the individual laboratory report

scores, H(2) = 92.34, $p < 0.005$. Therefore, Mann-Whitney (U) tests with a Bonferroni

correction were used to determine which level of inquiry was different from the others.

Statistical analysis determined that the laboratory report scores from experiments allocated as

Level-1 (Median = 9.30) or Level-2 (Median = 9.20) were not significantly different (Table 4.4).

On the other hand, laboratory report scores from experiments allocated as Level-0 (Median =

9.50) were statistically higher than those scores from experiments rated as Level-1 (Median =

9.30), U = 153487.00, $p < 0.005$, r = -0.25 and as Level-2 (Median = 9.20), U = 34933.50, $p <$

0.005, r = -0.25, respectively.

Table 4.4 Comparison of Individual Laboratory Report Score by Level of Inquiry.

Level of Inquiry	Number of Laboratory Reports	Median/Mean Laboratory Report Score (SD) [10.00-Point Scale]
0	509	9.50/9.39 (0.84)
1	855	9.30/8.99 (1.04)
2	200	9.20/8.86 (1.27)

Note: Level-0 was determined to be significantly higher than Level-1 and Level-2

Therefore, the data suggests that the inclusion of inquiry, at any level, into a laboratory experiment increases the degree of difficulty, which in turn yields lower laboratory report scores resulting in lower laboratory report average final grades. This is a reasonable finding since one goal of inquiry instruction is to enhance the development of critical-thinking skills, a process that requires effort.

Student Perseverance

The traditional laboratory curriculum produced 672 completed laboratory reports out of a possible 812, resulting in a completion rate of 82.8%. Additionally, the guided-inquiry curriculum yielded 892 completed laboratory reports out of a possible 980, which resulted in a completion rate of 91.0%. While these results appear different, statistical analysis via a Mann-Whitney (U) test indicated that the results were not statistically different (Table 4.5).

Table 4.5 Student Perseverance.

Curriculum (Semester/Year)	Laboratory Report Completion Rate	Number of Lab Reports Submitted by Subgroup (Median)	Withdrawal Rate (Median)
Traditional (F06, W07, F07)	82.8%	9.5	18.8%
Guided-Inquiry (F08, W09, F09)	91.0%	12.0	6.1%
College-wide (F06, W07, F07, F08, W09, F09)			Mean = 14.1%

Note: Subgroup refers to only those students who submitted less than 14 laboratory reports

However, a Mann-Whitney (U) test of the subgroup, containing only those students who submitted less than the 14 possible laboratory reports for a grade, revealed that the subgroup of

students in the guided-inquiry curriculum submitted significantly more laboratory reports (Median = 12.00) than the subgroup of students in the traditional curriculum (Median = 9.50), U = 226.00, $p < 0.005$, r = -0.40 (Table 4.5).

A similar trend was observed when withdrawal grades (W-grades) were analyzed (Table 4.5). A Mann-Whitney (U) test showed that the student withdrawal rate for the semesters that used the traditional laboratory curriculum (Median = 18.8%) were significantly higher than the withdrawal rate for the semesters that used the guided-inquiry laboratory curriculum (Median = 6.1%), U = 0.00, p = 0.05, r = -0.80. In an effort to support the decrease in withdrawal rate findings, additional data were collected and analyzed for all college-wide credit courses during the same semesters. The additional data produced a consistent college-wide withdrawal rate (Mean = 14.1%, SD = 1.3) over the six semester period.

Summary

The *t*-test analysis of students' ACT scores by laboratory curriculum (traditional and guided-inquiry) determined no statistical difference between the two student test groups, thus both groups of students were treated as equivalent samples drawn from the same population.

The overall IRR value of (0.85, $p < 0.01$) indicated a fairly strong agreement with respect to the level of inquiry independently assigned to every laboratory experiment by each researcher. Accordingly, the final level of inquiry assigned to each laboratory experiment, and thus laboratory curricula overall, can be considered consistent and reliable. A statistical comparison of the inquiry levels for the two laboratory curricula indicated that the level of inquiry in the guide-inquiry curriculum (Median = Level-1) was significantly higher than that of the traditional curriculum (Median = Level-0). Furthermore, comparison of the modified for college instruction rubric used in this study and the definitions of inquiry levels (Table 2.0) by Pavelich and

Abraham (1979) further support the label of guided-inquiry as appropriate for the new laboratory curriculum.

The final analyses with respect to student performance and perseverance directly address both the research question, "How does the degree or level of inquiry-based science laboratory instruction impact student performance and student perseverance in the first-semester general chemistry course (CM103) at GRCC?" as well as the hypothesis, "The implementation of a more inquiry-based instructional laboratory curriculum will positively impact student performance and student perseverance in the laboratory portion of the first-semester general chemistry course (CM103) designed to educate students majoring in science and engineering programs."

Student Performance

Comparison of the LRAFG by student group showed no significant differences. However, comparison of the ALRAFG by student group showed that the students (experimental group) in the guided-inquiry laboratory curriculum (median = 90.07%) scored significantly lower on their laboratory reports than the students (control group) in the traditional laboratory curriculum (median = 94.74%). Contrary to the hypothesis, adjusted laboratory report average final grades (ALRAFG) were found to be lower for the students enrolled in the guided-inquiry laboratory curriculum.

Statistical analysis revealed no significant difference between the laboratory report scores for Level-1 and Level-2 activities. However, laboratory report scores for Level-0 (Median = 9.50) activities were found to be significantly higher than the laboratory report scores for both Level-1 (median = 9.30) and Level-2 (median = 9.20) activities. Contrary to the hypothesis, the laboratory report scores were found to be lower for the guided-inquiry laboratory experiments.

Student Perseverance

Perhaps student perseverance produced the most compelling evidence as a result of the subgroup analysis of those students who submitted less than the 14 possible laboratory reports per semester. A statistical comparison of the subgroup of students revealed that the students in the inquiry-based laboratory curriculum submitted significantly more laboratory reports (Median = 12.00) than the students in the traditional laboratory curriculum (Median = 9.50). Withdrawal grades corroborate this finding as the withdrawal rate for the students in the inquiry-based laboratory curriculum (Median = 6.1%) was lower than that of the college-wide average for all courses (Mean = 14.1%) whereas the withdrawal rate for the students in the traditional laboratory curriculum (Median = 18.8%) was above that of the college-wide average for all courses (Mean = 14.1%). Thus, the traditional laboratory students showed a significantly higher withdrawal rate (Median = 18.8%) than the students in the inquiry-based laboratory (6.1%). However, when considering student withdrawal rates, the results must be interpreted with caution, particularly because there are many factors that influence this percentage (i.e. performance in the lecture component of the course, the economy, life experiences). With that said, these data suggest that the guided-inquiry laboratory curriculum had a positive effect on student perseverance in laboratory portion of the course, and perhaps the course as a whole.

Chapter Five: Conclusion

Summary of Study

The premise of this study was to use Fay et al.'s (2007) modified for college instruction rubric (Table 1.0/Table 3.0) to characterize the level of inquiry present in both the traditional and inquiry-based laboratory curricula, to examine the relationship between the level of inquiry present in a laboratory experience and student performance and perseverance outcomes, and to propagate a standard means of communication with respect to inquiry-based science instruction. As such, this investigation examined the research question, "How does the degree or level of inquiry-based science laboratory instruction impact student performance and student perseverance in the first-semester general chemistry course (CM103) at GRCC?" explored the hypothesis, "The implementation of a more inquiry-based instructional laboratory curriculum will positively impact student performance and student perseverance in the laboratory portion of the first-semester general chemistry course (CM103) designed to educate students majoring in science and engineering programs," and documented the changes observed when a laboratory program was transitioned from a structured traditional laboratory curriculum to a more inquiry-based laboratory curriculum. Hence, this study informs and provides quantitative data and evidence to chemistry instructors, science educators, schools and institutions as they contemplate inquiry-based science curriculum reform.

Conclusion

Researchers used the modified for college instruction rubric (Table 1.0/Table 3.0) to determine the level of inquiry present in each laboratory experiment and developed a graphic distribution of experiments (Figure 4.0) with respect to levels of inquiry across laboratory curricula. The distribution showed that the traditional laboratory curriculum was (64.3%) Level-

49

0 and (35.7%) Level-1, while the guided-inquiry laboratory curriculum was (7.1%) Level-0, (71.4%) Level-1, and (21.4%) Level-2, respectively. A statistical comparison of the inquiry levels for the two laboratory curricula indicated that the level of inquiry in the guide-inquiry curriculum (Median = Level-1) was significantly higher than that of the traditional curriculum (Median = Level-0). Thus, this research established that the new guided-inquiry laboratory curriculum was more inquiry-focused in nature than the old traditional verification curriculum.

Statistical analysis, via a Mann-Whitney (U) test, of the students' laboratory report average final grades (LRAFG) were determined to be the same for both curricula; however, the students' adjusted laboratory report average final grades (ALRAFG), which were derived solely from those laboratory reports that were completed and submitted to the instructor for grading, and excluded any/all laboratory report scores of zero, were found to be statistically significant as the guided-inquiry curriculum (Median = 90.07%) yielded a lower percentage over the traditional curriculum (Median = 94.74%), $U = 925.00$, $p < 0.005$, $r = -0.47$.

Analysis, via a Mann-Whitney (U) test, of the individual laboratory report scores as a function of inquiry-level discovered that laboratory report scores from experiments rated Level-0 (Median = 9.50) were statistically higher than the laboratory report scores from experiments rated as Level-1 (Median = 9.30), $U = 153487.00$, $p < 0.005$, $r = -0.25$; and as Level-2 (Median = 9.20), $U = 34933.50$, $p < 0.005$, $r = -0.25$, respectively. These findings imply that the integration of even a moderate level of inquiry into a laboratory activity increases the responsibility of the students to learn and the amount of effort required of the students to construct knowledge, (as defined in Table 1.0 inquiry level descriptions), and as such, decreases students' individual laboratory report scores by as much as 2-3%, thus resulting in lower adjusted laboratory report average final grades (ALRAFG).

Analysis, via Mann-Whitney (U) tests, of laboratory report completion rates were determined to be the same for both curricula. A statistical comparison of the subgroup, containing only student who submitted less than the 14 possible laboratory reports for instructor grading, revealed that the students in the inquiry-based laboratory curriculum submitted significantly more laboratory reports (Median = 12.00) than the students in the traditional laboratory curriculum (Median = 9.50), U =226.00, p < 0.005, r = -0.40. Withdrawal grades corroborate this finding as the withdrawal rate for the students in the inquiry-based laboratory curriculum (Median = 6.1%) was lower than that of the college-wide average for all courses (Mean = 14.1%) whereas the withdrawal rate for the students in the traditional laboratory curriculum (Median = 18.8%) was above that of the college-wide average for all courses (Mean = 14.1%). Thus, the traditional laboratory students showed a significantly higher withdrawal rate (Median = 18.8%) than the students in the inquiry-based laboratory (6.1%).

Therefore, the use of inquiry-based laboratory experiments places more demand and responsibility on the students. However, this demand is not so much as to discourage students, on the contrary, it appears the increased responsibility and demand required of the students to perform inquiry-based laboratory activities actually improved student perseverance in the laboratory portion of the course, and perhaps the course overall.

Discussion

These research findings with respect to student perseverance are similar to two studies discussed in the literature review (1) reported increased attendance retention (Cooper, 1994) and (2) reported a decrease in withdrawal rates (Farrell et al., 1999). However, those studies also found increased learning in inquiry-based lecture and laboratory courses via (1) increase in lecture exams (Cooper, 1994) and (2) increase in overall course grade. While this study cannot

make any claims about the role of inquiry-based science instruction in the laboratory with respect to improved student learning, due to institutional grading limitations, these results indicate that students are more invested in the laboratory experience and will likely complete a course with an inquiry-based laboratory curriculum. Perhaps the use of inquiry-based laboratory instruction has the effect of making the laboratory experience more valuable for students, and this increased their perseverance in the course. This appears to be the case even though the inquiry laboratories in this study were more demanding as measured by the students' laboratory report scores.

Recommendations

Although student retention is certainly important, these findings also generate additional questions that require future investigation. First, how does this inquiry-based curriculum impact student learning in chemistry? Perhaps data with respect to student learning could be collected and analyzed via an assessment instrument such as the new American Chemical Society Exams Institute laboratory exam. Second, a supplemental student survey could gather information regarding why students elect to withdrawal from or complete a course to further investigate and potentially answer the question: Why were the withdrawal rates lower for the students enrolled in the inquiry-based curriculum?

Dissemination

Portions of this work and results of this study have been shared with GRCC in the form of an annual department report and the National Science Teachers Association by way of manuscript publication in the *Journal of College Science Teaching* (Scott & Pentecost, 2013). In addition, the National Science Teachers Association granted permissions to (1) include in thesis the complete published research article (Appendix A), and (2) use, reproduce and include in this thesis any portion of the published research article (Appendix B).

References

Abraham, M. R. (1982). A descriptive instrument for use in investigating science laboratories. *Journal of Research in Science Teaching 19*(2), 155-165.

Abraham, M. R., Cracolice, M. S., Graves, A. P., Aldhamash, A. H., Kihega, J. G., Gil, J. G. P., & Varghese, V. (1997). The nature and state of general chemistry laboratory courses offered by colleges and universities in the United States. *Journal of Chemical Education 74*(5), 591-594.

Adamson, S. L., Banks, D., Burtch, M., Cox III, F., Judson, E., Turley, J., Benford, B.R., & Lawson, A. E. (2003). Reformed undergraduate instruction and its subsequent impact on secondary school teaching practice and student achievement. *Journal of Research in Science Teaching 40*(10), 939–957.

American Association for the Advancement of Science. (2009). *Benchmarks for Science Literacy (Project 2061)*. Retrieved from

http://www.project2061.org/publications/bsl/online/index.php?chapter=1

Blanchard, M. R., Southerland, S. A., Osborne, J. W., Sampson, V. D., Annetta L. A., & Granger, E. M. (2010). Is inquiry possible in light of accountability?: A quantitative comparison of the effectiveness of guided inquiry and verification laboratory instruction. *Science Education 94*(4), 577–616.

Bodner, G. M., Hunter, W. J. F., & Lamba, R. S. (1998). What happens when discovery laboratories are integrated into the curriculum at a large research university? *The Chemical Educator 3*(3), 1-21.

Bransford, J. D., Brown, A. L., & Cocking, R. R. (Eds.) (2000). *How people learn: Brain, mind experience, and school* (Expanded ed.). Washington, D.C.: National Academy Press.

Brown, P. L., Abell, S. K., Demir, A., & Schmidt, F. J. (2006). College science teachers' views

of classroom inquiry. *Science Education 90*(5), 784-802.

Bruck, L. B., Bretz, S. L., & Towns, M. H. (2008). Characterizing the level of inquiry in the

undergraduate laboratory. *Journal of College Science Teaching, 38*(1), 52-58.

Brunner, C. (2012). *How to: Inquiry*. Retrieved from

http://www.youthlearn.org/learning/planning/lesson-planning/how-inquiry/how-inquiry

Carin, A. A., Bass, J. E., & Contant, T. L. (2004). Children, science and inquiry. *Methods for

teaching science as inquiry* (9th ed., p. 21). Upper Saddle River, NJ: Pearson Prentice

Hall.

Cooper, M. M. (1994). Cooperative chemistry laboratories. *Journal of Chemical Education

71*(4), 307.

Creswell, J. W. (2009). *Research design: Qualitative, quantitative, and mixed methods

approaches* (3rd ed.). Thousand Oaks, CA: SAGE Publications, Inc.

Domin, D. S. (1999). A review of laboratory instruction styles. *Journal of Chemical Education,

76*(4), 543-547.

Fay, M. E., Grove, N. P., Towns, M. H., & Bretz, S. L. (2007). A rubric to characterize inquiry

in the undergraduate chemistry laboratory. *Chemistry Education Research and Practice,

8*(2), 212-219.

Field, A. (2005). Discovering statistics using SPSS. Thousand Oaks, CA: Sage Publications Inc.

Farrell, J. J., Moog, R. S., & Spencer, J. N. (1999). A guided inquiry general chemistry course.

Journal of Chemical Education 76(4), 570-574.

Fraser, B., McRobbie, C. J., & Giddings, G. J. (1993). Development and cross-national validation of a laboratory classroom instrument for senior high school students. *Science Education 77*(1), 1-24.

Gabel, D. (2000). Theory-based teaching strategies for conceptual understanding of chemistry. *Educaión Química 11*(2) 236-243.

Herron, M. D. (1971). The nature of scientific enquiry. *The School Review 79*(2), 171-212.

Hofstein, A., Ben-Zvi, R., & Samual, D. (1976). The measurement of the interest in and attitudes to, laboratory work amongst Israeli high school chemistry students. *International Science Education, 60*(3), 401-411.

Hofstein, A., & Lunetta, V. (2004). The laboratory in science education: Foundations for the twenty-first century. *Science Education 88*(1), 28-54.

Hofstein, A., Nahum, T. L., & Shore, R. (2001). Assessment of the learning environment of inquiry-type laboratories in high school chemistry. *Learning Environments Research 4*(2), 193-207.

Hofstein, A., Shore, R., & Kipnis, M. (2004). Providing high school chemistry students with opportunities to develop learning skills in an inquiry-type laboratory: A case study. *International Journal of Science Education 26*(1), 47-62.

Greenbowe, T., & Hand, B. (2005). Introduction to the science writing heuristic. In N. J. Pienta, M. M. Cooper & T. Greenbowe (Eds.), *Chemists' Guide to Effective Teaching* (pp. 140-154). Upper Saddle River, NJ: Pearson.

Kerner, N., & Lamba, R. (2008). Guided inquiry experiments for general chemistry: Practical problems and applications. Hoboken, NJ: John Wiley & Sons, Inc.

Kipnis, M., & Hofstein, A. (2007). Inquiring the inquiry lab in high school. In R. Pinto & D.

    Couso (Eds.), *Contributions from science education research* (pp. 297-306). Dordrecht,

    Netherlands: Springer.

Lederman, N. G. (2004, July). Laboratory experiences and their role in science education. In S.

    R. Singer, *America's lab report: Investigations in high school science.* Presentation

    conducted at the third fact-finding meeting of the National Research Council,

    Washington, DC.

National Research Council. (1996). *The National Science Education Standards.* Washington,

    DC: National Academy Press.

National Research Council. (2000). *Inquiry and the National Science Education Standards:*

    A guide for teaching and learning. Washington, DC: National Academy Press.

National Science Board. (1986). *Undergraduate Science, Mathematics and Engineering*

    Education (NSB Report No. 86-100). Washington, DC: U.S. Government Printing

    Office.

National Science Teachers Association. (2004). *Scientific Inquiry.* Retrieved from

    http://www.nsta.org/about/positions/inquiry.aspx

Pavelich, M. J., & Abraham, M. R. (1977). Guided inquiry laboratories for general chemistry.

    Journal of College Science Teaching 7(1), 23-26.

Pavelich, M. J., & Abraham, M. R. (1979). An inquiry format laboratory program for general

    chemistry. *Journal of Chemical Education, 56*(2), 100-103.

Poock, J. R., Burke, K. A., Greenbowe, T. J., & Hand, B. M. (2007). Using the science writing

    heuristic in the general chemistry laboratory to improve students' academic performance.

    Journal of Chemical Education 84(8), 1371-1379.

Richardson, V., & Renner, J. (1970). A study of the inquiry-discovery method of laboratory instruction. *Journal of Chemical Education 47*(1), 77-79.

Schwab, J. J. (1960). Inquiry, the science teacher, and the educator. *The School Review 68*(2), 176-195.

Scott, P., & Pentecost, T. C. (2013). From verification to guided inquiry: What happens when a chemistry laboratory changes? *Journal of College Science Teaching 42*(3), 82-88.

Wood, D. (1998). *How children think and learn* (2nd ed.). Malden, MA: Blackwell Publishers Inc.

Appendix A-Published Research Article

From Verification to Guided Inquiry: What Happens When a Chemistry Laboratory Curriculum Changes?

By Pamela Scott and Thomas C. Pentecost

How does the degree of inquiry-based laboratory instruction impact student performance and student perseverance in the laboratory portion of a first-semester general chemistry course? The implementation of a new first-semester general chemistry laboratory curriculum provided an opportunity to address this question. A modified version of Lederman's continuum of scientific inquiry rubric (Fay, Grove, Towns, & Bretz, 2007) was used to establish the degree of inquiry incorporated into each laboratory experiment in the old and new curricula. Laboratory report average final grades and individual laboratory report scores were used to measure student performance. A comparison of laboratory report completion between the two curricula was done to measure student perseverance. A final comparison sought to determine if any relationships exist between degree(s) of inquiry and student performance and perseverance.

Increasing the amount of inquiry-based instructional activities in both lecture and laboratory has been at the heart of most calls for curriculum reform at all levels (Bransford, Brown, & Cocking, 2000; Lederman, 2004). Analysis of the literature indicates that the effectiveness of inquiry-based laboratory instruction has been measured by changes in student attitudes in addition to quantitative comparisons of student learning. Further complicating the issue is the lack of a standard definition for an "inquiry" focused laboratory experience.

Pavelich and Abraham (1979) examined a guided/open-ended inquiry laboratory format in the general chemistry laboratory that relied on observational assessment of student learning improvement and attempted to measure growth in student mental maturity via a Piagetin-type test. The students in the guided/open-ended format had larger gains in intellectual development, and their description of the laboratory environment was in alignment with an inquiry environment. A direct comparison of inquiry and traditional laboratory environments (Hofstein, Nahum, & Shore, 2001; Kipnis & Hofstein, 2007) indicates that the inquiry format fosters the development of more positive student attitudes and perceptions of their learning. Students in the inquiry-based curriculum asked more questions, and these questions were more open-ended than those of the control group, suggesting that the teaching technique had a positive effect on encouraging inquiry. There is also evidence that the use of inquiry-based laboratory activities, both alone and with inquiry-based lecture instruction, increases student performance on lecture exams (Cooper, 1994; Cooper & Kerns, 2006; Greenbowe & Hand, 2005; Schroeder & Greenbowe, 2008). In a large-scale experiment Cooper (1994) found evidence that the use of cooperative learning with inquiry laboratories in general chemistry can impact student performance in lecture. In organic chemistry the effectiveness of inquiry is very dependent on the nature of the student groups and the interaction of the students and the instructor (Cooper & Kerns, 2006). These studies identified improvement in student learning that was due to inquiry in the lecture and laboratory; these studies did not evaluate the level of inquiry present in the laboratory experience.

It is often difficult to compare studies that investigate the effectiveness of inquiry-based teaching because the degree or level of inquiry used is often not characterized. The Continuum of Scientific Inquiry rubric (Lederman, 2004) was developed to characterize the level of inquiry for high school instruction and has been adopted for use in college settings by Fay, Grove,

Towns, and Bretz (2007). Rather than seeking to answer the question of whether inquiry-based instruction had value in laboratory application, the study focused on demonstrating that the level of inquiry present in a curriculum could be characterized. This work provided a rubric to aid instructors in selecting an inquiry-based curriculum before they mistakenly invest time implementing "new" programs that are in fact closer to a traditional verification curriculum.

The work reported in this article makes use of this rubric to characterize the level of inquiry of two laboratory curricula and to investigate the following question: How does the degree of inquiry-based laboratory instruction impact student performance and student perseverance in the laboratory portion of a first-semester general chemistry course?

Methodology

In 2008, a commercially published guided-inquiry laboratory curriculum (Kerner & Lamba, 2008) was instituted for the first-semester general chemistry course at a two-year community college. This change provided a case study of the new guided-inquiry laboratory curriculum versus the "old" traditional laboratory curriculum, which consisted of a collection of verification experiments written "in-house." Researchers used a modified version of Lederman's Continuum of Scientific Inquiry rubric (Fay et al., 2007) to assess both curricula and to establish the degree of inquiry incorporated into each laboratory experiment. Student performance was evaluated via laboratory report average final grades and individual laboratory report scores, whereas student perseverance was measured by comparing overall completion rates for

laboratory reports by curriculum to determine if any relationships exist between degree(s) of inquiry and student performance and perseverance in the laboratory portion of the course. It is worth noting again that, because of institutional limitations, we are unable to link the changes in the laboratory format to improvement in student learning in chemistry. Without external, course objective–related measures of learning, we cannot make any claims about the impact on student learning. By using student scores on the laboratory reports as a measure of student performance, we hope to compare this aspect of student performance in the two curricula.

The data set consisted of students' individual laboratory report scores and overall laboratory report final grades from intact laboratory sections, three semesters from the old traditional curriculum (fall 2006, winter 2007, and fall 2007) and three semesters from the new guided-inquiry curriculum (fall 2008, winter 2009, and fall 2009). In order to minimize instructor effect, data was collected from the same laboratory instructor for all six semesters. ACT test scores of the two groups of students were compared to establish population equivalency. There were a total of 183 students with allocated laboratory grades in the original data set. ACT scores were only available for 128 of these students. This smaller ($n = 128$) sample was used for statistical analysis. The control group consisted of 58 students who performed traditional verification laboratory experiments, whereas the experimental group consisted of 70 students who performed the guided-inquiry laboratory experiments.

The comparison of average ACT scores is shown in Table 1. The scores were normally distributed and have

equivalent variances, both of which are requirements for comparison of the groups using a t-test. On average, there was no difference in the ACT comprehensive score of the students in the traditional curriculum and the guided-inquiry curriculum, $t(126) = -0.12$, $p > .05$. The same was true for the students' ACT science scores, $t(126) = -2.12$, $p > .05$. Therefore, the two groups of students, those completing the old traditional verification laboratory activities and those completing the new guided-inquiry laboratory activities, were treated as equivalent samples drawn from the same population.

The level of inquiry present in the 14 laboratory experiments from each of the laboratory curricula (traditional and guided inquiry) was analyzed and characterized independently by two researchers using a modified version of the Continuum of Scientific Inquiry rubric (Fay et al., 2007), shown in Table 2. Laboratory experiments comprised of multiple parts were assigned a single inquiry level, which was determined by the highest level of inquiry present in any part.

All 28 laboratory experiments (14 from the old traditional verification and 14 from the new guided-inquiry curricula) were evaluated by both researchers independently using the rubric from Table 2, and then a consensus was developed. A Spearman rho (Field, 2005) correlation coefficient was used to assess the interrater reliability (IRR) of the level of inquiry classification for each laboratory curricula as shown in Table 3. The closer the overall value is to 1, the stronger the relationship between the ratings of the two researchers. The overall IRR for the collection of experiments was 0.853 and is significant at $p < .01$.

Table 4 shows the final level of inquiry appraised for each experiment

in both laboratory curricula. Note that for both curricula, the relevant chemistry concepts have been indicated in Table 4. When the level of inquiry for any given experiment resulted in disagreement, discussions between the two researchers negotiated a final level of inquiry. It's important to note that any initial differences regarding inquiry level were never more than one level different.

The distribution of the 14 laboratory experiments in each curriculum as rated across the levels of inquiry is shown in Figure 1. The majority of the experiments in the traditional laboratory curriculum were rated Level 0 (64.3%) with the remainder rated Level 1 (35.7%); conversely, the majority of the experiments in the guided-inquiry laboratory curriculum were rated Level 1 (71.4%) and Level 2 (21.4%), respectively.

A statistical comparison of the level of inquiry in the two curricula was done using a Mann–Whitney (U) test (Field, 2005), the nonparametric equivalent of a t-test. This more conservative comparison was warranted because the inquiry levels were not normally distributed within each curriculum. The level of inquiry in the guided-inquiry curriculum (Median = 1.00) was significantly higher than that of the traditional curriculum (Median = 0.00), U = 34.50, $p < .005$, $r = -0.62$. Likewise, comparison of the rubric used in this study and the definitions of inquiry levels by Pavelich and Abraham (1979) further support that the label of *guided inquiry* is appropriate for the new curriculum.

Before comparing student performance, it is important to note that the new inquiry laboratories were determined to be suitable replacements for the traditional experiments by the department. Therefore, these laboratories are not "watered-down" experiments and should have a similar level of expectations of the students.

Results and discussion
Effect of curriculum on student performance

Initially, the student performance evaluation compared the laboratory report average final grade (LRAFG) of both student groups for both laboratory curricula. The LRAFG was calculated using all 14 laboratory report scores per semester and included any/all zero scores assessed for

TABLE 1

Comparison of average ACT scores by student group.

Students (curriculum type)	Average ACT comprehensive score (SD)	Average ACT science score (SD)
Control, $N = 58$ (traditional laboratory)	21.2 (4.0)	22.2 (3.7)
Experimental, $N = 70$ (guided-inquiry laboratory)	21.3 (3.4)	22.3 (3.3)

TABLE 2

Rubric to identify level of inquiry.

Level of inquiry	Description
Level 0	The problem, procedure, and methods to solutions are provided to the student. The student performs the experiment and verifies the results with the manual.
Level 1	The problem and procedure are provided to the student. The student interprets the data in order to propose viable solutions.
Level 2	The problem is provided to the student. The student develops a procedure for investigating the problem, decides what data to gather, and interprets the data in order to propose viable solutions.
Level 3	A "raw" phenomenon is provided to the student. The student chooses the problem to explore, develops a procedure for investigating the problem, decides what data to gather, and interprets the data in order to propose viable solutions.

TABLE 3

Interrater reliability values for laboratory curricula.

Laboratory curriculum	Number of experiments with agreement	Total number of experiments	Interrater reliability (Spearman rho)
Traditional	12	14	0.730*
Guided inquiry	12	14	0.740*
Overall	24	28	0.853*

*Reliability significant, $p < .01$.

laboratory reports that were not submitted for a score. Further evaluation compared an adjusted laboratory report average final grade (ALRAFG) of both student groups for both laboratory curricula. The ALRAFG was derived solely from those laboratory reports that were completed and submitted for a score, thus it excluded any/all laboratory report scores of zero. Table 5 shows both comparisons by student group.

The LRAFG and ALRAFG for both student groups were statistically compared using the Mann–Whitney test because they were not normally distributed. Data analysis revealed that the LRAFG for students in the guided-inquiry curriculum (Median = 85.00) is not significantly lower than that that of students in the traditional curriculum (Median = 89.93). On the other hand, the ALRAFG for students in the guided-inquiry curriculum (Median = 90.07) is significantly lower than that of students in the traditional curriculum (Median = 94.74), $U = 925.00$, $p < .005$, $r = -0.47$. Given that both types of labs were taught and graded by the same person and covered similar topics, these data may indicate that expectations of students in the guided inquiry curriculum are higher and that the inquiry reports might be better probes of student understanding than traditional lab reports.

Effect of level of inquiry on student performance

The second student performance evaluation considered all students as one population and compared individual laboratory report scores by the level of inquiry. For ease of comparison, the scores for each laboratory report were converted to a 10-point scale. Ideally, had every student submitted each laboratory
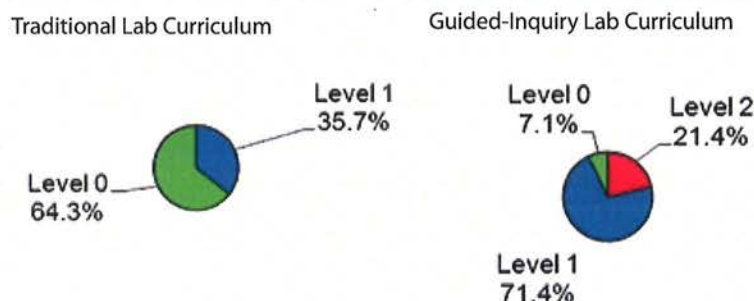
TABLE 4	

Laboratory curricula: Level of inquiry.

Experiment: Traditional laboratory curriculum	Inquiry level
1. Introduction to the Chemistry Lab	0
2. Determination of Density	*0*
3. Separation of a Mixture *(extraction using acid base properties)*	0
4. Electrons & Light *(atomic spectra and unknown identification)*	1
5. Chemicals & Reactions *(observe, describe, and identify chemical changes)*	1
6. Solution Chemistry *(determining the concentration of a solution)*	0
7. Molecular Modeling *(Lewis dot structures and geometries)*	0
8. Separation of Compounds *(intermolecular forces)*	1
9. A Cycle of Copper Reactions *(reaction types)*	0
10. Stoichiometry	0
11. Determining Concentration *(Beer's law)*	0
12. Enthalpy Changes & Hess's Law *(calorimetry—heat of solution)*	0
13. Signs of ΔH, ΔS & ΔG (qualitative thermodynamics)	*1*
14. Ten Unknowns *(experimental design and unknown identification)*	1

Experiment: Guided-inquiry laboratory curriculum	Level of inquiry
1. Introduction to the Chemistry Lab	0
2. How Long Can a Bubble Last? *(experimental design)*	2
3. Are All Pennies the Same? *(density)*	1
4. What Makes a Solution Colored or Colorless? *(absorbance, color, & periodic trends)*	1
5. What Factors Affect Color Intensity? *(solution prep & Beer's Law)*	1
6. Are There Property Patterns? *(reactivity and periodic properties)*	1
7. What Factors Affect the Solubility of Ions? *(double replacement reactions)*	2
8. Can Toxic Ions Be Removed From Water by Precipitation? *(separation of compounds by solubility)*	2
9. Do Like Repel or Attract? (intermolecular forces and solubility)	*1*
10. How Much Hydrogen? *(stoichiometry & reactivity of metals with acid)*	1
11. How Much Is Too Much? *(stoichiometry & limiting reagent)*	1
12. Which Salts Make Good Cold Packs & Hot Packs? *(calorimetry—heat of solution)*	1
13. How Is Heat Measured Indirectly? *(calorimetry—Hess's law)*	1
14. Thermodynamic Signs (qualitative thermodynamics)	*1*

Note: Bold italicized text denotes initial disagreement, and the value posted is the agreed-on level.

FIGURE 1

Distribution of experiments across levels of inquiry.

Traditional Lab Curriculum

Level 1
35.7%

Level 0
64.3%

Guided-Inquiry Lab Curriculum

Level 0
7.1%

Level 2
21.4%

Level 1
71.4%

report for a score, there would have been 1,792 individual laboratory report scores. However, scores were only available for 1,564 laboratory reports; consequently the comparison was made using these and is shown in Table 6. These data were not normally distributed so the comparison was done using the Kruskal–Wallis (H) test, nonparametric equivalent of an analysis of variance (Field, 2005), resulting in a significant effect with respect to level of inquiry on the individual laboratory report scores, H(2) = 92.34, $p < .005$. Mann–Whitney tests with a Bonferroni correction were used to determine which level of inquiry was different from the others. Statistical analysis determined that the laboratory report scores for activities rated as Level 1 (Median = 9.30) or Level 2 (Median = 9.20) were not significantly different. Alternatively, laboratory report scores for activities rated as Level 0 (Median = 9.50) were statistically higher than those scores for activities rated as Level 1 (Median = 9.30), U = 153,487.00, $p < .005$, $r = -0.25$, and Level 2 (Median = 9.20), U = 34,933.50, $p < .005$, $r = -0.25$, respectively.

The data suggests that the incorporation of inquiry, at any level, into

laboratory activities increases the level of difficulty of the activity, which in turn yields lower laboratory report scores and lower laboratory final grades. This is a reasonable finding because one goal of inquiry instruction is to enhance the development of critical-thinking skills, a process that requires effort.

Level of difficulty and student perseverance

To see if the increased efforts required of students to learn knowledge through guided-inquiry activities affected student perseverance, overall completion rates for laboratory reports by curriculum were compared. The traditional laboratory curriculum produced 672 completed laboratory reports out of a possible 812, resulting in a completion rate of 82.76%. Additionally, the guided-inquiry curriculum yielded 892 completed laboratory reports out of a possible 980, which resulted in a completion rate of 91.02%. Although these results appear different, a Mann–Whitney test indicates that the results are not statistically different. A subgroup statistical analysis of student perseverance for students who did not complete all 14 laboratory reports was used to cap-

ture the effect of curriculum on students who might be in danger of not completing the course. This analysis revealed that students in the guided-inquiry curriculum completed more laboratory reports (Median = 12.00), and their completion rate is significantly higher than that of students in the traditional curriculum (Median = 9.50), U = 226.00, $p < .005$, $r = -0.40$.

A similar trend was observed when withdrawal grades (W-grades) were analyzed. A Mann–Whitney test shows the student withdrawal percentage for the semesters that used the traditional laboratory curriculum (Median = 18.8) was significantly higher than the withdrawal percentage during the semesters during which the inquiry laboratory curriculum was used (Median = 6.1), U = 0.00, $p = .05$, $r = -0.80$. In an effort to support the decrease in withdrawal percentage findings, additional data was collected and analyzed for all collegewide credit courses during the same semesters. The additional data produced a consistent collegewide withdrawal percentage ($M = 14.1$, $SD = 1.3$) over the six-semester period.

When considering student withdrawals, the results must be interpreted with caution, particularly because there are many factors that influence this percentage (i.e., performance in the lecture component of the course, economy, etc.). With that said, these data suggest that the guided-inquiry laboratory curriculum had a positive effect on student perseverance in the laboratory portion of the course and perhaps the course as a whole.

Summary

This study shows that the new guided-inquiry laboratory curriculum was more inquiry focused in nature than the old traditional verification curriculum. The students' LRAFGs were statistically the same for both curri-

cula. However, the students' adjusted ALRAFGs were statistically significant, as the guided-inquiry curriculum yielded a lower percentage over the traditional curriculum. When the individual laboratory report scores were analyzed as a function of inquiry level, scores on the laboratory reports from Level 0 experiments were statistically higher than scores from reports that incorporated Levels 1 or 2. These findings imply that the integration of even a moderate amount of inquiry into a laboratory activity increases the level of difficulty and degree of effort required of the student to achieve the same level of performance as in the traditional experiments. Although the use of guided-inquiry laboratory experiments places more demand on students, the demand is not so much as to discourage students. On the contrary, it appears the increased demand of inquiry activities actually improved perseverance in the laboratory portion of the course and perhaps the course overall.

Our findings are similar to those that found increased learning in inquiry-based lectures and laboratory courses (Cooper, 1994; Schroeder & Greenbowe, 2008). Although our study cannot make any claims about the role of inquiry laboratories on improved learning, our results indicate that students are more likely to complete a course with inquiry-based laboratories. Perhaps the use of inquiry has the effect of making the experience more valuable for students, and this increases their perseverance in the course. This appears to be true even though the inquiry laboratories in our study were "more demanding" as measured by the students' scores. This finding is in line with Cooper and Kerns (2006), who found that students seemed to be more engaged in the inquiry laboratory experiments.

Although student retention is certainly important, these findings also generate additional questions that we would like to try and investigate in the future. First, how does this inquiry-based curriculum impact student learning in chemistry? We envision being able to collect student learning data with an assessment such as the new American Chemical Society Exams Institute laboratory exam. Second, we would like to investigate why students choose to drop out of or stay in a course to further answer the question: Why were the withdrawal rates lower with the inquiry-based curriculum? ∎

Acknowledgments

References

Bransford, J. D., Brown, A. L., & Cocking, R. R. (Eds.). (2000). *How people learn: Brain, mind, experience, and school.* Washington DC: National Academies Press.

Cooper, M. M. (1994). Cooperative chemistry laboratories. *Journal of Chemical Education, 71,* 307.

Cooper, M. M., & Kerns, T. (2006). Changing the laboratory: Effects of a laboratory course on students' attitudes and perceptions. *Journal of Chemical Education, 83,* 1356–1361.

Fay, M. E., Grove, N. P., Towns, M. H.,

TABLE 5

Comparisons of LRAFG and ALRAFG by student group.

Student group (lab curriculum)	Average/median % LRAFG (*SD*)	Average/median % ALRAFG (*SD*)
Control, *N* = 58 (traditional)	89.93/77.59 (27.25)	94.74/93.89 (3.83)
Experimental, *N* = 70 (guided inquiry)	85.00/81.00 (15.29)	90.07/88.75 (7.01)

Note: LRAFG = laboratory report average final grade; ALRAFG = adjusted laboratory report average final grade.

TABLE 6

Comparison of individual laboratory report score by level of inquiry.

Level of inquiry	Number of laboratory reports	Median/average laboratory report score out of 10 possible points (*SD*)
0	509	9.50/9.39 (0.84)
1	855	9.30/8.99 (1.04)
2	200	9.20/8.86 (1.27)

& Bretz, S. L. (2007). A rubric to characterize inquiry in the undergraduate chemistry laboratory. *Chemistry Education Reseach and Practice, 8,* 212–219.

Field, A. (2005). *Discovering statistics using SPSS*. Thousand Oaks, CA: Sage.

Greenbowe, T., & Hand, B. (2005). Introduction to the science writing heuristic. In N. J. Pienta, M. M. Cooper & T. Greenbowe (Eds.), *Chemists' guide to effective teaching* (pp. 140–154). Upper Saddle River, NJ: Pearson.

Hofstein, A., Nahum, T. L., & Shore, R. (2001). Assessment of the learning environment of inquiry-type laboratories in high school chemistry *Learning Environments Research, 4,*

193–207.

Kerner, N., & Lamba, R. (2008). *Guided inquiry experiments for general chemistry: Practical problems and applications*. Hoboken, NJ: Wiley.

Kipnis, M., & Hofstein, A. (2007). Inquiring the inquiry lab in high school. In R. Pinto & D. Couso (Eds.), *Contributions from science education research* (pp. 297–306). New York, NY: Springer.

Lederman, N. G. (2004, July). *Laboratory experiences and their role in science education*. Paper presented to the Committee on High School Science Laboratories: Role and Vision, Washington, DC.

Pavelich, M. J., & Abraham, M. R. (1979). An inquiry format laboratory program for general chemistry.

Journal of Chemical Education, 56, 100–103.

Schroeder, J. D., & Greenbowe, T. J. (2008). Implementing POGIL in the lecture and the science writing heuristic in the laboratory—student perceptions and performance in undergraduate organic chemistry. *Chemistry Education Reseach and Practice, 9,* 149–156.

Pamela Scott is a laboratory coordinator in the Physical Science Department at Grand Rapids Community College in Grand Rapids, Michigan. **Thomas C. Pentecost** (pentecot@gvsu.edu) *is an assistant professor in the Department of Chemistry at Grand Valley State University in Allendale, Michigan.*

Appendix B-Copyright Permission Forms

From: Emily Brady <ebrady@nsta.org>
To: Pam Scott <pscott@grcc.edu>
Date: 5/21/2013 12:57 PM
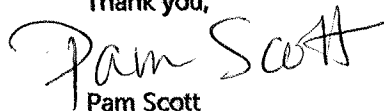**Subject:** RE: Permission Request

Hi Pam, you have our permission. Best of luck!

From: Pam Scott [mailto:pscott@grcc.edu]
Sent: Friday, May 17, 2013 12:54 PM
To: permissions
Subject: Permission Request

Dear National Science Teachers Association,

I'm contacting you to request permission to use a published article as my thesis project for a Master's of Education degree. My name is Pamela Scott and my manuscript *From Verification to Guided Inquiry: What Happens When a Chemistry Laboratory Curriculum Changes?* was published in the **Journal of College Science Teaching**, January/February 2013, Vol. 42, No.3.

Thank you,

Pam Scott
Pam Scott
Physical Science Laboratory Coordinator
Grand Rapids Community College
143 Bostwick NE
Grand Rapids, MI 49503
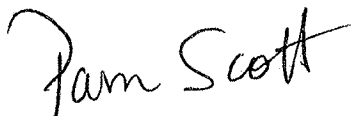(616) 234-4297 office
(616) 234-3590 fax

May 8, 2014

Emily Brady: ebrady@nsta.org

Dear Ms. Brady,

I am currently enrolled in the Grand Valley State University (GVSU) Graduate Studies in Education Program, and I am writing a thesis for the completion of my Master's in Education. My *thesis* is entitled "From Verification to Guided Inquiry: What Happens When a Chemistry Laboratory Curriculum Changes?" May I receive permission to include in the appendices a copy of the published article?

Your signature at the bottom portion of this letter confirms your ownership of the above item. The inclusion of your copyrighted material will not restrict your re-publication of the material in any other form. Please advise if you wish a specific copyright notice to be included on each page. My *thesis* will be cataloged in the GVSU library and will be available to other students and colleges for circulation.

Sincerely,

Pam Scott

Pam Scott
Grand Rapids Community College
143 Bostwick NE
Grand Rapids, MI 49329
Phone: (616) 234-4297
Fax: (616) 234-3590
E-mail: pscott@grcc.edu

PERMISSION IS GRANTED to you (Pam Scott) to include the requested material(s) in her GVSU Master's of Education *thesis*.

Name of Company/Organization
Permission granted by: *Emily Brady, NSTA*
Title: *Manager, permissions*
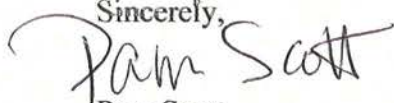Date: *5/9/14*

June 28, 2014

info@youthlearn.org

Dear youthlearn.org:

I am currently enrolled in the Grand Valley State University (GVSU) Graduate Studies in Education Program, and I am writing a thesis for the completion of my Master's in Education. My *thesis* is entitled "From Verification to Guided-Inquiry: What Happens When a Chemistry Laboratory Curriculum Changes?" May I receive permission to include in my thesis and appendices a copy of the following item?

- The Inquiry Process graphic depicted online at
  http://www.youthlearn.org/learning/planning/lesson-planning/how-inquiry/how-inquiry

Your signature at the bottom portion of this letter confirms your ownership of the above item. The inclusion of your copyrighted material will not restrict your re-publication of the material in any other form. Please advise if you wish a specific copyright notice to be included on each page. My *thesis* will be cataloged in the GVSU library and will be available to other students and colleges for circulation.

Sincerely,

Pam Scott

Pam Scott
Grand Rapids Community College
143 Bostwick NE
Grand Rapids, MI 49503
Phone: (616) 234-42978
Fax: (616) 234-3590
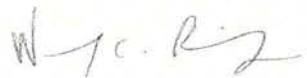E-mail: pscott@grcc.edu

PERMISSION IS GRANTED to you (Pam Scott) to include the requested material(s) in (his or her) GVSU Master's of Education *thesis.*

Name: W-*Jc. Rz*

Address: Education Development Center Inc., 43 Foundry Ave, Waltham, MA 02453

Date: July 3, 2014

NOTE: Please give credit for this image to "The YouthLearn Initiative at Education Development Center, Inc. © 2001"

EDC Learning transforms lives.

July 7, 2014

RE: "Inquiry Process Graphic" (Hereinafter, the "Work") and Pam Scott (the "Requestor").

Dear Pam Scott:

Education Development Center, Inc. ("EDC") is pleased to grant permission to the Requestor to use the Work in the thesis entitled "From Verification to Guided-Inquiry: What Happens When a Chemistry Laboratory Curriculum Changes?". The fee for this permission is waived for the limited, non-commercial purposes as described in this request. The requested materials may not be re-used without the written permission of EDC. EDC shall retain copyright to the requested work.

To accept this permission, please arrange for an authorized representative from the Requestor to accept and execute this permission in the space provided below and return a fully executed copy of this letter to me.

Please use the following attribute/credit line on all copies of the Work:

Copyright 2014 Education Development Center, Inc.
Reprinted with permission with all other rights reserved.
Retrieved from: http://www.youthlearn.org/learning/planning/lesson-planning/how-inquiry/how-inquiry

Sincerely,

Christine Filosa
Director and Senior Attorney, Office of Legal Affairs

Agreed and Approved
Pam Scott

Pamela S. Scott   _7/10/14_
Signature   Date

Pam Scott   _Graduate Student_
Name   Title

Appendix C-Institutional Review Board (GRCC) Forms

Grand Rapids Community College

143 Bostwick Avenue NE
Grand Rapids, Michigan 49503-3295
616·234·4040 FAX 616·234·3929

September 22, 2009

Ms. Pam Scott
Faculty – Physical Science
Grand Rapids Community College
143 Bostwick Ave NE
Grand Rapids, MI 49503

Dear Ms. Scott:

TITLE OF PROPOSAL: Target Inquiry: How Do Students Respond to Inquiry Instruction?

This letter is to officially notify you of the approval of your project by the Institutional Review Board (IRB) at Grand Rapids Community College. It is the Board's opinion that you have provided adequate safeguards for the rights and welfare of the participants in this study. Your proposal has been classified as "Exempt."

You are responsible for immediately informing the Institutional Review Board of any changes to your protocol, or of any previously unforeseen risks to the research participants.

This approval is good from September 1, 2009 to September 1, 2010. If you wish to continue your research after this date, you must complete and submit an updated protocol.

Please let me know if you have any questions.

Sincerely,

Donna Kragt

Donna Kragt
Dean of Institutional Research and Planning
Chair of the IRB

Grand Rapids Community College

INSTITUTIONAL REVIEW BOARD (I R B)
APPLICATION FOR APPROVAL TO USE HUMAN SUBJECTS IN RESEARCH

1.   Project Title: <u>Target Inquiry: How do Students Respond to Inquiry Instruction?</u>

PRINCIPAL INVESTIGATOR INFORMATION

2.   Principal Investigator: <u>Pam Scott</u>

   Department: <u>Physical Science</u>   Phone: <u>234-4297</u>   Fax: <u>234-3590</u>

   Email: <u>pscott@grcc.edu</u>
        (Required)

3.   Co-PI (if any): <u>Dr. Deborah Herrington</u> & <u>Dr. Ellen Yezierski</u>

   Department: <u>GVSU Chemistry</u>   Phone: <u>616-331-3317</u>   Fax: <u>616-331-3230</u>

   Email: <u>herringd@gvsu.edu</u> & <u>yezierse@gvsu.edu</u>
        (Required)

4.   Status (check one): ☐ Faculty ☐ Student
                     X Other (please explain): <u>Pam is faculty @ GRCC, Deborah & Ellen are faculty at GVSU</u>

For student and non-GRCC researchers *only*, please give your home address and phone number:

Dr. Herrington: <u>1867 Sun Park Drive, Zeeland MI 49464, (616)741-9124</u>
Dr. Yezierski: <u>14903 Hawthorne Street, Grand Haven MI 49417, (616)-850-8411</u>

PROTOCOL INFORMATION)*
5. Does your study involve individually identifiable protected health or mental health information (PHI), including demographic information and biological specimens identified to an individual, created or maintained by, or received from, a person or an entity covered by the Privacy Rule issued under the Health Insurance Portability and Accountability Act (HIPAA) (e.g., a hospital; a physician, or a practice in psychology, psychotherapy, or social work; a health insurer, HMO, or health plan; or a community clinic, or a social service or mental health agency)?
        ___Yes **X No**

6. If your answer to question (5) is Yes, please list below or on a separate sheet the PHI that is necessary for your research and that you intend to use in your research.
_____

7. If your answer to question (5) is Yes, please list below or on a separate sheet the name and address of each person or entity that is creating, maintaining or providing the PHI for your research.

_____
_____

8. Does your study involve the collection of data from a vulnerable population? ☐ Yes **X No**
   If yes, please specify type of population:

| ☐ Children/Minors |
| ☐ Prisoners |
| ☐ Fetuses |
| ☐ Pregnant Women |
| ☐ Cognitively Impaired Persons |
| ☐ Other _____ |

> For a complete list of categories of vulnerable populations, as well as the special safeguards required when conducting research with them, see pages 9-10 of the PI manual. Special Informed Consent procedures are necessary when conducting research with minors. See page 20 of the PI Manual for information.

9. Does this study involve deception (research in which the subject is purposely led to have false beliefs or assumptions)? ☐ Yes **X No**

10. If the study involves risk to subjects, is the risk greater than that incurred in ordinary life or tasks? ☐ Yes **X No**

11. Has this study ever been previously approved by this IRB? ☐ Yes **X No**

12. Is this proposal new or revised in response to previous IRB review? **X New** ☐ Revised

13. Is funding being sought for this study? If yes, through what sponsoring agency? ☐ Yes **X No**
    Agency: _____

   I certify that the research plan and safeguards to human subjects described in this application conform to that which has been submitted/will be submitted to an external funding source.

➡ Principal Investigator: _____.

   Date: _____

14. Is this study being reviewed by an IRB at another institution? If yes, please list the institutions below. **X Yes** ☐ No
    Grand Valley State University (GVSU)

> Documentation of IRB reviews of this study conducted at other institutions must be provided when it becomes available. **Research may not begin until IRB review has been concluded at all institutions involved.**

Please answer the following questions on a separate sheet.

15. State the purpose of the research. Include major hypotheses and research design. If the study is part of a larger study, briefly describe that larger study and indicate whether it has received IRB approval from another institution. **Please keep in mind that the IRB is composed of individuals from many disciplines and thus the description of your research should be written in terms readily comprehensible by non-experts.**

This study is part of the Target Inquiry (TI) program at GVSU designed to increase the frequency and quality of inquiry instruction in the classroom. As part of this program Pam Scott was involved in designing new inquiry activities and is now looking to use action research to study the impact of inquiry instruction on students. The action research project portion of the TI program has been approved by GVSU's IRB. The IRB application, renewal, and approval letters can be found in the appendix.

GRCC's Physical Sciences Department recently instituted a guided-inquiry lab curriculum for CM103 and CM104, the general chemistry course sequence. The change in laboratory curriculum provides an opportunity to study the impact of the "new" guided-inquiry lab curriculum compared to the "old" traditional lab curriculum on student success. Lederman's Continuum of Scientific Inquiry rubric will be used to assess both curricula to establish the degree of inquiry incorporated into each lab experiment. Student performance will then be evaluated using individual laboratory report grades as well as final course grades to determine if any correlations exist between degree of inquiry and student performance. Additionally, we will collect data concerning course retention/attendance (lab and lecture) in general chemistry to determine whether or not the laboratory curriculum impacts these factors. Laboratory and final course grades for CM103 will be collected from participating faculty members, and data collection will tentatively be completed by May 2010.

16. Describe the source(s) of subjects and the selection criteria. Selection of subjects must be equitable and, in the case of protected populations such as children, prisoners, pregnant women, the mentally disabled, etc. should address their special needs. Include the number of subjects. The text of any advertisement, letter, flier, oral script or brochure used to solicit potential subjects **must be attached**.

Physical Sciences faculty member, Mr. Bill Faber, has agreed to provide the student data (individual lab report grades and course attendance/retention) for this study.

- CM103 "old" traditional lab curriculum:

Fall 2006	1 section	24 students
Winter 2007	2 sections	48 students
Fall 2007	1 section	<u>24 students</u>
		96 students (max.)

- CM103 "new" guided-inquiry lab curriculum:

Fall 2008	1 section	24 students
Winter 2009	2 sections	48 students
Fall 2009	1 section	<u>24 students</u>
		96 students (max.)

17. Provide a description of the procedures to be followed. If available, include copies of questionnaires and/or interview protocol, or a sufficiently detailed description of the measures to allow the IRB to understand the nature of subjects' involvement.

As this project involves comparing student scores for the sections that did not use the inquiry lab curriculum and the section(s) that did use the inquiry curriculum in Mr. Faber's sections of CM103, the participants will not be directly involved with the researcher in any way. Student ACT scores, final course grades and identification of lecture instructor, will be obtained from GRCC's Institutional Research and Planning Department for all students enrolled in the "old" and "new" courses to help establish the equivalency of the student groups. Individual student laboratory report grades will be provided by Mr. Faber. As all findings will be reported using class aggregate data, student names will not be attached to the scores in any way. Additionally, in recording the data each student will be assigned a unique, unidentifiable number so that the data cannot be linked to the student.

18. Describe any potential harms or benefits to be derived by subjects, with a discussion of the risk/benefit ratio. For approval of any study with more than minimal risk, the benefits must clearly be shown to outweigh the risk. Describe how the study may expose participants to stress, physical, psychological or interpersonal hazard, including the possibility of pain, injury, disease, discomfort, embarrassment, worry or anxiety.

As these data are readily available, require no interaction with the participants, and cannot be linked to a particular participant with the use of a unique identifier number, there are no potential harms to the participants. Although there are no benefits to the current participants, analysis of the impacts of the new inquiry laboratory curriculum on student achievement in the CM103 course can help inform future curricular changes and therefore there is a potential benefit to future students.

19. Describe the specific methods by which confidentiality and anonymity will be protected, including the use of data coding systems, how and where data will be stored and who will have access to it, and what will happen to data after the study has been completed.

See attached Adult Consent Form.

20. If applicable, provide the following: 1) a description of the debriefing procedures to be used in cases where deception has occurred; 2) a statement describing what actions you will take should the research reveal the possibility of a medical or other potentially troubling condition.

Not Applicable.

21. Describe the oral and written consent processes and attach all consent documents. When the consent form to be used will be in a language other than English, an English translation must be provided. **Unless one or more of the required elements described below is explicitly waived by the IRB, informed consent documents should contain:**
   A. A fair explanation of the purposes of the research and the expected duration of the subject's participation, a description of the procedures to be followed, and identification of any procedures which are experimental;
   B. A description of any possible discomforts and risks reasonably expected. This includes any potential financial risks that could ensue;
   C. A description of any benefits reasonably expected;
   D. A disclosure of any appropriate alternative procedures;
   E. A statement that participation is voluntary, refusal to participate will involve no penalty or loss of benefits to which the subject is otherwise entitled, and the subject may discontinue participation at any time without penalty or loss of benefits to which the subject is otherwise entitled;
   F. An offer to answer any inquiries concerning the goals of the research or the research procedures and to provide a summary of results upon request and an explanation of whom to contact for answers to pertinent questions about the research and research subjects' rights, and whom to contact in the event of a research-related injury to the subject;
   G. An instruction that the subject is free to withdraw or discontinue participation at any time without prejudice.
   H. A statement describing the extent, if any, to which confidentiality of records identifying the subject will be maintained; and
   I. Provisions for parent or guardian approval for participation of minors or for subjects from vulnerable populations when appropriate.

Upon approval of the study, the consent document will be stamped with an expiration date. **Only this document may be used when enrolling subjects.** Studies extending beyond the expiration date must be submitted for a continuation review. **Any changes in the consent form must be approved by the IRB.**

This research is considered exempt under 45 CRF 46.101(b)(1) (research in an established educational setting comparing instructional techniques), The students are not asked to do anything outside of their normal classroom activities, and by using class aggregate data information cannot be linked to a particular student.

22. Please provide any other information that might be pertinent to the IRB's decision.

Appendix D-Human Research Review Committee (GVSU) Forms

HUMAN RESEARCH REVIEW COMMITTEE

'see attached' **is not acceptable as a fill-in on this form**

Principal Investigator(s): <u>Deborah Herrington and Ellen Yezierski</u>

Contact email address: <u>herringd@gvsu.edu and yezierse@gvsu.edu</u>

Address and Telephone

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

GVSU Department or School: <u>Chemistry Department</u>

Title of the Project: <u>Target Inquiry: How do Students Respond to Inquiry Instruction?</u>

Date(s) and Location(s) of Subject Enrollment: <u>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.</u>

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.)

<u>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."</u>

Check one:

___This is a request for exemption from HRRC approval requirements as specified by 46.101 of the <u>Federal Register</u> 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 <u>Federal Register</u> 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)

(Original must be signed in ink)

Signature of Unit 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).

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: Kellogsville 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,

79

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[1]. 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.
(1) Students will experience a more authentic science experience.
(2) Students may have their misconceptions challenged and as such develop the correct scientific explanations for phenomena.
(3) Students may gain a deeper understanding of key chemistry concepts.
(4) Students may gain a more accurate idea about the process of science.
(5) Students may improve their ability to think scientifically and critically.
(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 National Science Foundation.

---

[1] Sawada, D., Piburn, M., Judson, E., Turley, J., Falconer, K., Russell, B., & Bloom, I. (2002).Measuring reform practices in science and mathematics classrooms: The reformed teaching observation protocol. *School Science and Mathematics, 102*(6), 245-253.

Human Research Review Committee
Change in Protocol Form

Date: __05/18/09__

Principal Investigator(s):___Deborah Herrington and Ellen Yezierski_____

Contact email address: __herringd @gvsu.edu_____

Title of the Research Protocol: _ *Target Inquiry: How do Students Respond to Inquiry Instruction?*

Protocol File number : __07-243-H_____

Directions:

1. Explain only but exactly the change(s) that you want to make in the approved protocol.
    We are adding new teacher researchers to the project senior personnel. The new teachers researchers and their schools are as follows:
    Pam Scott   Grand Rapids Community College
    Dale Eizenga   Holland Christian
    Chad Bridle   Grandville High School
    Deanna Cullen Whitehall High School
    Angela Slater   Muskegon Heights High School
    Joseph O'Malley   City High School
    Michelle Mason   Portage Northern High School
    James Doug Mandrick   Portage Central High School

2. Justify the change(s) and explain why it could not reasonably have been anticipated and incorporated at the time the original application for protocol review was submitted.
    Target Inquiry is a cohort program that enrolls new cohort of teachers every two years. The first cohort of teachers completed the program and is no longer with the program. The teacher researchers listed above are the second cohort of TI teachers, and they began the program in January of 2008, after the initial approval for the project was obtained. The teachers in the second cohort will be conducting action research projects related to the inquiry labs they develop during summer 2009, like those that the first cohort of teachers conducted. Although the specific questions that these teachers choose to investigate may be slightly different, the types of data they collect and the data collection and storage methods will be the same.

3. Explain whether in your judgment the proposed change materially effects
    (a) the level of risk to the participants _____(YES) __X___(NO), or
    (b) the relationship of the benefits to the risks of participation in the study as a whole
    _____(YES __X__(NO).

4. In your judgment does the change(s) warrant either or both of the following?
    (a) re-consenting the previously enrolled participants? _____(YES) __X___(NO)

    (b) a new consent form? _____(YES) __X__(NO) If YES, attach a new consent form   and clearly indicate the changes therein.

5. You can add a new group of study participants to be recruited by following the change in protocol procedure. Each step needs to be addressed separately. Note that new invitation to participate letters, a description of the distribution method for that letter, method for selection of subjects (if more express an interest in participating than can be accommodated), and a new consent form need to be submitted for review.

Appendix D

Informed Consent Letters

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.

We are requesting your child's participation. The study will take place in your child's classroom and require 2 hours during the academic year during the regularly scheduled school day. 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.

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 a possible benefit to your child since it will provide added practice taking standardized chemistry exams. The study 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

This research protocol has been approved by the Human Research Review Committee at Grand Valley State University. File No. 25738 Expiration: 07/24/2010.

STUDENT ASSENT

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. The study involves taking two tests. 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

PARENT PERMISSION LETTER POST-MATERIALS STUDY

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, your child's teacher has developed new inquiry teaching materials that will be used in the classroom. These materials are aligned with the new Michigan High School Chemistry Content Expectations. To further improve his/her teaching, your child's teacher 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 your child's teacher 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
This research protocol has been approved by the Human Research Review Committee at Grand Valley State University. File No. 25738 Expiration: 07/24/2010.

STUDENT ASSENT

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

ADULT CONSENT LETTER

Dear

    We are associate 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. This study will take place in your classroom and at GVSU (Padnos Hall), and you will be videotaped while teaching in your classroom for a maximum of 4 times during each school year you participate in the study.

    We are requesting your participation, which will involve no more than 10 hours per year for two to five years beyond scheduled teaching time at your school and/or scheduled class time at GVSU. Your participation in this study is voluntary. You are free to decide not to participate in this study or to withdraw at any time without adversely affecting your relationship with the investigators or GVSU. Your decision will not result in any loss of benefits to which you are otherwise entitled. Specifically, your withdrawal from the study will not affect your grade or status in the chemistry concentration certificate program or M.Ed. program. In the case of early withdrawal stipends will be prorated. Additionally, you have the right to request that taping be stopped at any time.

    The results of the research study will be published at professional meetings and in research journals. To maintain confidentiality, you will be assigned a code and your name 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. After theses data are analyzed by the researchers, tapes will be erased and records/data will be destroyed.

    The study has many possible benefits to you since it involves your participation in a new professional development program. In the program, teachers can:

1) Expand their conceptual knowledge of chemistry by applying a research-oriented approach:
   a. Identify gaps in their knowledge and generate questions to address deficiencies.
   b. Access chemistry research literature and other appropriate resources.
   c. Collaborate with peers and scientists to refine and enhance understanding.
2) Develop a high school chemistry curriculum that is aligned with NSES and promotes the process of scientific inquiry.
3) Use action research to improve instruction and student learning by implementing and evaluating new teaching methods and curriculum.

You will also be exposed to research methods commonly used in quantitative and qualitative educational research. The study has possible benefits to those who design professional development programs for teachers, conduct research on 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 to participate in the study described above.

_____
Name

_____   _____
Signature   Date

This research protocol has been approved by the Human Research Review Committee at Grand Valley State University. File No. 25738 Expiration: 07/24/2010.

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.

      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. 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.

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

This research protocol has been approved by the Human Research Review Committee at Grand Valley State University. File No. 25738 Expiration: 07/24/2010.

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.

     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.ed

This research protocol has been approved by the Human Research Review Committee at Grand Valley State University. File No. 25738 Expiration: 07/24/2010.