Writing-to-Learn in High-School Chemistry: The Effects of Using the Science Writing Heuristic to Increase Scientific Literacy

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WRITING-TO-LEARN IN HIGH-SCHOOL CHEMISTRY: THE EFFECTS OF USING THE SCIENCE WRITING HEURISTIC TO INCREASE SCIENTIFIC LITERACY

A Dissertation Presented
to
The Faculty of the School of Education
Learning and Instruction Department

In Partial Fulfillment
of the Requirements for the Degree
Doctor of Education

by
Denae Nurnberg
San Francisco
May 2017
Writing-to-Learn in High-School Chemistry: The Effects of Using the Science Writing Heuristic to Increase Scientific Literacy

The purpose of this study was to investigate the effectiveness of using the Science Writing Heuristic (SWH) as an instructional tool to improve academic achievement and writing in the context of scientific literacy. This quasi-experimental study compared the effects of using the SWH in five laboratory settings over a 16-week span. The SWH was administered to a treatment group \((n=63)\), whereas the comparison group \((n=67)\) received laboratory sessions using a traditional laboratory report format.

There were four classes \((n=130)\) of general chemistry enrolled in the study with two teachers. Each teacher taught a treatment and comparison class during the study. A pretest was administered to investigate any between-group mean differences. There was no statistically significant difference in between-group mean differences. The dependent measures administered to investigate differences between the treatment and comparison group included five SWH laboratory scores, a posttest content assessment (CA), a posttest written assessment (WA), and a student perceptions questionnaire. Teacher interviews were conducted as anecdotal evidence of teachers’ opinions about the use of the SWH compared with a traditional laboratory format.

The means on the CA and the WA were higher in the treatment group than the comparison group. Two independent-samples \(t\) tests were conducted to compare the means of the CA and the WA by treatment and comparison groups. Ten paired-samples \(t\) tests were used to make planned pairwise comparisons between the laboratory scores. There were five statistically significant differences in laboratory scores; however, there was no clear linear trend of an increase in means over time. There were no statistically significant differences in the posttest CA
or posttest WA. There was a statistically significant difference in one of the student-perceptions-questionnaire components focused on writing as a tool for learning chemistry. The results favored the traditional laboratory format group. Post-hoc data analyses were conducted due to treatment fidelity concerns. A statistically significant difference in means was found between a treatment and comparison class through the post-hoc analyses. Additional research may be conducted on professional development to support teachers in implementing the SWH with fidelity.

*Keywords: Scientific Literacy, Science Writing Heuristic, Writing-to-Learn, Science Laboratories*
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This dissertation, written under the direction of the candidate’s dissertation committee and approved by the members of the committee, has been presented to and accepted by the Faculty of the School of Education in partial fulfillment of the requirements for the degree Doctor of Education. The content and research methodologies presented in this work represent the work of the candidate alone.

Denae Nurnberg 5/12/2017
Candidate

Dissertation Committee

Dr. Patricia Busk 5/12/2017
Chairperson

Dr. Robert Burns 5/12/2017

Dr. Nathan Alexander 5/12/2017
CHAPTER I
INTRODUCTION

There is a call to action among educators to adopt the shift in the pedagogy of curriculum design in order to address the evolving needs of the educational landscape in the United States. The new Common Core State Standards (CCSS) adopted by 42 of 50 states as of Fall 2016 emphasize the importance of literacy skills in order to help build foundational skills and conceptual understanding in all content areas. The Next Generation of Science Standards (NGSS) are a set of teaching standards to address science content and literacy development that are parallel to the CCSS. Past standards had a focus on knowledge students possess, whereas the NGSS focus on what students must do to demonstrate and apply their knowledge (Best & Dunlap, 2014). The NGSS were developed by a multistate consortia to support and promote the increase of scientific literacy among the nation’s students.

It is the responsibility of science educators to adopt these new NGSS standards and uphold their vision with rigor and relevance in their classrooms (Bybee, 2014). In the context of education, rigor refers to educators upholding high academic standards and expectations, whereas relevance emphasizes the importance of application in education so content is not being taught esoterically (Blackburn, 2012). The focus of the new NGSS is on the development of scientific literacy as a progression of skills over time rather than a discrete set of skills or knowledge to cover in the science classroom (NGSS, 2013). Scientific literacy includes the ability to use observable scientific phenomenon (e.g., data) and the marriage of these data points to predict and understand a scientific event (National Research Council, 2012). The skills required to develop scientific literacy
over time are embedded in a 12-year scope and sequence of “disciplinary core ideas, crosscutting concepts, and practices” (NGSS, 2013, p.41). Science educators, however, are not trained within teacher-education programs to teach literacy skills while developing content knowledge in their students resulting in the underuse of literacy strategies embedded into curriculum (Balgopal & Wallace, 2013). Thus, further research needed to be conducted in order to help inform evidence-based writing strategies to support the implementation of literacy skills within the scientific domain in an effort to help narrow the gap between research and practice (Carnegie, 2009). This study focused on assessing the value in a literacy-based high-school science laboratory writing format named the Science Writing Heuristic (SWH).

The SWH is a laboratory protocol that includes the following steps in its process: (a) student-generated laboratory question constructed in a group setting, (b) student development of identifying the procedures to test the question, (c) recording of data in experimental manipulation, (d) making a claim based on the data, (e) identifying evidence in the data to support the claim, and (f) reflections on how a student’s understanding of the world has been effected by this increased understanding of scientific concepts. The process of generating questions as part of a collaborative experience for students is rooted in the Vygotskyan (1978) framework for learning in context of social interaction. The SWH is a collaborative student process where the co-construction of knowledge is at the core of the work.

Statement of the Problem

Previous research has demonstrated that students are not meeting required standards for literacy and science skills (American College Testing (ACT), 2016;
Carnegie, 2009; National Assessment of Educational Progress (NAEP), 2011; National Science Foundation, 2012). The 2015 Programme for International Student Assessment (PISA) indicated that the United States ranks 24th out of 71 countries in science. These assessments of the nation’s underperforming students are based on the standardized expectations of college-readiness markers for literacy in mathematics, science, reading, and writing that are not being met compared with their international peers. Additionally, research has been conducted on students who have not met literacy standards across subject-matter content areas and subsequently are placed in developmental literacy courses early in college (Boatman & Long, 2010; Hughes & Scott-Clayton, 2011; Quint, Jaggars, Byndloss, & Magazinnik, 2013).

The process of writing and synthesizing information is an essential skill for the 21st-century workplace and educational settings (National Association of State Directors of Career Technical Education Consortium, 2006; National Council of Teachers of English (NCTE), 2009). Unfortunately, this necessary skill set is still needing development within the secondary level in order to prepare students for postsecondary success in college or the workplace. This process of scientific-literacy development begins with teachers. Aydeniz and Ozdilek (2015) found that preservice science teachers’ knowledge of science, scientific argumentation, and the difference between scientific explanation and scientific argumentation is underdeveloped and that these skills are all major tenets of scientific literacy. Research in science education helps teachers with curriculum development in order to reinforce and develop scientific-literacy practices. In a 2-year study focused on professional development for science educators, researchers found that with the integration of science inquiry into science content, the development of
scientific literacy is fostered (Lederman, Lederman, & Antink, 2013). The Lederman et al. (2013) research suggested the importance of providing teachers additional training and practical resources for use in their classrooms to improve scientific literacy. Thus, the goal of this research study was to provide additional research on a practical scientific-laboratory-inquiry application that develops scientific literacy.

The National Center for Educational Statistics (NCES) reported in 2011 that 74% of eighth graders, and 73% of 12th graders performed at or below basic levels on writing proficiency (NCES, 2011). Within the national benchmarks, students also failed to perform well in scientific standards with over one-third of eighth graders having earned below basic scores on the 2015 NAEP science assessment (NAEP, 2015). Additionally, 62% of high-school graduates failed to meet the 2015 readiness benchmark levels in science on the ACT assessment (ACT, 2015). Students in the United States are performing poorly in science readiness and literacy, and research around the use of science laboratories for teaching these skills was the purpose of this study in order to support the development of scientific literacy.

In 2010 the United States government signed into law the Every Student Succeeds Act (ESSA) in order to provide flexibility to the states to design accountability systems and support that align with their educational standards. The ESSA was signed into law to replace the No Child Left Behind Act (2001) that was prescriptive. The ESSA requires annual proficiency assessments administered alongside the reporting of success indicators for economically disadvantaged students, students from major racial and ethnic groups, children with disabilities, and English learners. ESSA requires the administration of science assessments over three age groups in kindergarten through 12th grade and
language arts and mathematics over seven age groups. These assessments provide the public with information regarding the progress state and local education agencies are making in providing high-quality, standards-based instruction. These accountability measures encourage alignment between classroom and assessments to ensure high standards for all students. While ESSA was taking shape in the United States, new standards (Common Core State Standards and Next Generation Science Standards) were being developed and administered in classrooms with a focus on writing as a tool for learning.

Common Core State Standards and the Next Generation Science Standards require students to write arguments focused on discipline-specific content. The shift in expectations of teachers has high-stakes consequences based on standardized-testing outcomes, but the process of developing the literacy content within the curriculum is not well-developed in terms of guidance and direction for classroom teachers. The NGSS are focused on student-performance expectations and are not curricula. Thus, it is essential for researchers to investigate the most effective strategies to support this pedagogical shift in curriculum design (NGSS Framework, 2012).

**Purpose of the Study**

The purpose of this study was to examine the effectiveness of a writing framework in high-school science in order to help inform the best practices for developing scientific literacy and learning science content through writing. This study included a format of writing within the scientific framework that required students to think differently about the observable phenomenon compared with the traditional laboratory. The protocol, named the Science Writing Heuristic (SWH), provided a
framework that promotes the use of observable data points as evidence to support the
students’ claim. As seen in Table 1, this skill of using data as evidence in order to reason
through a claim is one of the main conceptual shifts of the NGSS and CCSS. The
educational purpose underlying this skill is to develop scientific literacy within high-
school science students.

Table 1

Traditional Laboratory Report Format Versus SWH Format

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<td>1. Beginning questions- What are my questions about this experiment?</td>
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<td>2. Outline and procedure</td>
<td>2. Tests— What tests will I do or what procedure will I follow to help me answer my questions?</td>
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<td>3. Data and observations</td>
<td>3. Observations- What did I observe? What did I find?</td>
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<td>4. Discussion</td>
<td>4. Claims— What can I claim to answer my beginning question(s) or the class beginning question(s)?</td>
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<td>5. Balanced equations, calculations, and graphs</td>
<td>5. Evidence—How do I know? Why am I making these claims?</td>
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<td>6. Reflections—How do my ideas compare with other ideas? How have my ideas changed?</td>
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*Note: Adapted from Burke, Greenbowe, and Hand (2006)*

With scientific literacy being the focus of the work of science teachers nationwide, it is important to understand the significance of this term and its definition. As part of the National Society for the Study of Education’s Yearbook (1932), scientific literacy was defined as the understanding the influence that the natural world has on individual lives and the utility of knowing science in their personal worlds. By 1946, the National Society for the Study of Education evolved into the reliance of including an element of critical thinking on behalf of the science consumer when making decisions in
society. Later in the 20th century, scientific literacy primarily was defined as having a relevance in everyday life to make decisions informed by scientific understanding (DeBoer, 2000). The commonly accepted definition, as used in NGSS, is that of the National Research Council (2012) to include the understanding of scientific concepts and processes required to convert observable phenomenon into describable, explainable, and predictable scientific events. This process includes the ability to pose and evaluate arguments based on evidence and to apply conclusions from such arguments appropriately.

The need for increased research in scientific curricula areas is rooted in the goal of science education to develop a scientifically literate society. Scientific literacy is the essential outcome and mastery objective of all science teachers and courses; it is the goal of the NGSS to develop scientifically literate persons who can make sense of and apply scientific knowledge to unique settings (NGSS Framework, 2012). Scientific literacy is an essential skill for students to acquire in order to communicate the methods of the natural world and make an informed and cohesive argument about personal and societal problems (Balgopal & Wallace, 2013). Scientific literacy includes the traditional science processes of observing, inferring, classifying, predicting, measuring, questioning, interpreting, and analyzing data and also includes the confluence of these processes with scientific knowledge, scientific reasoning, and critical thinking (Lederman et al., 2013). The incorporation of literacy strategies helps build connections between lecture and laboratory practices, which have been shown to have positive academic results (Harmon & Pegg, 2012). The process of mastering scientific literacy and developing this skill set is the work of classroom teachers during the elementary-, middle-, and secondary-school
years. The process of scientific-literacy development occurs through classroom lessons, experiments, and opportunities for students to produce scientific language in order to explain scientific phenomenon. Research shows, however, that there are varied literacy standards in classrooms, which creates a call for a more systematic approach to implementation of scientific literacy (Adams & Pegg, 2012).

This study included high-school general-chemistry classes using the SWH protocol during the Fall and Spring semester of study. The study included a 10-item pretest administered at the beginning of the unit to assess prior knowledge of chemistry and any between-group mean differences, half of the students received instruction using the traditional science laboratory protocol (comparison group), whereas the other half of the students received instruction using the SWH laboratory protocol (treatment group), a posttest content assessment (CA) directly pertaining to the laboratories, a posttest writing assessment (WA), and a questionnaire regarding student opinions about the SWH and traditional laboratories referred to as the student-perceptions questionnaire.

The purpose of this research was to examine the effectiveness of the SWH as a writing-to-learn activity in 10th-grade chemistry classes. There have been a number of research studies conducted in high-school and college science around the effectiveness of writing-to-learn activities. Most of the research conducted to date has not assessed the effectiveness of the SWH in the 15- to 16-year-old age range, which is the age of a typical 10th-grade high-school student. The cognitive demands of writing, making claims, and processing the scientific evidence are a gap in the literature at this age level in a chemistry course. Additionally, several studies have been conducted to investigate the effectiveness of the Science Writing Heuristic (SWH) after one use of the laboratory
protocol (Greenbowe, Rudd & Hand, 2007; Keys, Hand, Prain, & Collins, 1999; Nam, Choi, & Hand, 2011). This research design was unique in its methodology of assessing the development of scientific-literacy skills with implementation of the SWH over an extended period of time. This research was designed with an extended time and frequency component of implementing the laboratory protocols in order to fill a gap in the literature of the effectiveness of the SWH.

The independent variable in this research design was the laboratory format with one-half of the classes of students receiving the SWH laboratory protocol and the other half of the classes of students receiving the traditional laboratory format. The dependent variables in this research were the students’ scores on the posttest content assessment (CA), the scores on the posttest writing assessment (WA), and the scores on the laboratory write-ups. The Likert-type scale scores were analyzed from the student-perception questionnaires.

This research was focused on developing the literature around best practices for improving scientific literacy and science-content knowledge in high-school students. Scientific literacy was assessed through the writing assessments where students were asked to develop and support a claim about an observable scientific phenomena. The student-perception questionnaire assessed the ease of use of the SWH versus the traditional laboratory report in order to help practitioners understand student needs and interests with a redesigned laboratory format.

**Educational Significance of the Study**

This study was important in the field of education for several reasons. The first reason was to provide research-based instructional strategies for teachers to employ in
their classrooms using writing as a mode of learning. Writing is a fundamental component of the CCSS and NGSS in reasoning through concepts. By providing a research-based teaching framework, teachers have a practical strategy for processing laboratory experiments that require writing as a method for reasoning through concepts. The SWH is an activity that is rooted in the shift toward CCSS and NGSS due to the incorporation of evidence-based claims, and, therefore, timely in terms of supporting instructional design for science educators.

The second reason this study was relevant is to narrow the gap in research-based literature around the Science Writing Heuristic (SWH) writing-to-learn model. There are several studies that focus on university-level chemistry and a limited number of studies in the foundational high-school science courses. Very few research studies of the SWH follow the conventions of an experimental design in a high-school chemistry class using SWH as the writing-to-learn framework. This writing modality has limited research with younger students ranging in age from 15 to 16 years. The cognitive skill set required to synthesize ideas into a complex-writing framework needs be researched with this age range in order to establish its effectiveness as a learning tool.

Finally, this study is important due to its approach in researching a practical instructional strategy and its effectiveness over time with the design including the incorporation of five chemistry laboratory experiments over the course of a semester. This work assessed the cumulative effects of students practicing a writing skill over time and its academic effects. Most of the relevant research includes the assessment of the SWH’s effectiveness after a one-time implementation. This research investigated the effects of the SWH over a longer time period with more frequent use of the SWH. In
previous studies (Hand & Prain, 2002; Keys et al., 1999; Nam et al., 2011; Rudd, Greenbowe, & Hand, 2007), the research is conducted with one laboratory session as the treatment whereas this study was conducted with five laboratory sessions over 5 months.

**Background and Need**

The use of scientific-literacy skills have taken on many variations over time and has evolved into the foundation of the current NGSS and broader CCSS as they pertain to reading and writing within the sciences. Scientific literacy is a paramount skill in the 21st century in order for students to be able to identify useful evidence, draw conclusions from evidence, and develop policies based on these data (NGSS, 2013). The Next Generation of Science Standards are aligned with the Common Core State Standards in order to promote literacy development across all content areas and prepare students for a future of informed and educated decision-making. An increased emphasis on building a scientifically literate society has shifted within the standards, and the support for instructional design to align with these standards is necessary in order to provide practitioners with a research-based option for developing scientific literacy as a skill and knowledge base within their students.

Scribner and Cole (1981), in a seminal study, positioned literacy to include three components of practice: technology, knowledge, and skills. These practices of literacy include “patterned ways of using technology and knowledge to accomplish tasks” (p. 236). Scientific literacy incorporates the regular use of these patterns and technological skills to apply knowledge in unique scientific settings. Scientific literacy requires more than rote memorization and recall of facts and data. Scientific literacy includes the use of observable data and inquiry to make cogent arguments and connect evidence at a deeper
level (National Research Council, 2011). Lederman et al. (2013) argued that a very “narrow and distorted view” of scientific inquiry is taught and reinforced in the kindergarten to 12th-grade educational system that limits a student’s imagination and connectedness to scientific inquiry. This research study was conducted in order to approach inquiry from a different viewpoint in order to broaden the inquiry paradigm and allow students to think more openly about science and the many scientific connections that can be made during the laboratory process. The inquiry model in this research included the co-construction of knowledge in order for students to explore scientific phenomenon from a social perspective. Inquiry through the SWH framework is a platform for students to write informally about their observable findings and mentally negotiate meaning of their observed data into formal writing (Akkus, Gunel, & Hand, 2007).

Experts in the field of science education and research have called for the increase of inquiry as a means to teach science in order to integrate scientific content knowledge within scientific practices (National Research Council, 2012). Inquiry is one of the main foci for the NGSS Framework and are rooted partially in the *Benchmarks for Scientific Literacy* (2009), which maps out standards for scientific literacy development by the end of the 12th grade. Inquiry, as a means for learning, is a social and exploratory framework that supports the learning of complex scientific concepts through laboratory settings (Becker, 2012). This learning method was the foundation for this research study and was the main focus of the writing-to-learn paradigm. There was a need for further research around the effectiveness of the SWH as a learning tool in order to support the process of developing scientific literacy and knowledge acquisition.
Theoretical Framework

Writing is not only a method for expressing literacy but also a method to help process scientific information and formulate a cohesive argument or explanation about a concept. The process of writing helps focus students on the schematic knowledge and skills that build memory and require organization of thought versus the lower-level cognitive process of declarative knowledge (Magnifico, 2010). The theoretical framework behind writing as a method for learning is rooted in the constructivist theory of learning (Treadwell, 2010) and the schema theory (Beene & And, 1985; Schatzberg-Smith, 1988). The learning process is generative, and meaning is constructed through negotiation with complex concepts. The SWH laboratory process builds a schema for students for students in terms of understanding and doing science that facilitates them becoming more scientifically literate. Vygotsky (1978) argued that learners do not acquire knowledge in isolation, rather they co-construct knowledge, and learning in a social interaction. The process of negotiating ideas and reasoning through complex scientific evidence is an essential part of the knowledge-construction process (Tobin & Tippins, 1993; Vygotsky, 1978). The process of co-constructing the scientific question to test for the laboratory process in the SWH relies on Vygotskyan framework for student learning.

Schema theory is a theoretical underpinning in the process of developing arguments within the scientific laboratory setting. When a student observes a scientific phenomenon, he or she must connect it to prior knowledge and develop a progressive definition of the scientific world (Bischoff & Anderson, 1998). The laboratory experience reinforces a student’s prior understanding of the natural world and continues to develop a
schema for newly learned scientific knowledge. The laboratory experience promotes the development of knowledge with increased experience with scientific phenomenon (She, 2004).

Writing requires the process of organizing thoughts, evaluating and supplying supporting evidence, and drawing connections between concepts to explain phenomenon. The co-construction of knowledge through writing and discussion with peers in a laboratory setting has been found to have beneficial learning outcomes (Balgopal & Wallace, 2009; Hand, Hohenshell, & Prain, 2004; Hand, Wallace, & Yang, 2004; Saul, 2004; Wellington & Osborne, 2001). Therefore, formative writing assignments used to support a laboratory experiment and develop conceptual understanding should improve learning outcomes in a high-school chemistry course. Formative writing assessments that require schematic knowledge skills are better able to develop students’ mental models and conceptions (Furtak & Ruiz-Primo, 2008).

There are two types of writing classifications in formative assessments: Writing-to-Learn (WTL) and Writing-to-Communicate (WTC). WTL is an effective instructional strategy that centers on the process of organizing and articulating ideas as opposed to WTC that focuses on the finished written product (Balgopol et al. 2013). WTL strategies are classified by the process of writing as a method of reasoning through a concept in order to facilitate learning (Zinsser, 1988). WTL strategies are designed to use writing as a process in which students generate and clarify understanding of scientific concepts for themselves, rather than simply communicating with a teacher for evaluation such as a WTC assignment (McDermott, 2010). The Science Writing Heuristic is a WTL activity situated in a science laboratory setting that draws on scientific-literacy skills and is
focused on scientific-knowledge development (Memiş & Seven, 2015).

The SWH is a method of scaffolding laboratory experiences that is inquiry group-based and require processing the learning of scientific phenomenon through writing. The SWH is considered a WTL strategy due to nature of the writing process that is structured in a way to deepen learning and make connections between prior knowledge and the observable data. As seen in Table 1 (Appendix A), the SWH relies on the use of guided questioning techniques in the laboratory setting to include questioning of scientific phenomenon observed, knowledge claims, evidence, and observable data (Nam et al., 2011) in order to guide the inquiry process. The process requires both students and teachers to take an active role in the laboratory process versus more traditional laboratory settings that are cookbook in nature. The SWH is a cooperative negotiation of conceptual understanding through the writing process rooted in the constructivist theory of learning.

Included in Table 1 (Appendix A) that was adapted from Burke, Greenbowe, and Hand (2006) is a list of the traditional science laboratory formats and prompts and the proposed science-writing-heuristic format questions. These are outlined in a way to provide a comparison between the two sequences of the laboratory protocols.

In a seminal study on the SWH, Rudd et al. (2007) conducted a SWH experiment with 52 students in an undergraduate chemistry course. One-half of the participants were assigned a traditional laboratory process including a laboratory write-up with title, purpose, outline of procedure, data and observations, balanced equations, calculations, graphs, and discussion. The treatment group participated in an SWH laboratory process that included a write-up with beginning questions or ideas, tests and procedures, observations, claims, evidence, and reflection. The SWH treatment group outperformed
the traditional laboratory group that resulted in a statistically significant different achievement on a posttest between the two groups holding their prior knowledge constant. The results of this study suggest that with appropriate structure of writing protocols to help students process a complex scientific process, students may have a deeper and stronger understanding than those taught with a traditional laboratory protocol. This research study is one of several SWH studies (Cronje, Murray, & Rohlinger & Wellnitz, 2013; Hand, Therrien, & Shelley, 2013; Keys et al., 1999; Kingir, Geban, & Gunel, 2013; Nam et al., 2011) conducted to assess the effectiveness of the SWH protocol.

**Research Questions**

The intent of this research was to add to the body of literature around effective Writing-to-Learn (WTL) strategies in order to help students learn high-school science and develop scientific literacy. The research included a locally created pretest, intervention, and a locally created posttest. Each of the assessments included in the research were vetted through a validity panel of experts. Grades were collected for the laboratory report in order to ensure standardization of the laboratory process and write-ups. The research included a questionnaire regarding students’ opinions about the scientific writing protocol as compared with the traditional protocol. The research was administered over several months with five total laboratory sessions. Thus, a research question regarding improvement of writing over time was included. The research, overall, was aimed at identifying the effectiveness of the SWH teaching methodology as a means to improve scientific literacy and content knowledge. The research questions below were designed to address the purpose of the research:
1. To what extent is there a difference between SWH and traditional laboratory groups’ scores on the posttest of content assessment?

2. To what extent is there a difference between SWH and traditional laboratory groups’ scores on the posttest of a writing assessment?

3. To what extent are there differences in student scores on the SWH laboratory protocol over five laboratory experiments?

4. Was there a statistically significant difference in student perceptions of the usefulness of the SWH laboratory report and student perceptions of the usefulness of the traditional laboratory report?

**Definitions of Terms**

The following terms are defined as they are applied within this study. There may be additional definitions of these terms used in other contexts, however, for the purposes of this study, these terms were used as they are defined below.

**Common Core State Standards (CCSS)** are the state standards for 43 out of 50 states. The state standards are learning goals for each grade level, kindergarten to 12th grade, that define the content-area knowledge and skills that students are expected to know and be able to do by the end of each grade level in Mathematics and English Language Arts. The Common Core originally included 48 states working together to develop the standards (National Governors Association Center for Best Practices, Council of Chief State School Officers, 2010).

**Evidence-Based Claims** is the process by which students use observable data to make and support a scientific claim. This practice extends past the sciences and is used in English Language Arts and other content areas by using textual evidence. Within the sciences,
this process includes the use of observable scientific phenomenon (National Research Council, 2012).

Formative Writing Assessment is a method used by teachers to assess learning progress by students. This evaluation is used as a practice application of learning by the student as well as a learning evaluation by the teacher in order to assess how much a student has learned of a particular concept. Often times the writing or assessment assignment is used as a reflective tool for students to gauge their own learning progress as well as a tool for teachers to modify their instruction to improve learning (Garrison & Ehringhaus, 2007).

Next Generation of Science Standards (NGSS) are the Common Core State Standard equivalent for the science content area. The NGSS are the core scientific concepts and skills as identified by the scientific and research community. The standards are articulated across grade bands and are organized by disciplinary core ideas, crosscutting concepts, and science and engineering practices (NGSS Lead States, 2013).

Posttest Content Assessment (CA) The posttest CA was one of the dependent variables in this study. The posttest CA was a multiple-choice with 20 multiple-choice questions. These questions were related directly to the content learned in the laboratories during the study. The scores on the CA were used as one of the dependent variables in this study. Each question is scored as 1 point per question. Scores range from 0 to 20.

Posttest Writing Assessment (WA) The posttest WA was a dependent variable in this study. The WA was included as a measurement of writing growth and was linked to the scientific-literacy development of student participants. The WA includes a laboratory description of a scientific phenomenon, laboratory procedures, and observed data. Students make a scientific claim and support their claim based on the provided data. The
WA was aligned with the SWH laboratory write-ups and assessed the students’ scientific literacy. The WA included a 9-point rubric scale using the SWH laboratory rubric categories for the “observations, claims, and evidence” category for 3 points on each. Scores range from 0 to 9.

Pretest was the baseline assessment conducted prior to the commencement of the experimental treatment. The pretest was administered to investigate any between-group mean differences (Creswell, 2014). In this study, the pretest assessment included a 10-item multiple-choice test with questions from previously released California Standardized Tests (CST). Items were selected from CSTs administered from 2003 to 2007. Scores range from 0 to 10.

Science Writing Heuristic (SWH) was a science laboratory protocol that included investigations including idea expression, collaborative peer discussion, and writing. The protocol was designed to guide teachers and students in negotiating meaning through investigation (Keys et al., 1999). SWH was a WTL activity in a science laboratory setting that focused on scientific literacy skills and scientific knowledge development (Hand et al., 2004; Hand et al., 2004; Memiş et al. 2015, Nam et al., 2011)

Science Writing Heuristic (SWH) Laboratory Rubric The SWH laboratory rubric was designed to assess students’ ability to complete effectively each section of the science writing heuristic. The elements of the SWH laboratory assessed were (a) beginning questions, (b) test or experiments, (c) observations, (d) claims, (e) evidence, (f) reflection, and (g) work cited. The rubric ranged in scored points from 1, 2, or 3 for a total of 21 points possible in order to maintain overall grade weighting scores in the class. The SWH laboratory scores were collected over time for each student participant. For the purposes
of this study, the rubric scores were used in data analyses as a dependent variable looking at change over time.

**Scientific Literacy** Scientific literacy is the knowledge and understanding of scientific concepts and processes required to convert observable phenomenon into describable, explained, and predicted scientific events. This process includes the ability to pose and evaluate arguments based on evidence and to apply conclusions from such arguments appropriately (National Research Council, 2012).

**Student-Perceptions Questionnaire** The student-perceptions questionnaire was administered following the posttest CA and posttest WA. The student-perceptions questionnaire included 10 Likert-type scale items on the SWH questionnaire and 7 Likert-type scale items on the comparison-group questionnaire. The questionnaire included three overall components: (a) chemistry students' perceptions of the importance of WTL assignments and their understanding of chemistry, (b) chemistry students’ attitudes toward WTL assignments, and (c) the extent that chemistry students perceived writing as a method of helping them make deeper curricular connections. Each item was scored based on the Likert-type scale with each statement assigned point values for each rating: 1=Not at all true, 2=A little true, 3=Somewhat true, and 4=Very true. There was one reverse verification item that was adjusted during data analysis. Scores ranged from 10 to 40 for the SWH questionnaire and 7 to 28 for the comparison-group questionnaire.

**Traditional Laboratory Protocol** The traditional laboratory protocol was an agreed upon set of standardized questions that traditionally have been taught in the Kindergarten to 12th-grade science course and commonly is referred to as the scientific method. These protocols include the title and purpose, outline and procedure, data and observations,
discussion, balanced equations, and graphs (Helmenstine, 2016).

**Writing Protocols** Writing protocols are assignments required of students during the reflection phase of learning as a follow-up course-work activity (Langer & Applebee, 1987).

**Writing-to-Communicate (WTC)** WTC activities focus on the final written product and the method of writing in order to communicate an idea. The most common WTC assignments in a formal classroom include (a) expository, (b) persuasive, and (c) narrative essays (Balgopal et al., 2013; Hillocks, 2002).

**Writing-to-Learn (WTL)** Writing to learn is the process to order and represent experiences to make meaning of concepts through written language. This process helps the learner shape meaning, reach a deeper understanding, and developing a stronger ability to reason through evidence (Zinsser, 1988).

**Summary**

Outlined in chapter I of the proposed research is the need to develop a scientifically literate society. Extant data were presented to reflect the current reality of academic achievement in the domain of writing as part of the compelling need for improved educational practices. The research included a writing-to-learn strategy through the scientific laboratory process known as the Science Writing Heuristic.

Chapter II included a review of relevant research of the Science Writing Heuristic as a means for students learning science laboratory content as compared with the traditional laboratory protocols used in high-school science. This review included an outline of the development of the Science Writing Heuristic as a laboratory protocol and its use as part of evidence-based writing.
The methodology for this study is included in Chapter III. The validity measurements of the locally generated assessments, the content of the SWH protocol and its application in the chemistry units, and an outline of the student opinion questionnaire development are outlined in Chapter III. This chapter also includes the data-collection process as well as data analysis postresearch. Chapter IV includes a review of the descriptive data and data analysis pertaining to the research questions. Chapter V includes a summary, limitations, discussion, and implications of the research results.
CHAPTER II

REVIEW OF THE LITERATURE

The purpose of this study was to examine the effectiveness of a writing framework in high-school science in order to help inform the best practices for developing scientific literacy and learning science content through writing. This research investigated the effectiveness of a laboratory protocol in developing scientific literacy and science-content knowledge through writing. The study incorporated a writing protocol as a framework for students to process observable scientific phenomenon. The protocol, named the Science Writing Heuristic (SWH), provided a framework that promoted the use of observable data points as evidence to support the student’s claim. This skill of using data as evidence in order to reason through a claim is one of the main tenants of the Next Generation Science Standards (NGSS) and the Common Core State Standards (CCSS). The educational purpose underlying this skill is to develop scientific literacy within high-school science students.

The United States engaged in a focus on education reform in the 1980s including an emphasis in science, technology, engineering, and mathematics in order to develop a scientifically literate society (Duschl, 2008). Scientific literacy is an essential skill for students to acquire in order to communicate the methods of the natural world and make an informed and cohesive argument about personal and societal problems (Balgopal & Wallace, 2013). Scientific literacy not only includes the traditional science processes of observing, inferring, classifying, predicting, measuring, questioning, interpreting, and analyzing data but also includes the confluence of these processes with scientific knowledge, scientific reasoning, and critical thinking (Lederman, Lederman, & Antink,
Scientific literacy is the essential outcome and mastery objective of all science teachers and courses; it is the goal of the NGSS to develop scientifically literate persons who can make sense of and apply scientific knowledge to unique settings (NGSS Lead States, 2013). Scientific literacy is the foundation for the proposed research using the science writing heuristic. Below is a review of scientific literacy and its importance in education, cognition of writing, writing protocols, writing-to-learn instructional strategies, previous research on writing-to-learn strategies, science writing heuristic, metacognitive writing prompts, and writing audiences. Each of these areas is reviewed in the context of relevant literature.

**Scientific Literacy**

Scientific literacy is the foundational skill that all students are expected to learn prior to high-school graduation in order to become active citizens who can assimilate into society with a working knowledge of science knowledge consumption (Cavagnetto, 2010). The process of mastering scientific literacy and developing this skill set is the work of classroom teachers during the elementary-, middle-, and secondary-school years. The process of scientific literacy development occurs through classroom lessons, experiments, and opportunities for students to produce scientific language in order to explain scientific phenomenon (Ross, Hooten, & Cohen, 2013).

The incorporation of literacy strategies helps build connections between lecture and laboratory practices, which have been shown to have positive academic results (Harmon & Pegg, 2012). The understanding of laboratory procedures and drawing inference from data collected is part of the development of scientific literacy. Research
shows, however, that there are varied literacy standards in classrooms, which creates a call for a more systematic approach to implementation of scientific literacy (Adams & Pegg, 2012).

A scientifically literate student is able to communicate effectively his or her ideas through writing or speaking while demonstrating a clear understanding of a scientific concept (Deming, O’Donnell, & Malone, 2012; Krajcik & Sutherland, 2010; Norris & Phillips, 2003). The writing required in CCSS helps improve scientific literacy as the standards emphasize the use of evidence-based arguments in all subject areas and promotes the movement from the vernacular to scientific expression. Jagger and Yore (2012) argued that all members of the educational community need to encourage and promote the use of evidence-based arguments in writing in order to increase scientific literacy in students. The use of evidence-based arguments are the hallmark of the CCSS and are essentially the anchor of the pedagogical shift in education. Research has shown that integrating literacy skills into science curriculum has had a positive effect on students’ inquiry skills and also has improved student attitudes toward science (Guzzetti & Bang, 2011).

In a recent study conducted by researchers Maulucci, Brown, Grey, and Sullivan (2014), a multiple-case study design was used to look in depth at the experiences of 6 fifth-grade students and an inquiry-based science education at an urban middle school. A variety of data sources were collected to reflect on authentic inquiry including teaching journal entries, samples of student work, photographs of students and their work, classroom video, semistructured focus-group interviews, and performance-assessment data. The data were analyzed to investigate six dimensions of science inquiry in which
(a) students develop authentic and personally relevant science knowledge; (b) students’ funds of knowledge shape their inquiries; (c) students’ relationships with science and sustained interest in science are transformed; (d) students’ identities as potential scientists are affirmed; (e) students engage in science as a social enterprise; and (f) student develop a sense of agency. (Maulucci et al., 2014, p.1119)

Maulucci et al. (2014) concluded through a close examination of all artifacts that science-inquiry experiences provided students with a greater sense of academic agency, fostered expertise, challenged students’ views of science concepts, improved science achievement and enhanced their relationship with science. This research provided the meaningful context in which the study was situated. The study was looking to foster a strong connection between students and scientific inquiry in order to increase scientific literacy and improve science achievement.

Guided Inquiry

The science writing heuristic uses a guided inquiry framework with the teachers providing prereading, and contextual scientific information and working with the students to develop a guiding question. Guided inquiry includes a laboratory process where the teacher asks the question and students construct the solution through experimental observations (Ural, 2016). Guided inquiry is more structured than an open-inquiry process where students are searching for the problem and the solution through experimental means. Guided-inquiry research suggests that students’ attitudes toward science and their academic achievement increase (Taitelbaum, Mamlik-Naaman, Carmeli, & Hofstein, 2008; Hofstein, Shore, & Kipnis 2004). Sen and Oskay (2016) conducted research on 34 undergraduate chemistry students with half of the students receiving inquiry learning activities and the other half receiving lecture-based traditional chemistry teaching. The results suggested that there was a statistically significant
difference between the experimental and comparison group with the experimental group showing positive academic gains $t(32)=3.63$, with a reported large eta squared=.29. These results suggest that students taught with an inquiry framework benefit academically from this structure.

Research conducted by Ural (2016) with 37 undergraduate science students was centered around the use of a guided-inquiry laboratory framework. The students received the traditional laboratory teaching method in the fFall semester of a two-semester course of study. In the second semester, the laboratory protocols were all guided inquiry facilitated by the professor. Affective data were collected using the Chemistry Laboratory Attitude Scale (CLA), Chemistry Laboratory Anxiety Scale (CLAx), and a semistructured interview form. The academic achievement data collection included seven laboratory quizzes in each semester, a chemistry achievement pretest, and a chemistry achievement posttest for each semester. Results indicated that there was a statistically significant increase in student’s attitudes toward chemistry laboratories, their academic-achievement, and a decrease in their chemistry laboratory anxiety. The paired-samples $t$ test results indicated a statistically significant difference in the attitudes of students toward chemistry favoring the guided inquiry laboratory framework, $t(36)=-3.84, r=.54$. Additionally, there was a statistically significant effect for laboratory anxiety with students reporting less anxiety within the guided-inquiry laboratory setting, $t(36)=4.54, r=.60$. Last, there was a statistically significant difference in academic achievement between semesters of study with the guided-inquiry quiz and posttest scores being higher on average than the traditional laboratory achievement scores, $t(36)=15.06, r=.93$. The achievement score differences suggested a very large effect favoring the guided-inquiry laboratory
Cognition of Writing

The guided-inquiry framework builds scientific-literacy skills through the laboratory experience. Scientific-literacy development is the foundational goal of this study. In order to investigate the process by which scientific literacy is developed through writing, the framework behind the cognition of writing was explored. Understanding cognition of writing is intertwined with understanding the development of academic literacy, namely science. Hillocks (1975) emphasized the importance of inquiry in writing, noting that students need to be writing about something that was observed in the content area in which they are writing. Hillocks (1979), a leading researcher in the field of writing assessments in education, prioritized the process of writing following an observation in order for students to make inferences and connections to the content they were learning.

The process of writing is an essential skill for most workplace and educational settings (National Education Association, 2007). It is an emphasized skill in the CCSS and a prioritized shift in the development of curriculum within the new standards (CCSS, 2010). Unfortunately, this necessary skill set has not yet translated into student application in unique settings (Vázquez et al., 2012). This skill of using writing to learn and communicate will be the foundation of the work during the CCSS curriculum development with teachers prioritizing writing to learn in their lesson designs (Rhodes & Feder, 2014). With writing being the backbone of the CCSS and NGSS, it is imperative that educators understand the mechanics of writing paired with their specific content area in order to maximize student learning outcomes (Gillespie, Graham, Kiuhara, & Hebert, 2010).
Research indicates that teachers have not been trained in the mechanics of teaching writing in their preservice coursework (Cutler & Graham, 2008; Gilbert & Graham, 2010; Kiuhara, Graham, & Hawken, 2009). In a study conducted by Gillespie et al. (2013) 800 ninth-grade and 12th-grade teachers nationwide were selected randomly to complete a questionnaire on their preparation and use of writing strategies to help student learn classroom content. The questionnaire was stratified between four content areas: (a) language arts, (b) mathematics, (c) science, and (d) social studies. Teachers reported using writing-to-learn strategies in their classes, yet they were not applied appropriately. Teachers also reported a lack of preservice or inservice preparation on how to use writing to support learning. The purpose of this research was to provide teachers a research-based writing tool to use in laboratory reports that use a writing-to-learn model in order for students to process the information and develop their scientific-literacy skills.

The process of writing is one that is complex in that it requires the use of both long-term and short-term memory in order to plan, organize, and execute. Researchers began developing models of the cognition of writing around the 1970s following Emig’s (1971) seminal study involving 12th-grade students. Emig’s (1971) study focused on the process of writing rather than analyzing the end product of student work in order to inform writing as an instructional paradigm. Flowers and Hayes (1980), expanded on Emig’s (1971) work and are known as the experts in the field of the cognition of writing. Flowers and Hayes (1980) organized the mental model of writing cognition into two types of information: the writer’s knowledge stored in long-term memory and the writer’s representation of the task environment. Hayes (2012) developed an updated cognition of writing model for adults and writing but due to the age range is not being explained or
presented here.

Figure 1. Mental Model of Writing by Flower and Hayes (1980).

Flowers and Hayes (1980) outlined the long-term memory as the warehouse of knowledge that a writer can access during the planning stages. The “planning” of writing, as defined by Flower and Hayes (1980) requires the use of long-term memory to generate ideas in order to build an internal representation (Figure 1). “Organizing” was defined as the process of selecting the useful memories and placing them into a logical structure that requires formulating ideas and searching memory for subordinate ideas, “translating” was defined as the process of transforming a logical structure into written sentences, and “reviewing” is the process of rereading, evaluation, and editing. This process is not one that is linear in nature, rather it requires the use of hierarchical mental systems in order to fluctuate between the stages.

Holliday, Yore, and Alvermann (1994) expanded on the cognitive process of writing that was outlined previously by Hayes and Flower (1980). Holliday et al. (1994) detailed the process of writing as requiring the use of long-term memory, working
memory, and sensory motor activity. The process of writing is knowledge transforming and interactive due to the requirement of complex retrieval of concepts, negotiation of meaning, and the constructive process that ensues. This iterative process of planning writing, generating, translating, and reviewing helps build schematic and conceptual knowledge based on a constructivist theory of learning. Constructivist theorists maintain that learning takes place when meaning is made by prior knowledge being activated (Stahl, 1995).

The notion of writing-to-learn (WTL) through a constructivist framework is a concept that is rooted in the foundation of a meaningful experience to the writer. If a person perceives that he or she emotionally is connected to the topic they are writing about then conceptual understanding will be refined and developed during the knowledge construction process (Iverson, 2010). This educational approach to employing writing-to-learn strategies helps students activate prior knowledge, make meaningful connections, and construct meaning as part of the learning process.

In an experimental study conducted with fifty 12th-grade students, the role of affect was investigated during a WTL assignment on biosecurity (Tomas & Ritchie, 2012). The students were assigned six writing tasks on biosecurity over the course of an eight week period. Data were collected on affective measures through student questionnaires, interviews, and video recordings of emotional expressions as tied to the writing task. Researchers found that favorable emotions elicited during writing were positively and strongly connected to students’ interest in the writing assignment. This is an important connection to the following research due to the link between a positive and meaningful writing activity and the construction of knowledge during the writing process.
Figure 2. Learner-centered writing model.

This study’s research design included the co-construction of knowledge during the laboratory experiment planning and the meaningful writing process of assimilating the information being observed and the output of meaning constructed in a WTL activity.

Writing Protocols

Writing protocols help teachers facilitate learning experiences through writing as can be seen in the learner-centered writing model (Iverson, 2010) in Figure 2. Writing protocols are defined as assignments required of students during the reflection phase of learning as a follow-up course work activity (Langer & Applebee, 1987). In Figure 2, the inner ring of the model includes four separate, but interconnected, components of the theoretical frameworks that provide context and background to the writing process: creative writing, learning theory, cognitive neuroscience, and technical writing. The outer ring includes the best practices for teaching and learning in order to maximize the results of the outcomes for learner-centered writing: engage readers, make a connection, facilitate meta-cognitive strategies, enhance learning and memory, practice, and apply.
Each of these best practices are rooted in the constructivist theory of learning and help students to continue to negotiate meaning with prior knowledge and construct new knowledge through writing.

Writing protocols provide the structure to tap into each of these best practices when properly implemented in the classroom. Writing protocols require students to apply cognitive and meta-cognitive strategies (Nückles, Hübner, & Renkl, 2009) through the knowledge-construction process. Writing protocols that are scaffolded appropriately to allow for meaning making promote the learning process through negotiation of long-term memory and newly constructed knowledge (Higgins & Flower, 1994). These learning strategies are applied through writing-to-learn opportunities that require students to access long-term knowledge while articulating thoughts in the course of writing. This knowledge production process is iterative in design.

**Writing-to-Learn**

Writing is a method for expressing literacy, but it is also a method to help process scientific information and help formulate a cohesive argument or explanation about a concept. As previously outlined, the process of writing helps focus students on the schematic knowledge skills that build memory and require organization of thought versus the lower-level cognitive process of declarative knowledge (Magnifico, 2010). Writing requires process of organizing thoughts, evaluating and supplying supporting evidence, and drawing connections between concepts to explain phenomenon. Formative writing assessments that require schematic knowledge skills are better able to access students’ mental models and conceptions (Furtak et al., 2008). Shanahan and Shanahan (2008) additionally argued that disciplinary literacy is the practice of using the unique tools that
an expert in a content area may use in order to communicate a concept. These notions of scientific and disciplinary literacy are the theoretical underpinnings of the need to incorporate more writing into the discipline of science.

Writing-to-learn (WTL) activities can focus on the production of nontraditional writing assignments such as poems, brochures, or letters to different audiences in order to develop understanding of a concept (Yore & Treagust, 2006), whereas others use writing in a more formal writing protocol such as the Science Writing Heuristic (SWH). The use of WTL activities during instruction have been reported by researchers as having favorable outcomes in learning (Balgopal & Wallace, 2009; Bullock, 2006; Hand, Gunel, & Ulu, 2009; Hand, Wallace, & Yang 2004; Saul, 2004; Wellington & Osborne, 2001) although they have been based primarily on context of the learning environment. Therefore, further research was needed in order to establish the most advantageous writing repertoire and match it to the appropriate context.

Previous Research on WTL Strategies

Previous research on WTL strategies have included the use of writing assignments such as the Science Writing Heuristic (Rudd et al., 2007; Hand et al., 2002; Keys et al., 1999; Nam et al., 2011), writing to audiences of different ages and relationships to the student (Gunel, Hand, & McDermott, 2009; Hand, Yang, & Bruxvoort, 2007; Magnifico, 2010), meta-cognitive prompts (Berthold, Nückles, & Renkl, 2007; Nückles et al., 2009), journal writing (Hübner, Nückles, & Renkl, 2010; Klein, 2004; Nückles et al., 2009; Schwartz, Lederman, & Crawford, 2004; Towndrow, Ling, & Venthan, 2008), prewriting (Hand, Hohenshell, & Prain, 2004; Hand et al., 2002), multiple writing tasks across connected topics (Hand, Wallace, & Yang, 2004).
metaphors (Levin & Wagner, 2006), persuasive essays (Balgopal et al., 2013), and multimodal representations used during writing tasks (Hand, et al., 2009; McDermott & Hand, 2013). Each of these WTL strategies has been shown to have a positive academic influence in science classrooms. Several studies have shown mixed results in terms of the gains in academic performance. These studies, as previously mentioned, have been limited to the context in which they were situated due to a lack of true experimental designs.

Gunel et al. (2009) sought to answer two research questions: (a) are students’ conceptual understanding effected by participation in a writing-to-learn activity and (b) does the particular audience that a student’s writing is addressing have an effect on the conceptual understanding gained by the student? Research was conducted with 108 students in a Midwestern high school. The study included a pretest posttest quasi-experimental design. There were two phases in the study broken up into two units. Each phase included ten 50-minute lessons that had two different science topics with the WTL assignment at the end of each unit. The first phase included 118 students enrolled in the 9th and 10th grade. Teachers assigned a writing-to-learn assignment for four classes with the topic of how the nervous system maintains homeostasis in humans. This test was used as a way for students to become familiar with a writing task in the course while also assessing the student’s ability to write and process the biological concept. The students wrote to their teacher as their audience in this prompt. The students were then administered a posttest assessment following the writing activity.

The results for the Gunel et al. (2009) research phase showed a statistically significant difference in posttest scores with students in the writing group outperforming
their peers with $R^2=0.33$, $F(3, 97)=15.79$. The results on the posttest assessment for the first phase of this research are pertinent to the proposed research in that the writing process helps students learn the science content through the WTL activity.

Prior to the Gunel et al. (2009) study, Hand et al. (2007) focused on the complex concept of stoichiometry in a general 11th-grade chemistry course in a rural Iowa high school. The study consisted of 52 students as participants. The researchers addressed the following research questions: (a) Does the use of a writing-to-learn strategy improve Year 11 students’ conceptual understanding of stoichiometry calculations compared with traditional end-of-chapter activities? and (b) In what ways (if any) did Year 11 students value using a writing-to-learn strategy to promote their understanding of stoichiometry? The treatment group was required to write a business letter to a seventh-grade student. Students were given a pretest before treatment (comparison groups used a traditional questioning-and-answer structure) and a posttest following treatment. Interviews were conducted with 9 students at random to assess their perceptions of the writing task.

Results indicated that out of seven questions on the posttest, one question showed a statistically significant difference between the treatment and the comparison group with the treatment group scoring higher, $F(1,47) = 5.24$, MSE = 3.43, $\eta^2=0.10$. These results indicate a medium measure of practical importance and are suggestive of an effect between the treatment and conceptual knowledge retention. The qualitative portion of the study resulted in four assertions from the data analyses: (a) students were aware that writing to a younger audience required them to change the language one uses when constructing explanations, (b) when responding to feedback received from the audience, students were required to expand on their initial explanations, (c) completing the writing
task enabled the students to identify for themselves the depth of their understanding of stoichiometry, and (d) students were aware that completing the writing task required different thinking patterns and resulted in a greater sense of ownership of the scientific knowledge with which they were dealing. These assertions and results of this study are relevant to this study due to the connection to the students’ ability to think more deeply about the scientific concepts in order to break them down into simpler concepts for the younger students to understand. This cognitive process is relevant in the learning process as described by Flower and Hayes (1980) with the “translation” of the concepts from more complex into easier to understand ideas. This process builds understanding and long-term memory.

Tatar, Yildiz, Buldur, and Akpinar (2012) incorporated preservice, prospective science teachers in WTL research on writing audiences. Tatar et al. (2012) conducted a pretest, posttest, quasi-experimental research study with 73 students at Ataturk University in Turkey. The experimental group was required to write a summary of special relativity theory in physics to high-school students. The posttest exams indicated that there was a positive academic gain for students in the experimental group with statistically significant results, $t(71)=3.93$, $\eta^2=.18$. These results indicate a large measure of practical importance and are consistent with Hand et al. (2007) and Gunel et al. (2009). WTL strategies have demonstrated positive academic gains in the sciences when students are prompted to explain their thinking around a particular scientific process through writing. Within the list of WTL activities, the SWH and meta-cognitive prompts are presented in more detail in the following sections as they were the foundation of this study.

**Science Writing Heuristic**
The science writing heuristic is a method of scaffolding laboratory experiences that are inquiry based and require meta-cognitive processing through writing (Akkus et al. 2007). One of the key tenets of the NGSS and CCSS is developing the skill of data-based decision making known as argumentation. The SWH moves beyond developing just the skill of argumentation and moves into a deeper development of understanding scientific practices as well (Cavagnetto, 2010). The SWH is an instructional framework that guides the teacher and student through the laboratory-inquiry process and provides metacognitive support to help students reason through data.

The SWH is considered a WTL strategy due to nature of the writing process that is structured in a way to deepen learning and make connections between prior knowledge and the observable data. In order to guide the inquiry process the SWH relies on the use of guided questioning techniques in the laboratory setting to include questioning of scientific phenomenon observed, knowledge claims, evidence, and observable data (Nam et al., 2011). The process requires both students and teachers to take an active role in the laboratory process versus more traditional laboratory settings that are cookbook in nature. The SWH is a cooperative negotiation of conceptual understanding through the writing process. The traditional laboratory report format is compared with the SWH format in Table 1 (Appendix A).

Greenbowe et al. (2007) conducted a SWH experiment with 52 students in an undergraduate chemistry course. One-half of the participants were assigned a traditional laboratory process including a laboratory write-up with title, purpose, outline of procedure, data and observations, balanced equations, calculations, graphs, and discussion. The treatment group participated in an SWH laboratory process that included
a write-up with beginning questions or ideas, tests and procedures, observations, claims, evidence, and reflection. An analysis of covariance was conducted using baseline knowledge as a covariate. In order to investigate the effectiveness of the SWH, the students’ chemistry knowledge was assessed on a lecture exam question and a laboratory practical exam task. The SWH treatment group outperformed the traditional laboratory group that resulted in a statistically significant different performance between the two groups holding their prior knowledge constant, $F(1, 49)=11.61, \eta^2=.19$, which indicates a large measure of practical importance. The results of this study suggest that with appropriate structure of writing protocols to help students process a complex scientific process, students may have a deeper and stronger understanding than those taught with a traditional laboratory protocol.

Keys et al. (1999) conducted research in two eighth-grade science classes to examine the results of implementing SWH protocols. Researchers used several data points randomly selected across the two classes and selected 19 students to examine in depth. The data collected included (a) students’ written reports, (b) videotapes of target team discussions, (c) audiotapes of target team interviews, and (d) prestudy questionnaires. Researchers found that the SWH protocol increased student expansion of ideas by 15% and explanation of scientific phenomenon in the laboratory investigation. Preliminary writing samples were low level in their application of scientific criteria, but with continued use of the SWH protocol students drew stronger conclusions using data and also built inferences based on prior knowledge. Prior to indepth use of the SWH, students gave concrete answers with low-level analyses and minimal connections based on inquiry. Statistical significance was not calculated for this study as it was primarily
qualitative in nature, which is a major shortcoming of this study in terms of generalization.

Nam et al. (2011) researched the effects of the implementation of the science writing heuristic in three lower performing Korean middle schools. One teacher at each school taught the SWH and the comparison classes. There were eight total lessons developed by the teachers using the SWH protocol over one semester of study. There were 189 student participants in the SWH group and 156 students in the comparison group. The results of the Reformed Teacher Observation Protocol (RTOP), SWH writing, and a Summary Writing Test (SWT) were all analyzed to assess the effectiveness of the SWH. The results of this study showed a statistically significant difference between the SWH and the comparison groups on the SWT, $F(1, 96) = 17.99, \eta^2 = .17$ (large measure of practical importance). Effect sizes across the three schools were reported as medium for school A (Cohen’s $d = .61$) and school B (Cohen’s $d = .64$) and as small for school C (Cohen’s $d = .05$). There was very little difference (not statistically significant) between the SWH and comparison groups on the RTOP. The results of the study suggest that due to the differences in student writing production and concept retention on the SWT, this method of WTL is an effective tool in increasing student achievement. Current laboratory practices in high-school science typically are more scripted than the SWH and do not employ nearly as much of the inquiry-based approach as the SWH protocol. These three studies show the effectiveness of WTL strategies in helping students transform vernacular into canonical science writing with the help of scaffolded learning processes. Fellows (1994) found that the more structured writing opportunities students had, the more they were able to logically argue their ideas that led to conceptual change.
Hand, Prain, and Wallace (2002) had results that positively favored the SWH as a treatment for 9th-grade and 10th-grade science classrooms. The research results showed positive academic gains in students required to answer higher-order thinking questions. Scores for end-of-unit exams were collected after the SWH and comparison (traditional lab write-up) were given. The year 10 science class included 46 participants ($n=23$ in treatment group, $n=23$ in comparison group). The treatment group was required to write a letter to the newspaper editor regarding the lesson content before taking the unit exam. The second study included year 9 science students studying light with 52 participants ($n=25$ in treatment group, $n=27$ in comparison group). The treatment group completed five writing heuristics and an explanatory letter prior to taking the unit exam. The results indicated that for the first study, there were no treatment effects with the letter to the editor on cloning. For the second study, there was a statistically significant difference between the treatment and comparison groups for the higher-order questions on the end-of-unit exam with the treatment group outperforming the comparison group, $F(1, 41) = 15.85$, $\eta^2=.28$, which is a very large measure of practical importance. There was no difference on the lower-level recall questions on the exam. The results of these studies indicate that there are benefits from structured writing versus traditional laboratory write-ups. The type of writing is an essential component in helping support student learning. These results are consistent with the results from the Gunel et al. (2009) study with students writing letters to the adults that had no effect on the learning outcomes.

**Metacognitive Writing Prompts**

The SWH serves as a metacognitive support to help student reason through data they have collected in the laboratory process (Akkus et al., 2007). Several research
studies are described in this section that are relevant to the process of meta-cognitive prompts and their educational significance. This area of research is important to describe as part of the structure of the SWH includes metacognitive writing prompts embedded into the laboratory protocol. The following research designs were selected as relevant research supporting the use of metacognitive prompts in WTL activities.

Berthold, Nückles, and Renkl’s (2007) research investigated strategies for journal writing that help students reflect on the content learned. Previous research has examined the effectiveness of journal writing in general as a means for building schema and supporting the learning process. This research was conducted in order to fill a gap in the literature and identify what type of learning journals actually are effective in helping students learn. Students were randomly assigned to four different journal conditions: (a) cognitive journal prompts, (b) meta-cognitive prompts, (c) a mixture of meta-cognitive and cognitive prompts, and (d) no prompts at all (comparison condition). Cognitive prompts included questions around organization and elaboration of the content, whereas meta-cognitive prompts included questions to induce monitoring and self-regulation. Within the SWH the questions aligned with cognitive prompts include (a) beginning questions, (b) tests including safety and procedures, (c) observations, (d) claims, and (e) evidence. The meta-cognitive questions include the reflection component of the SWH laboratory.

The research was designed to answer the following five questions: (a) Which set of prompts enhance cognitive and meta-cognitive learning strategies in learning protocols as compared with a no prompts condition? (b) Which set of prompts enhance understanding and retention of the learning contents as compared with a no prompts
condition? (c) Which effects do different sets of prompts have on the accuracy by which students are able to self-assess their learning outcomes? (d) Are learning outcomes mediated by the specific learning strategies elicited in the protocols? (e) Are prompted strategies that prove to be effective also perceived as helpful? The results indicated that students in the cognitive and mixed prompts condition statistically significantly outperformed the students in the no prompts (comparison) condition, $F(1,80)=14.01$, $\eta^2=.15$ (large measure of practical importance). Berthold et al. (2007) identified a need for further research in cognitive writing protocols in subjects other than college-level psychology in order to be able to generalize the results and build the body of literature in this area.

The Berthold et al.'s (2007) research resulted in positive student academic gains due to writing prompts that have metacognitive learning strategies embedded within them. Research conducted by Armstrong, Wallace, and Chang (2008) results indicated that metacognitive prompts do not always result in increased academic gains when metacognitive training is not part of the learning process. Researchers examined the effectiveness of using written arguments to promote learning in college biology and to examine the meta-cognitive processes of writers who had instruction in scientific writing but lacked specific meta-cognitive training.

Armstrong et al. (2008) conducted research at a Southeastern University including 212 students. Of the 212 students enrolled in the lecture course, 26 of these students were enrolled in a writing course. The students enrolled in the writing course were the treatment group and received six short writing prompts asking them to describe the concepts in the introductory biology course to an audience who is not familiar with the
concepts. The students received peer feedback, but there were no comments or grading completed by the professor as this was purely an exercise in metacognitive strategies and self-regulated learning. For both treatment and comparison groups, the students were tested on a summative exam with multiple-choice test questions at the end of the course. There was no statistically significant difference in the academic performance factors with the end-of-course exam. These results are not consistent with other writing-to-learn outcomes and may have been limited due to the lack of professor feedback given to students and the lack of grade assigned for the writing. There may have been affective factors in the treatment group due to the lack of accountability that influenced the outcome of this study.

Cognitive and metacognitive learning strategies were the focus in the Hübner et al. (2010) study on remediating production deficiencies through journal writing. The study focused on the inconsistencies in the literature around the effectiveness of learning journals as a writing-to-learn strategy. The research aimed at filling a gap in the literature around how to structure effectively learning journal practice in order to promote self-regulated writing-to-learn techniques, which are correlated to increased learning. The research included 70 high-school students in a 2 x 2 experimental design. The researchers made note to detail the age range in which students cognitively can process the learning journal strategies and highlighted the 10-to-12-year-old range as being an appropriate time-frame to increase their familiarity and training around the use of writing prompts and learning journals. Researchers found that learning journal writing with informed prompting statistically significantly enhanced learning outcomes. The researcher indicated an interaction effect between learning journals and informed prompting, $F(1,$
63)=5.97, η²=.09 (a medium measure of practical importance). These results provide support for the self-regulation argument of writing-to-learn instructional strategies. These research areas around prompting are important to detail due to the metacognitive writing prompts in the SWH laboratory protocol. The laboratory protocol includes specific areas of assigned writing for students to process the information they are expected to observe and assimilate.

**Summary**

Scientific literacy is the foundation of the work of science teachers in order to help build students’ working knowledge of how to process observable data and become accurate consumers of information (Cavegnetto, 2010). As outlined in the previous literature, the process of becoming an active processor of information is broadened through WTL strategies in conjunction with laboratory experiments (Harmon et al., 2012). Student knowledge of scientific phenomenon increases with the use of science-inquiry laboratory experiments (Maulucci et al., 2014), writing protocols (Nückles et al., 2009; Higgins et al., 1994) including the SWH (Greenbowe et al., 2007; Keys et al., 1999; Nam et al., 2011). These studies all show improvements in student learning over the traditional laboratory reports when conducted in a single laboratory session. A traditional school year in a high-school science course includes more than one laboratory report that suggests that this method of assessing the effectiveness of the SWH is limited due to the time and frequency factor. Therefore, the purpose of this study was to investigate the effectiveness of the SWH laboratory format when used in several laboratory experiments over time.

The knowledge construction process is an iterative cycle of activating prior
knowledge, connecting concepts to meaningful learning experiences, and applying this knowledge. The writing-to-learn process prompts the learner to engage in this iterative cycle to negotiate meaning from a constructive experience. The use of writing-to-learn assignments as an instructional strategy will help teachers facilitate their students understanding of scientific concepts through structured writing prompts. This shift in writing expectations is in line with the CCSS and the NGSS. The process of students constructing meaning through meaningful writing assignments is the role of educators today and tomorrow.

Further research on the area of writing-to-learn in the context of a high-school chemistry classroom was designed to bridge the gap between the existing research on WTL strategies and the practical use in a high-school context. The implications for further research in this area are the expansion of an effective writing method to embed in secondary education and specifically in a science classroom in order to broaden the use of writing, as emphasized in the CCSS and the NGSS. In the CCSS era, teachers are shifting away from a standards-based curriculum that has been a laundry list of factoids and concepts that students were expected to learn. With the shift to CCSS and NGSS, teachers are expected to slow down their curriculum to deepen the skill set of students and their foundational knowledge. A well-researched instructional strategy in the sciences to increase literacy is timely and essential in order to help teachers build their curricula and for students to expand their use of writing skills.
CHAPTER III

METHODOLOGY

The purpose of this study was to examine the effectiveness of a writing framework in high-school science in order to help inform the best practices for developing scientific literacy and learning science content through writing. The following was the methodology outlining the research design of the study. First, the research design and study sample are presented, which is followed by the detailing of the protection of human subjects, instrumentation, treatment, and procedures. The chapter concludes with the data analysis and descriptive statistics as context of the study. The study was conducted Fall of 2016 and Spring of 2017 based on agreement with the host school’s chemistry-unit calendar.

Research Design

This study was a two-group comparison quasi-experimental study conducted in four General Chemistry classes. Chemistry was chosen as the course of study due to the large population enrolled in the course as well as the laboratory component that made up a large percentage of the coursework. In order to be eligible to graduate from high school in the state of California, students must complete a life-science and a physical-science course. Chemistry is a physical-science course of study and is the typical science course in which students register during their 10th-grade year in high school within the district of study.

The study investigated the following research questions with respect to the implementation of the Science Writing Heuristic (SWH) within 10th-grade chemistry courses:
1. To what extent is there a difference between SWH- and traditional-laboratory groups’ scores on the posttest of content assessment?

2. To what extent is there a difference between SWH- and traditional-laboratory groups’ scores on the posttest of a writing assessment?

3. To what extent are there differences in student scores on the SWH laboratory protocol over five laboratory experiments?

4. Is there a statistically significant difference in student perceptions of the usefulness of the SWH laboratory report and student perceptions of the usefulness of the traditional laboratory report?

To address the research questions, the quasi-experimental design included a pretest, treatment, posttest content assessment, a posttest writing assessment, and a student-perceptions questionnaire as seen in Figure 3. The independent variable had two levels: the SWH-laboratory format and a comparison group using a traditional laboratory write-up. There were six General Chemistry classes within the school. Four of these classes participated in the study. The study included two groups: (a) two General Chemistry classes received instruction using a traditional laboratory write-up and (b) two General Chemistry classes received instruction using the SWH laboratory write-up.

**Figure 3.** Research design diagram for proposed study.

The pretest administered prior to treatment included a 10-item multiple-choice assessment consisting of questions from the California Standardized Test (CST). The
questions on the pretest were extracted from CST administrations from years 2003 to 2007. The purpose of this pretest was to assess and adjust for any between-group differences during data analysis.

There were four dependent variables in this study: the laboratory scores on the SWH laboratory protocol, the posttest content assessment scores, the posttest writing assessment scores, and the Likert-type scale scores on the student-perceptions questionnaire. The dependent variable for question one was the scores on the posttest content assessment (CA). The dependent variable for question two was the scores on the posttest writing assessment (WA). The dependent variable for question three was the scores from the SWH laboratory rubric. The dependent variable for question four was the responses to the Likert-type scale items from the student-perceptions questionnaire. Each group received a posttest regarding student perceptions of the usefulness of each laboratory format.

Sample

A convenience sample of one-hundred-thirty 10th-grade students were invited to participate in this study. Treatment class 1 (T1) had \( n = 30 \), treatment class 2 (T2) had \( n = 33 \), comparison class 1 (C1) had \( n = 35 \), and comparison class 2 (C2) had \( n = 32 \) students participate in the study. Teacher A taught T1 and C1, and teacher B taught T2 and C2. The study was conducted at a public high school in Silicon Valley in Northern California. The school houses approximately 2,400 students annually. The study took place in General Chemistry courses with two classes receiving the Science Writing Heuristic treatment and two classes receiving the traditional laboratory format during the Fall and beginning of Spring semesters. The most recent registration data for students enrolled in
10th grade for school year 2016-17 indicate that 50% of students were female as of August 2016.

Chemistry is a standard course in a 10th grader’s schedule within the district of study. Chemistry satisfies both the California State high-school graduation requirement as one year of physical science. There are some students who opt out of chemistry in order to enroll in physics or environmental science during their 10th grade. The number of students who opt out is small and represents less than one percent of the 10th-grade class who do not enroll in chemistry. General Chemistry courses studied were not entirely representative of the school’s demographic make-up as seen in Table 2. The school’s ethnic breakdown includes 40% Asian American, 32% European American, 17% Hispanic or Latino American, 2% Filipino American, and 1% African American. There are a disproportionate number of African American and Hispanic students in the General Chemistry classes studied as compared with the school’s demographics. There are fewer

Table 2

<table>
<thead>
<tr>
<th>Frequency and Percentage of Gender and Ethnicity for Sample</th>
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<td>Variable</td>
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</tr>
<tr>
<td>Gender</td>
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<tr>
<td>Male</td>
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<td>Female</td>
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<tr>
<td>Ethnicity</td>
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<tr>
<td></td>
</tr>
<tr>
<td>African American</td>
</tr>
<tr>
<td>Asian American</td>
</tr>
<tr>
<td>European American</td>
</tr>
<tr>
<td>Hispanic American</td>
</tr>
<tr>
<td>Filipino American</td>
</tr>
</tbody>
</table>

Asian American and European American students in the classes studied than the school’s demographics represent. The school where the study was conducted also has 16%
socioeconomically disadvantaged as determined by the Federal Free and Reduced Lunch Program, 8% Special Education, and 7% English language learners. Additionally, the gender breakdown of the classes study is not representative of the overall percentage of males and females in the school with the school having an overall split of 50% males and 50% females.

The school is situated in an economically and ethnically diverse community with students coming from communities in Silicon Valley that is situated in Northern California. There is a large technology industry surrounding the school that attracts families from around the globe. Many of the families who move to the neighboring areas of this school are English language learners. Thus, a chemistry-sheltered course is offered at the school for these students and was not included in the study due to compounding variables with a writing-to-learn framework.

 Traditionally, all 10th-grade students matriculate within the same school from Biology as their ninth-grade science course. All students in their ninth grade of study are enrolled in Biology and a ninth-grade-only Literature and Writing course. Prior to enrollment in this high school, the students matriculate from one of two local feeder middle schools. Both schools have transitioned over to the Common Core State Standards (CCSS) and are working on implementing the Next Generation of Science Standards (NGSS). These sample details are important to note in order to reduce confounding variables that may influence the preparation of the students.

The students enrolled in General Chemistry are scheduled in their course of study by self-selection. The school and district have an open-enrollment policy that allows students to decide which courses they would like to take based on the graduation
requirements and college-admission course offerings. The sample is not randomized due to this self-selection into courses as well as other constraints within the master schedule. Students are enrolled in courses predominantly at random by the Infinite Campus data warehouse manager through the scheduling mode. There are some constraints in scheduling that prevent a completely random schedule (e.g., all marching-band students meet first and second period for band and physical education), but the majority of students are placed in classes at random due to multiple sections being offered throughout the day for 10th-grade courses.

**Participating Teachers**

The study included two participating chemistry teachers who served as both the panel of experts in test development and served as the practitioners conducting the classroom laboratory treatments. Each of the teachers is credentialed to teach chemistry at the secondary-education level. Teacher A has been teaching 11 years at the school and 12 years in the district, teaches General Chemistry, and has taught Honors Chemistry in the past. Teacher B has taught for 10 years at the school and in the district and teaches both General Chemistry and Biology. Both teachers are English-speaking, although English is the second language for Teacher A.

**Protection of Human Subjects**

In accordance with Standard 8: Research and Publication (American Psychological Association, 2012) and the University of San Francisco Institutional Review Board for the Protection of Human Subjects, all information obtained during the course of this study remained confidential and only group scores and means are reported in the data analysis. Informed consent is constituted as follows: parents were notified in
writing from the principal about data being collected during this study and their parental right to have their student opt-out of the study without academic penalty. The letter notifying parents of this research study was sent home early Fall 2016 with 2 weeks prior to the pretest administration. The researcher visited each class at the end of the study to inform students about their rights to opt-out, and the data for two students who opted out were not used for the study. Confidentiality of each student’s data was maintained with each student being identified throughout the data-collection procedures by their unique student identification number. See Appendix B for the parent letter sent home notifying them about the data collection. The parent letter was translated into Chinese and Spanish. Parents, students, and teachers were given access to the results at the end of the study without identifying any students’ individual data. Letters summarizing the results of the study were translated into Spanish and Mandarin prior to being sent to families.

Student scores on the pretest and posttest remained private between the student and instructor without providing the researcher names of student-data files. All student data were recorded by a unique student identification number given to them. Each quiz, laboratory, or test score was recorded electronically through an electronic grading system named GradeCam. These data were sent in an Excel® file to the researcher for data-collection purposes, and all assignments were then given back to the students for their own use. The student perceptions’ questionnaire data were given to instructors after the unit of study had concluded as summary scores on Likert-type scale items. Permission to conduct the study was secured from district leadership before beginning the research investigation.

Instrumentation
This section includes the development of the pretest for the 10-item chemistry baseline knowledge quiz, the laboratory rubric for the SWH, the posttest CA, the posttest WA, and the questionnaire of student perceptions. Each of these instruments were assessed for validity evidence through expert panels and have been developed following the conventions of appropriate test construction. Cronbach’s coefficient alpha for reliability was computed to assess internal consistency.

The expert panel consisted of four chemistry teachers at the school of study. Teacher A and Teacher B were the teachers administering the study content; Teacher C and Teacher D are current chemistry teachers and both teach Honors Chemistry. Teacher C has been a chemistry teacher at the school of study for 19 years. Teacher D is in his first year of teaching at the school of study and has taught previously in several other institutions amounting to 7 years of teaching science. These four teachers represent the expert panel referenced in instrumentation development.

**Pretest**

The chemistry content on the pretest assessment was selected based on the General-Chemistry-course-content sequence. The questions were extracted from the California Standardized Test (CST) exams over several years of test administrations. The last CST exam was administered Spring of 2013 as a state-wide standardized assessment. These exams were replaced subsequently by the California Assessment of Student Performance and Progress exam, which to date has not yet embedded science assessments.

The content of the 10-question assessment includes the following concepts essential to the understanding of first-semester General Chemistry: investigation and
experimentation (CST CHIE1.K), atomic and molecular structure (CST CH1.A), nuclear processes (CST CH11.A), chemical bonds (CST CH2.A, CH2.B, CH2.C), acids and bases (CST CH5.A), and conservation of matter and stoichiometry (CST CH3.A). These questions have been analyzed for their reliability during test development prior to the proposed research as seen in Table 3.

Table 3

<table>
<thead>
<tr>
<th>Item #</th>
<th>CST Standard</th>
<th>Year Released</th>
<th>Cronbach Coefficient Alpha</th>
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<tbody>
<tr>
<td>1</td>
<td>CH2.B</td>
<td>2005</td>
<td>.90</td>
</tr>
<tr>
<td>2</td>
<td>CH11.A</td>
<td>2005</td>
<td>.90</td>
</tr>
<tr>
<td>3</td>
<td>CH1.A</td>
<td>2007</td>
<td>.89</td>
</tr>
<tr>
<td>4</td>
<td>CHIE1.K</td>
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<td>NA</td>
</tr>
<tr>
<td>5</td>
<td>CH2.C</td>
<td>2004</td>
<td>.90</td>
</tr>
<tr>
<td>6</td>
<td>CH5.A</td>
<td>2006</td>
<td>.90</td>
</tr>
<tr>
<td>7</td>
<td>CH2.A</td>
<td>2006</td>
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</tr>
<tr>
<td>10</td>
<td>CH1.A</td>
<td>2007</td>
<td>.89</td>
</tr>
</tbody>
</table>

Note: Cronbach coefficient alpha is reported by test and not by item for individual questions. Cronbach coefficient alpha for the CST administered in 2003 has not been released.

Additional reliability data were collected by administering the 10-item quiz to a class (n=30) not assigned to the experiment. The validity evidence of this pretest was assessed by an expert panel using a validity rubric (Appendix C). The results of the validity panel exercise did not result in any changes to the assessment. The pretest was scored on a 10-point scale with each correct answer assigned one point. The pretest is multiple choice in format and was graded using the Gradecam® software. The reliability of the pretest was assessed in a pilot class using Cronbach’s coefficient alpha and resulted in a questionable reliability estimate, α=.57 (George & Mallery, 2003).
Laboratory Scoring Rubric

The SWH-laboratory-rubric scores were based on a rubric outlining each section of the laboratory protocol. As seen in Appendix D, the total score possible on the SWH laboratory assignment was 21 points. Each of the seven sections of the laboratory protocol were assigned 3 points each. The seven sections of the rubric included (a) Beginning Questions, (b) Tests and Experiments, (c) Observations, (d) Claims, (e) Evidence, (f) Reflection, and (g) Work Cited. These seven sections were aligned with the laboratory protocol. The laboratory-report scores reflect both content knowledge and writing proficiency in making a scientific claim while using the observable data as evidence. The SWH scoring rubric was developed by an expert panel of chemistry teachers. The rubric was developed to ensure that the study is being implemented with fidelity with the SWH protocols being followed for the treatment group. Interrater reliability was assessed, and a calibration exercise was conducted to ensure common grading practices using the rubric. The degree of agreement was 86% over five rubric-scored laboratory reports, which is an acceptable amount of agreement. Disagreements were handled by discussion between the two teachers grading the laboratories.

Posttest Content Assessment

The posttest content assessment (CA) (Appendix E) was a locally developed examination designed to investigate the science content learned during the laboratory experiments. The final assessment included the CA with 20 multiple-choice questions and was administered after a week following the last laboratory experiment in the study. Each question on the CA is worth one point for a total of 20 points possible.

Reliability data were collected as part of a pilot study prior to the administration
of the CA to students in a class \((n=30)\) not part of the experimental design. The CA was analyzed using the validity rubric (Appendix F) process by the expert panel. Details of the expert panel are reported under Instrumentation. The expert panel suggested several revisions to the CA to align with the content of the classroom teaching, the academic language used in the classroom, and balancing the content of the assessment over the five laboratory content areas. The panel adjusted the content and language in 5 of the 20 questions. A General Chemistry class \((n=30)\) that was not part of the study was administered the CA prior to the end of the study in order to provide ample time for an item analysis and potential corrections. The reliability of the posttest CA was found to be very reliable with a high Cronbach coefficient alpha, \(\alpha=.91\).

**Posttest Writing Assessment**

The posttest writing assessment (WA) (Appendix G) was a locally developed writing prompt. The WA included a writing prompt that required students read the details of a laboratory experiment and then write a claim about the scientific phenomenon using evidence to support their claim. Section four and section five of the SWH laboratory protocol required students to make a claim and support their claim with evidence they observed in the laboratory experiment. The WA followed the same laboratory framework as the SWH laboratory protocol. The WA was scored on a 6-point rubric scale (Appendix I) with 3 points assigned to the claim and 3 points assigned to evidence to support the claim.

Reliability data were collected prior to the administration of the writing assessment to students in a general chemistry class \((n=30)\) not part of the experimental design as part of a pilot study. One general chemistry class was taught the SWH writing
framework as part of a laboratory experiment prior to conducting the pilot so they were familiar with the SWH writing expectations. The pilot study was conducted prior to the end of the study in order to provide ample time for an item analysis and corrections.

Teacher A conducted the reliability pilot in one of his classes not part of the overall study design. The writing assessment was analyzed by the expert panel using the validity rubric (Appendix H) process. Details of the expert panel are reported under Instrumentation.

The expert panel suggested revising the language used in the prompt to more closely align with the language used in the laboratory writing prompts. The reliability of the writing assessment was $\alpha = .69$, which is poor.

**Student-Perceptions Questionnaire**

The student-perceptions questionnaire was constructed by the researcher based on a literature review of previous research that included questionnaires conducted around student perceptions of writing (Appendix K). The questionnaire was developed through the protocols for scholarly questionnaire writing (Fowler, 2013) and included the following steps in order to ensure reliability and validity. First, a panel of experts in the field of high-school science was convened in Spring 2014 to develop items regarding student perceptions of writing in science that would be useful for practitioners. This expert panel were not all the same teachers as the expert panel that assessed validity in this study. The expert panel from 2014 included a teacher who is no longer at the school who had 20 years of teaching experience, a teacher who is on leave and taught 15 years in biology and chemistry, as well as Teacher C from this study’s expert panel. Second, the validity evidence of the Likert-type scale items was assessed by an expert panel of high-school science educators using a rubric (Appendix J). Details of the expert panel are
reported under Instrumentation. The expert validity panel suggested moving the negatively worded item away from another question in order to add clarity in the overall flow of the questionnaire. The expert panel also suggested a revision to the language in the last question asking about the effect of laboratories on their final assessment. Third, this questionnaire was assessed for reliability prior to its implementation by administering it to the General Chemistry pilot class \((n=30)\) that did not participate in the experimental design.

A pilot study was conducted on the student questionnaire in the Fall of 2016 following a WTL assignment in a science course \((n=30)\). Cronbach coefficient alpha was computed for the SWH questionnaire and resulted in a questionable reliability rating, \(\alpha=.50\). Cronbach coefficient alpha also was computed for the traditional laboratory questionnaire and also resulted in questionable reliability, \(\alpha=.54\). Adjustments were made to the questionnaire tool based on this pilot and the validity panel of experts recommendations. The validity panel of experts were reported on under Instrumentation. Items were adjusted to reflect clarity of the question and align language more closely to terminology regularly used in the classrooms of each teacher.

The questionnaire was developed with argumentative writing as the specific Writing-to-Learn (WTL) strategy in mind as it was already a method of writing instruction embedded into the host school’s science classes. Upon further discussion with the expert panel, alterations to the proposed questionnaire included the following: (a) Change the WTL mode of instruction from “argumentative writing” to “Science Writing Heuristic,” (b) data collection were done electronically through a Google® Form, and (c) data for the pilot study were collected in a chemistry course instead of administering the
questionnaire to another science course (e.g., Biology, Environmental Science, or Physiology). The final questionnaires administered to each group are found in Appendix L.

Research was conducted regarding the effects of WTL as previously detailed in Chapter II. There has been additional research that indicated an increase in student attitudes toward writing as a means for learning (Brown, Morrell, & Rowlands, 2011; Cumberworth & Hunt, 1998). Research also has been completed regarding the effects that writing interventions and training has on students’ attitudes toward writing, motivation to write, and confidence in their writing ability (Cuevas, 1995; Gomer, 1992). These studies show that with structured writing interventions, there are positive gains in student attitudes toward writing. Each of these studies used an instrument to assess the pre- and postintervention perceptions of students’ attitudes toward WTL assignments. These instruments were not generalized to all learning environments and, therefore, were not appropriate for reuse in this current study.

As seen in Table 3, the first 10 questions of the questionnaire included response choices based on a 4-point Likert-type scale. The following response guide was provided to the students on the questionnaire: 1 = Not at all true, 2 = A little true, 3 = Somewhat true, and 4 = Very true. One item is worded negatively and was reverse coded prior to data analysis.

There were three components of the questionnaire: (a) chemistry students’ perceptions of the importance of WTL assignments and their understanding of chemistry, (b) chemistry students’ attitudes toward WTL assignments, and (c) the extent that chemistry students perceived writing as a method of helping them make deeper curricular
connections. For the first component, questions 1, 4, 7, and 10 were combined during data analyses to represent chemistry students' perceptions of the importance of WTL assignments and their understanding of chemistry. Means were computed after items were combined so that all subscales were on the same scale, ranging from 1 to 4.

Table 4

<table>
<thead>
<tr>
<th>Question</th>
<th>Component</th>
<th>Laboratory</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. I understood how to complete the laboratory assignments assigned in this class.</td>
<td>a</td>
<td>SWH Traditional</td>
</tr>
<tr>
<td>2. I tried my best on the laboratory assignments.</td>
<td>b</td>
<td>SWH Traditional</td>
</tr>
<tr>
<td>3. I have completed every portion of the laboratory assignments in this class.</td>
<td>b</td>
<td>SWH Traditional</td>
</tr>
<tr>
<td>4. The laboratory writing assignments helped me understand chemistry better.</td>
<td>a</td>
<td>SWH Traditional</td>
</tr>
<tr>
<td>5. The laboratory assignments were not useful for helping me learn chemistry.</td>
<td>c</td>
<td>SWH Traditional</td>
</tr>
<tr>
<td>6. While writing the laboratory response, I had to think critically about chemistry.</td>
<td>c</td>
<td>SWH Traditional</td>
</tr>
<tr>
<td>7. The SWH laboratory write-up helped me learn the information better than traditional lab write-ups we do in this class.</td>
<td></td>
<td>SWH</td>
</tr>
<tr>
<td>8. The SWH laboratory write-ups were just as effective in helping me learn as traditional labs we complete in this class.</td>
<td></td>
<td>SWH</td>
</tr>
<tr>
<td>9. The SWH write-ups took me longer, on average, to complete than the traditional labs we complete in this class.</td>
<td></td>
<td>SWH</td>
</tr>
<tr>
<td>10. The laboratory write-ups helped me prepare for the chemistry laboratory assessment.</td>
<td>a</td>
<td>SWH Traditional</td>
</tr>
</tbody>
</table>

Questions 2, 3, 8, and 9 were combined to investigate the questionnaire component of chemistry students’ attitudes toward WTL assignments with scores ranging from 4 to 16 for the SWH group. Scores ranged from 2 to 8 for the comparison group when statement 8 and 9 are removed. Means were computed after items were combined so that all subscales were on the same scale, ranging from 1 to 4. For the third
component, questions 5 and 6 were combined to analyze the extent that chemistry students perceive writing as a method of helping them make deeper curricular connections. Means were computed for each of the subscales in order for the subscales to be on the same scale as the items responses, ranging from 1 to 4.

Question 7, 8, and 9 were removed when administered to the comparison-group classes as these questions are specific to the SWH group. The questionnaire included descriptive questions: gender, ethnicity, grade unique student identifier number, and whether English is the first language of the responder. The questionnaire results were analyzed for between-group differences.

**Teacher Interview**

Following the pretest, treatment, and student assessments, a teacher interview was conducted to learn about the experience of using the SWH in a chemistry classroom from the teacher’s perspective. The interview was focused on teacher facilitation of the SWH laboratory framework, grading practices associated with this format, and student work associated with this model. Additionally, the interview focused on the context of a chemistry classroom as the learning space for this treatment and its effectiveness from the teachers’ perspective.

**Treatment**

Treatment conditions were assigned randomly within participating teacher sections, and students were assigned randomly to a class period through master scheduling at the beginning of each school year. The two chemistry teachers were trained on the SWH model laboratory report writing and agreed-upon comparison group using a traditional scientific laboratory write-up. A standard PowerPoint® presentation was
created (Appendix M) and was used across both treatment sections for the SWH treatment so that instruction was aligned across classrooms using the SWH model. Both teachers were trained on how to use the PowerPoint® presentation in order to provide common language in order to prompt student input into the SWH experiment development. The SWH laboratory treatment included a prereading section on the science content of the laboratory. The students are then asked to develop experimental questions in partner groups, share them with a laboratory group, and then share with the class. The class agreed upon an experimental question that tests the science content of the prereading.

Every effort was made to reduce the confounding variable of teaching style by dividing treatment and comparison groups within each teacher’s schedule. Teacher A taught Treatment 1 and Comparison 1, whereas Teacher B taught Treatment 2 and Comparison 2. The comparison group was taught using the traditional laboratory write-up and was assigned to their other two General Chemistry sections. On average, there are 32.5 students in each class based on teacher contractual limits. Teachers began laboratory treatments during the 11th week of instruction and completed the curriculum by the 26th week of instruction. The final assessment took place during the 27th week of instruction.

**Treatment Design**

The Science Writing Heuristic treatment is a laboratory format that combines inquiry and collaborative learning in a writing-to-learn format. The SWH format provided a guided-inquiry approach to experimental design, discussions, student-thinking, and writing to connect prior knowledge to laboratory activities. The laboratory included beginning questions, claims, and evidence and final reflections (Burke et al.,
2006). Students made a claim about the scientific phenomenon they observed and provided evidence to support their claim.

As seen in Table 1 (Appendix A), the laboratory report was structured to elicit the co-construction of knowledge within a collaborative group based on the guided questions. The students were paired initially with a partner following the prereading activity to develop an experimental question to test the scientific phenomenon that they read about at the beginning of the laboratory. The partner groups then shared their questions with a larger teacher-assigned laboratory group of four total students. After agreeing upon one question for the laboratory group, the question was then shared with the entire class. The class then determined the best question to answer collectively based on their reading. Once the experimental question was developed, the laboratory groups then went through a similar process in order to develop the safety considerations for the laboratory experiment as well as the methodology. Once the experiment concluded, then the students were asked to make claims based on evidence (e.g., observable data) that they recorded during the experiment.

*Treatment Procedures*

Two weeks prior to the study commencing, parent notifications were sent home with a passive consent model indicating that their student was assigned randomly to a treatment- or comparison-group condition. These notifications made clear that the science content is not altered; however, the method of processing the information is the intended nature of the research and would be different for each group. Following parent notifications, the pretest was administered in each of the four classrooms to assess prior knowledge of chemistry.
Following the pretest, the students received common lessons throughout the semester on general chemistry content. There were five laboratory experiments during the first semester of general chemistry titled as follows: Flame Test Lab, Mole Lab, Periodic Properties Lab, Chemical Reactions #1, and Chemical Reactions #2. Prior to each laboratory experiment, all sections received a laboratory prereading activity. An example of the common laboratory prereading assignment can be seen in Appendix N. The laboratory write-up was different for each class session depending on the random assignment as seen in Appendix N for the SWH and Appendix O for the traditional laboratory write-up. The treatment condition used the SWH laboratory write-up that included a teacher-led discussion modeling thinking of each of the SWH prompts due to the novelty of this write-up. This lesson was common across each of the treatment-condition classrooms as it was developed by the researcher in conjunction with the chemistry teachers. The comparison group was given a traditional laboratory write-up that includes the commonly accepted scientific-method prompts (Appendix A). The researcher visited each laboratory session across the four sections to ensure that the SWH laboratory treatment was being taught solely using the SWH protocols for the treatment group and the traditional laboratory protocols for the comparison group.

Table 5

| Name of Laboratory and Time of Instruction for Each Laboratory Session |
|---------------------------------------------------------------|----------------------|
| Laboratory Name                                             | Instructional Time Prior to Laboratory (weeks) |
| Flame Test                                                   | 2                    |
| Mole                                                         | 4                    |
| Periodic Properties                                          | 3                    |
| Chemical Reactions #1                                        | 4                    |
| Chemical Reactions #2                                        | 3                    |
Each laboratory session was embedded within a unit of study associated with the content being learned in each chemistry class. The treatment group and comparison group received equivalent instruction time and content preceding the laboratory work. Table 5 outlines the amount of instructional time leading up to each laboratory session.

**Data Collection**

As seen in Figure 3, a pretest was administered to assess prior knowledge before instruction begins in the chemistry courses. The means of each class were calculated in order to investigate any between-group differences. Using a one-way analysis of variance, there were no differences in means between four classes, which meant that the two experimental and two comparison classes could be combined, respectively.

There were 130 students total in the study from four chemistry classes. There are six overall class sections of General Chemistry, but only four were included in the study. One teacher instructed two General Chemistry courses, whereas the other teacher instructed four General Chemistry courses. In order to balance the number of students in each treatment group, an equal number of class sections for each chemistry course was included in the study. Therefore, four General Chemistry class sections were selected at random to participate in the study with each teacher having had at least two class sections participating. Within each teacher’s course sections, two of their chemistry classes were assigned randomly to the SWH or traditional laboratory write-up treatment with each teacher having one section assigned randomly to the SWH, whereas another section in their schedule was assigned to the traditional laboratory.

During the study, the SWH laboratory format included a writing component as part of the write up. These writing components were collected to identify learning over
time and to validate the content of the treatment-group laboratory protocol. These writing scores were assessed on a 21-point rubric scale.

A locally generated posttest was administered a week after the conclusion of the treatment as the final laboratory examination. The final laboratory examination included both a posttest CA and the posttest WA. The scores were computed and reported separately. For the WA, the laboratory writing instructions was provided from the SWH and scored using a rubric. The laboratory description was included as a prompt for the students, and they were asked to make a claim and provide evidence for their claim as the WA. The WA included Section 4 (Claims) and Section 5 (Evidence) of the laboratory protocol for a total of 6 points based on the SWH laboratory rubric. The CA included 20 questions pertaining to content learned in the laboratories as part of this study. The CA questions were multiple choice and were scored as one point per question for a total of 20 points.

Finally, a student-perceptions questionnaire was administered following the posttest to gauge student-perceptions of the laboratory treatments as a method for learning chemistry content. The student-perceptions questionnaire was administered in the same class session as the content assessment. Laptop computers were set up in the classroom for students to complete the questionnaire through Google® Forms once they had completed their final laboratory examination during the extended-finals class period. T2 had a low student response rate (n=11) due to a delay in them receiving the questionnaire to their student e-mail accounts.

**Fidelity of Treatment Implementation**

The treatment instructors completed implementation logs and also participated in
an interview following the research in order to assess implementation fidelity and ease of treatment use. The implementation logs indicated a few setbacks with regard to implementing the treatment that were out of the instructors’ control. With five laboratory sessions being conducted over 5 months there is inherently student movement due to transient families, course-level changes in a student’s scheduled, and program status changes (e.g., qualifying for Special Education). The following terms are used to reference the two treatment classes: Class T1 and Class T2, whereas the comparison classes are referred to as Class C1 and Class C2. Class T1 had two students disenroll and added one student to the roster. One student disenrolled from high school, of the two students who disenrolled from T1, whereas the other student disenrolled from the class after satisfying his physical science credits for high-school graduation. Class T2 had three students disenroll and no additions; all three students from T2 disenrolled from the school to move to another public high school. Class C1 experienced no changes to the roster during the course of the study. Class C2 had two students disenroll from the course and added three students during the time of the study. One student disenrolled from the school and moved to another public high school, whereas the other student disenrolled from the course at the end of the first semester because he had earned enough science credits toward graduation. Each of the additions to the rosters were due to newly enrolled students to the school. The data associated with each of the disenrolled students were not used in the analysis as they are not comparable with the students who were present for the entirety of the treatment. The data for the students who were added in the middle of the study were not used because they were not informed properly about the study when they were added to the course and they were not comparable with the students who were
present for the entirety of the treatment.

There were inconsistencies in the implementation of the treatment with regard to the Science Writing Heuristic beginning questions. The beginning questions should have been co-developed by the students and the overall class group as part of the collaborative student laboratory experience. The instructor for class T1 did not establish this process with fidelity, and the beginning questions were only negotiated between partners and not as a class discussion. This adjustment to the laboratory process may have had an effect on the results of the student assessments and overall laboratory scores.

Additionally, there were limitations in treatment fidelity with regard to the student-perceptions questionnaire. Data are limited from T2 due to an error in implementation of the questionnaire to this class. The limited data from this class may have had an effect on the outcome of the data analyses.

**Data Analyses**

The mean differences in pretest scores were assessed by a one-way analysis of variance (ANOVA) for the four groups (two sections of SWH, two sections of traditional) using the .05 level of significance. As seen in Table 6, the one-way ANOVA of the four class means indicated that there were no statistically significant differences in the class means on the pretest $F(3,129)=0.76$. The classes were subsequently combined into two groups for data-analysis purposes — treatment ($M=12.35$, $SD=3.42$) and comparison ($M=11.36$, $SD=4.29$) — and an independent-samples $t$ test on the posttest of the content assessment was used to address research question 1.

For research question 2, a comparison was made between the scores on the WA for the two groups using an independent-samples $t$ test. Laboratory scores for the
treatment group were analyzed for research question 3 to assess the extent to which there were any differences across the laboratory experiments using a repeated measures analysis of variance. If statistical significance was found in the data analyses, then effect sizes were calculated using Cohen’s $d$.

Table 6

<table>
<thead>
<tr>
<th>Class</th>
<th>Sample Size</th>
<th>Mean</th>
<th>SD</th>
<th>df</th>
<th>$F$</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>30</td>
<td>5.00</td>
<td>1.88</td>
<td>3</td>
<td>0.76</td>
</tr>
<tr>
<td>T2</td>
<td>33</td>
<td>5.03</td>
<td>2.46</td>
<td>126</td>
<td></td>
</tr>
<tr>
<td>C1</td>
<td>35</td>
<td>4.60</td>
<td>1.68</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C2</td>
<td>32</td>
<td>4.41</td>
<td>1.99</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Note: Cronbach’s $\alpha=.57*$

In order to address research question number 4, data analyses were conducted on the Likert-type-scale questions. There were seven questions in common between the questionnaire administered to the SWH treatment group and comparison group. These seven questions made up three overarching components of the comparison-group questionnaire. All 10 questions made up the three overarching components of the treatment group questionnaire. An independent-samples $t$ test was conducted on the three components of the questionnaire.
CHAPTER IV
RESULy

The purpose of this study was to examine the effectiveness of a writing framework in high-school science in order to help inform the best practices for developing scientific literacy and learning science content through writing. This chapter includes the results of the prescribed treatment and quasi-experimental design with the Science Writing Heuristic and traditional laboratory implementation over the course of 5 months and five laboratory sessions. Additionally, this chapter includes six sections describing the results of the study: descriptive statistics, an analysis of the four research questions, and a summary of the findings. The means and standard deviations for the pretest, laboratory treatments, posttest writing-assessment scores, posttest content-assessment scores, and student-perceptions questionnaire with Likert-scale items are reported. The results of the statistical analyses are presented within the context of the research questions.

Descriptive Statistics

As seen in Table 6 (Chapter III), the pretest means were higher in the treatment group than the comparison group but did not have a statistically significant difference. The five laboratory scores (Table 7) included the following laboratory science writing heuristic (SWH) sessions: Flame Test Laboratory, Mole Laboratory, Periodic Properties Laboratory, Chemical Reactions I Laboratory, and Chemical Reactions II Laboratory. The scores for the Mole Laboratory were lower, on average, than the remaining laboratories and because it was the second laboratory conducted it then eliminated the possibility for an increase in scores over time. The laboratory means did not have a
consistent upward trend over the five laboratory reports. The first laboratory mean, the Flame Lab, had the highest mean out of all five laboratory reports. The second laboratory, the Mole Lab, had the lowest means of all five laboratory reports. The mean in the treatment group was higher than those of the comparison group on the posttest content assessment. The mean also was higher in the treatment group than those in the comparison group on the posttest written assessment.

Table 7

Means, Standard Deviations, and Independent Samples t-test Results for all Assessments and Laboratory Measures for the Treatment and Comparison Groups

<table>
<thead>
<tr>
<th>Variable</th>
<th>Treatment (n=63)</th>
<th>Comparison (n=67)</th>
<th>t (df=130)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
<td>M</td>
</tr>
<tr>
<td>Flame Lab</td>
<td>18.75</td>
<td>1.71</td>
<td>17.46</td>
</tr>
<tr>
<td>Mole Lab</td>
<td>18.38</td>
<td>2.64</td>
<td>18.68</td>
</tr>
<tr>
<td>Periodic Properties Lab</td>
<td>17.70</td>
<td>2.25</td>
<td>17.70</td>
</tr>
<tr>
<td>Chemical Reactions I</td>
<td>7.36</td>
<td>1.02</td>
<td>7.21</td>
</tr>
<tr>
<td>Chemical Reactions II</td>
<td>12.44</td>
<td>3.50</td>
<td>11.25</td>
</tr>
</tbody>
</table>

Note: Range of scores for laboratories were 1-20. Range of scores for the WA were 1-9. Range of scores for the CA were 1-20.

Analyses for Research Questions

The pretest means were analyzed using a one-way analysis of variance (ANOVA) to investigate any between-group mean differences. The results of the ANOVA were not statistically significant in terms of between-group differences so the two treatment groups and two comparison groups were combined for subsequent data analyses. The first two research questions were analyzed using an independent-samples t test. The third research question was analyzed using a dependent-sample t test in order to assess whether there were changes over multiple measures. A repeated measures ANOVA was the planned statistical test, however; the distributions, for the laboratory data were skewed. Finally,
the fourth research question was addressed by comparing means on Likert-scale item components from the student perceptions questionnaire. At the time of the pretest administration, there were 71 students enrolled in class T1 and T2 combined. There were 67 students enrolled in the comparison classes, C1 and C2. Given that each sample size was greater than 30, the Central Limit Theorem applies and the assumption of a normal distribution for each of the variables is robust with respect to the violation.

Prior to conducting the statistical tests, the assumption of homogeneity of variance and the normally distributed sampling distribution were investigated (Field, 2009). The pretest, the posttest WA, and the student perceptions questionnaire components and three additional questions on the SWH questionnaire were all robust with respect to the violation. Levene’s test for equality of variances was found to be violated for the posttest CA independent-samples t test, \( F(1,128)=4.24 \), so the Welch-Aspin test was used.

**Research Question 1**

*To what extent is there a difference between SWH and traditional laboratory groups’ scores on the posttest of content assessment?*

The posttest assessment was analyzed based on the students who were enrolled in the class at the time of both the pretest and the posttest assessments, which included 63 students in the treatment group and 67 students in the comparison group. An independent-samples t test was conducted between the means for the treatment group and the comparison group on the 20-item multiple-choice posttest. A graph of the difference between the two groups is found in Figure 4. The results of the independent-samples t test indicated that there was no statistically significant difference between the treatment- and
comparison-group content-assessment posttest scores (Table 7).

**Research Question 2**

*To what extent is there a difference between SWH and traditional laboratory groups’ scores on the posttest of a writing assessment?*

![Boxplot of posttest Content Assessment (CA) scores between treatment and comparison groups.](image)

*Figure 4.* Boxplot of posttest Content Assessment (CA) scores between treatment and comparison groups.

The posttest writing assessment was analyzed based on the 63 students in the treatment group and 67 students in the comparison group. An independent-samples *t* test was conducted between the means for the treatment and comparison group on the rubric-scored 9-point writing assessment. The results of the independent-samples *t* test indicated no statistically significant difference in means between the treatment and comparison groups (Table 7). A graph of the difference between the two groups is found in Figure 5.

**Research Question 3**
To what extent are there differences in student scores on the SWH laboratory protocol over five laboratory experiments?

Figure 5. Boxplot of posttest Written Assessment (WA) scores between treatment and comparison groups.

Due to skewed distributions of the laboratory scores, the assumption of equal variances and covariances and multivariate normality were violated. Therefore, dependent-samples $t$ tests were conducted between the five SWH laboratory reports collected from the treatment group.

Ten paired-samples $t$ tests were used to make planned pairwise comparisons between the laboratory scores. If there was change over time, then the pairwise comparisons would have resulted in a statistically significant difference for each pairing in a positive direction. As seen in Table 8, the first paired-samples $t$ test indicated that there was a statistically significant difference in means between the Mole Laboratory and the Flame Test Laboratory, Cohen’s $d=0.41$, with the Mole Laboratory scores being
lower (Table 8), which is a small to medium effect size. Pair 5 resulted in a statistically significant difference between the Periodic Properties Laboratory and the Mole Laboratory, Cohen’s $d=-0.40$, with the Mole Laboratory scores being lower on average (Table 8), which is a small to medium effect size. Pair 6 indicated a statistically significant difference between the Chemical Reactions I Laboratory and the Mole Laboratory, Cohen’s $d=0.52$, with the Mole Laboratory scores being lower on average (Table 8), which is a medium effect size. Last, pair 10 resulted in a statistically significant difference in means between the Chemical Reactions I Laboratory and the Chemical Reactions II Laboratory, Cohen’s $d=0.36$, with the Chemical Reactions I Laboratory scores being higher (Table 8), on average, which is a small to medium effect size. Finally, there was a statistically significant difference in means between the Flame Test Laboratory and Chemical Reactions II, Cohen’s $d=0.41$. All other pairwise comparisons were not statistically significant.

<table>
<thead>
<tr>
<th>Lab Report</th>
<th>Mole</th>
<th>Periodic Prop</th>
<th>CR1</th>
<th>CR2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flame Test</td>
<td>-1.23*</td>
<td>-0.10</td>
<td>0.08</td>
<td>-0.68*</td>
</tr>
<tr>
<td>Mole</td>
<td>1.13*</td>
<td>1.31*</td>
<td>0.55</td>
<td></td>
</tr>
<tr>
<td>Periodic Prop</td>
<td>0.18</td>
<td>-0.58</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CR1</td>
<td></td>
<td></td>
<td></td>
<td>-0.80*</td>
</tr>
</tbody>
</table>

*Statistically significant at the .05 level

**Research Question 4**

*Was there a statistically significant difference in student perceptions of the usefulness of the SWH laboratory report and student perceptions of the usefulness of the traditional laboratory report?*

As seen in Table 9, the descriptive statistics of the student-perceptions
questionnaire for the treatment and comparison group are reported. The data reported in these tables include question 7 with reverse coding. Question 7 was reverse coded for data-analysis purposes as it was originally a negatively-worded questionnaire question.

There were seven items that made-up the components of the questionnaire. As seen in Table 3, the component scales were derived from seven questions that were consistent between the treatment and comparison questionnaire. The component scale means were computed by combining the individual questionnaire items and then dividing them based on the number of questions in which the component was comprised. The Likert-scale items were all ranked on a 1-point through 4-point value based on student responses. The closer the score is to 4 points, the more positive the students reported being about writing activities in their chemistry class.

Table 9

*Means, Standard Deviations, and Independent-Samples t-Test Results for Treatment- and Comparison-Group Student-Perception Questionnaire*

<table>
<thead>
<tr>
<th>Questionnaire Component</th>
<th>Treatment (n=41)</th>
<th>Comparison (n=61)</th>
<th>t (df=100)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemistry students' perceptions of the importance of WTL assignments and their understanding of chemistry.</td>
<td>3.06 .46</td>
<td>2.95 .64</td>
<td>0.92</td>
</tr>
<tr>
<td>Chemistry students’ attitudes toward WTL assignments.</td>
<td>3.45 .62</td>
<td>3.56 .52</td>
<td>-1.01</td>
</tr>
<tr>
<td>The extent that chemistry students perceive writing as a method of helping them make deeper curricular connections.</td>
<td>2.50 .61</td>
<td>3.15 .54</td>
<td>-5.65*</td>
</tr>
</tbody>
</table>

*Statistically significant at .05 level

The mean component was higher for the treatment group for the first component referring to students’ perceptions of the importance of writing-to-learn (WTL).
assignments and understanding chemistry but was not statistically significant. The second two components, students attitudes toward WTL assignments and the extent that students perceive writing as a means of making deeper curricular connections, resulted in higher means for the comparison group indicating that they were more positive, on average, toward WTL than the treatment group with the third component being statistically significant.

Independent-samples t tests were conducted in order to investigate any between-group differences on the questionnaire components. As seen in Table 8, there was a statistically significant difference in means between treatment and comparison groups on component 3, indicating that the comparison group perceives writing as a method of helping them make deeper curricular connections than the treatment group, Cohen’s $d=-1.00$. The effect size for the difference between the groups is large.

There were three additional questions unique to the SWH student-perceptions questionnaire. As seen in Table 10, question 8 on the SWH student perceptions questionnaire indicated that a majority of students (71%) reported that the SWH laboratory write-ups were just as effective as the traditional laboratory write-ups as indicated by their selection of “a little true” and “somewhat true” on the Likert-scale items. Question 9 results indicated that

Table 10

| SWH Student-Perceptions Questionnaire Questions 8 to 10 Frequencies (n=41) |
|-------------------|-----------------|-----------------|-----------------|-----------------|
| Question | Not at all true | A little true  | Somewhat true  | Very true       |
| 8       | 4 (10)           | 14 (34)         | 15 (37)         | 8 (19)          |
| 9       | 6 (15)           | 7 (17)          | 12 (29)         | 16 (39)         |
| 10      | 9 (22)           | 12 (29)         | 14 (34)         | 6 (15)          |

Note: Values outside the parentheses indicate frequency of item selected by students and the number inside the parentheses is the percent.
68% of students reported that the SWH laboratory write-ups took longer on average than the traditional laboratory write-ups. Question 10 results indicated that 63% of students reported that the SWH laboratory write-ups helped them prepare for the laboratory examination (posttest CA and WA).

![Boxplot of treatment group and comparison group component 3 responses on student questionnaire.](image)

*Figure 6.* Boxplot of treatment group and comparison group component 3 responses on student questionnaire.

**Teacher Interviews**

Both teachers were interviewed to assess their perception of the usefulness of the SWH laboratory format for general chemistry. Teacher A reported the laboratory format to be challenging for his students when developing the guiding question together in both the laboratory groups and whole-class discussion. He indicated that his “students did not know enough chemistry in order to develop these questions.” He also suggested that the SWH laboratory format paired better with some laboratory content than others favoring
the lower-level chemistry-content laboratories. Teacher A also acknowledged that should he be facilitating the SWH laboratory format again, he would be more comfortable doing so with the additional experience and would likely implement with higher fidelity.

Teacher B reported that he found value in the SWH laboratory format and that he would like to adjust some of his current laboratory practices to embed elements of the SWH format. He found the student-collaborative experience positive when discussing the guiding questions, and although it was challenging to narrow down eight group questions to one class question, he found the process to build more engagement from the students. He also noticed that this collaborative process leveled everyone’s understanding of the content and put all students in the same starting place with content knowledge. Teacher B also indicated that the SWH laboratory format took longer, on average, than the traditional laboratory format so he had some pressure to move the students through the content so that he could keep all of his classes on the same schedule. He also found the laboratory format to build a stronger connection to the classroom content than the traditional laboratory format.

Additional Findings

As previously noted, the implementation of the laboratory format was not consistent between chemistry teachers. Teacher A (T1 and C1) did not implement the laboratory procedures with fidelity, whereas Teacher B (T2 and C2) did implement the treatment laboratory procedures as designed. Due to this discrepancy in the research implementation, additional tests were conducted to assess whether there was a difference in posttest CA scores, posttest WA scores, and laboratory scores between the four groups.
As seen in Table 11, T2 and C2 had a higher mean on the posttest CA and the posttest WA than T1 and C1.

The results of a one-way ANOVA indicated that there was a statistically significant difference on the posttest WA scores between groups, $F(3, 126)=4.56$. A post-hoc Tukey honest significant difference (HSD) test was conducted on the WA between-class groups. There was a statistically significant difference between T2 and C1 on posttest WA scores. There was no statistically significant difference between the remaining class groups on the posttest WA. There was no statistically significant difference in CA results between class groups.

### Table 11

<table>
<thead>
<tr>
<th>Group</th>
<th>$n$</th>
<th>Posttest CA</th>
<th>Posttest WA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$M$</td>
<td>$SD$</td>
</tr>
<tr>
<td>T1</td>
<td>30</td>
<td>12.07</td>
<td>3.59</td>
</tr>
<tr>
<td>T2</td>
<td>33</td>
<td>12.79</td>
<td>3.43</td>
</tr>
<tr>
<td>C1</td>
<td>35</td>
<td>10.60</td>
<td>4.45</td>
</tr>
<tr>
<td>C2</td>
<td>32</td>
<td>11.96</td>
<td>4.28</td>
</tr>
</tbody>
</table>

*Note: Cronbach’s α= .91 for the CA, Cronbach’s α=.69 for the WA*

Additional tests were conducted to assess whether there was a statistically significant difference in laboratory scores between groups T1 and T2. As seen in Table 12, the means for T2 were higher than those of the T1 on all five laboratories. An independent-samples $t$ test was conducted between each of the five laboratory means, and there was a statistically significant difference in Chemical Reactions I (CR1) Laboratory scores between T1 and T2, $t(61)=-3.36$ with a large effect size of Cohen’s $d = .84$. This difference in laboratory report performance is seen in Figure 7. Additionally, the independent-samples $t$-test results indicated that there was a statistically significant
difference in means between T1 and T2 on the Chemical Reactions II (CR2) Laboratory, $t(61)=-2.00$ and Cohen’s $d=.50$ which is a medium effect size. As seen in Figure 8, the means on Chemical Reactions II Laboratory were higher in the T2 group than T1. There were no statistically significant differences between treatment groups on the remaining laboratory report scores.

Table 12

<table>
<thead>
<tr>
<th>Laboratory Report</th>
<th>Treatment Group 1 ($n=30$)</th>
<th>Treatment Group 2 ($n=33$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$M$</td>
<td>$SD$</td>
</tr>
<tr>
<td>Flame Test Lab</td>
<td>18.62</td>
<td>2.20</td>
</tr>
<tr>
<td>Mole Lab</td>
<td>17.30</td>
<td>3.40</td>
</tr>
<tr>
<td>Periodic Properties Lab</td>
<td>18.35</td>
<td>2.39</td>
</tr>
<tr>
<td>Chemical Reactions I Lab</td>
<td>17.88</td>
<td>2.62</td>
</tr>
<tr>
<td>Chemical Reactions II Lab</td>
<td>17.47</td>
<td>2.66</td>
</tr>
</tbody>
</table>

Figure 7. Boxplot comparing CRI laboratory mean scores between treatment groups.

An independent-samples $t$ test was conducted on the three components of student-
perceptions questionnaire between treatment classes. There was no statistically significant difference between the classes on the three component scales. A chi-square test of independence was performed to examine the relationship between the two treatment classes and their responses on the SWH student-perceptions questionnaire specific questions. There was no statistically significant difference in responses between the two classes.

Figure 8. Boxplot comparing CRII laboratory means between treatment groups.

Summary

The results of the statistical analyses indicated that the means for the posttest CA and the posttest WA were higher for the treatment group than the comparison group, although there was no statistically significant differences. Due to the data being skewed in the laboratory reports the planned multivariate repeated-measures ANOVA was not
conducted. As a result, a dependent-samples t test was conducted to compare differences between the laboratory report scores. The results indicated that there was a statistically significant difference in 5 out of 10 of the laboratory pairwise comparisons.

The student-perceptions questionnaire included three components and was assessed for statistically significant results between the treatment and comparison group. The results indicated that only component 3 yielded a statistically significant difference between groups with a higher positive response for the comparison group in the context of writing helping students make deeper curricular connections.

Additional tests were conducted to assess any differences between treatment and comparison groups in posttest measures due to a lack of experimental fidelity by one teacher. The results indicated a statistically significant difference in the posttest written assessment scores with Teacher A’s comparison (C1) class scoring lower than Teacher B’s treatment (T2) class. These results are consistent with respect to the treatment fidelity.
CHAPTER V

SUMMARY, LIMITATIONS, DISCUSSION, AND IMPLICATIONS

The purpose of this study was to examine the effectiveness of a writing framework in high-school science in order to help inform the best practices for developing scientific literacy and learning science content through writing. This concluding chapter includes a summary of the study and its purpose, a summary of the findings within the study, the limitations of the research study, and a discussion of the findings. The chapter concludes with implications for research and practice given the limitations of the study’s implementation and design.

Summary of Study

Scientific literacy is a foundational educational skill set developed through inquiry-based laboratory settings (Minner, Levy & Century, 2010). Inquiry-based laboratory settings that incorporate a writing-to-learn (WTL) framework result in students outperforming their peers in understanding science (Demirbag & Gunel, 2014) and, thus, improve their scientific literacy. Scientific literacy, in its simplicity, is defined as the ability of students to identify a scientific problem, collect data to address the problem, and then reason through the data-based supporting evidence (Keys, 1999). This skill set continues to increase in importance as society drives the use of science to make claims, formulate opinions, and develop policies (Autieri, Amirshokoohi, & Kazempour, 2016).

The Science Writing Heuristic (SWH) encapsulates the use of a WTL framework within a science laboratory format to increase scientific literacy. The heuristic incorporates a student-centered learning environment where students are prompted to develop their guiding questions that drives the laboratory work. They also are prompted
to employ a writing framework that focuses on their ability to synthesize the evidence they collected to develop a claim and make reason of their claim. Hand and Prain (2002) emphasized the importance of WTL to enhance students’ conceptual knowledge and to think critically around scientific issues. The SWH provides a scaffolded structure to develop science literacy through laboratory experiments and writing about the experiments (Demirbag et al., 2014).

The development of scientific literacy is an area that is increasingly important in society yet continues to be underdeveloped in the kindergarten through 12th-grade school years. On the Trends in International Mathematics and Science Study (TIMSS) report (National Center for Education Statistics, 2016), the United States ranks eighth in both the fourth-grade and eighth-grade science assessments. This trend has held consistent since the TIMSS was administered in 1997. This ranking indicates a lack of progress in scientific-literacy development within the United States as compared with its international peers. The Program for International Student Assessment (PISA) report indicates that the United States is ranked 25th internationally on the scientific literacy scale (NCES, 2015). These rankings highlight the need for an increased emphasis and development of scientific literacy in the United States education system.

As previously noted, the SWH incorporates the use of writing and an inquiry-based laboratory format to develop scientific literacy. The SWH laboratory format has been found to increase student’s conceptual understanding of science (Akkus et al., 2007; Cronje et al., 2013; Hand & Keys, 1999) and their ability to think critically about science (Stephenson, & Sadler-McKnight, 2016) and to improve student’s attitudes toward science (Putti, 2011).
Research on the SWH has been positive in its findings as an effective tool for teachers to use in the science classroom for increasing scientific literacy. This research was focused on adding to the body of literature around the effectiveness of the SWH in a high-school general chemistry class over a 16-week course of time. This study furthers the SWH research in addressing a time component, grade-level component, and a scientific subject-matter component. The quasi-experimental study included a pretest, treatment including five SWH laboratory sessions, a comparison group using a traditional laboratory format, a posttest written assessment (WA), a posttest content assessment (CA), and a student-perceptions questionnaire. The following research questions were addressed by the design of the study:

1. To what extent is there a difference between SWH and traditional laboratory groups’ scores on the posttest of content assessment?
2. To what extent is there a difference between SWH and traditional laboratory groups’ scores on the posttest of a writing assessment?
3. To what extent are there differences in student scores on the SWH laboratory protocol over the five laboratory experiments?
4. Was there a statistically significant difference in student perceptions of the usefulness of the SWH laboratory report and student perceptions of the usefulness of the traditional laboratory report?

Summary of Findings

This study had several findings as related to the research questions. First, the SWH and the traditional laboratory format were equally as effective in developing chemistry content knowledge. Second, the SWH and the traditional laboratory format
were equally as effective in facilitating the development of students’ writing skills as
evidenced by equivalent scores on the posttest WA. Third, there were changes in the
laboratory-report scores over time, but they were not all in a positive direction. Thus,
there was no overall difference in student scores on the SWH over time.

Last, there was no difference in student perceptions of the importance of WTL
activities and their understanding of chemistry. Students in the treatment group reported a
more positive attitude toward WTL activities, whereas students in the comparison group
reported a more positive perception of writing as a method of helping them make deeper
curricular connections.

**Limitations**

There were several limitations to this study in design and implementation. These
limitations are important to note due to their influence on the generalizability of this
study’s findings. The first limitation is associated with the design of the study using a
convenience sample that was not randomly selected from the population. The students
were not selected randomly for this study that eliminates a true experimental design and
effects the results of the data analyses. The sample was one of convenience, and the
students self-select into stratified course levels based on their past performance in
Biology, teacher guidance, parent guidance, and scheduling demands. The potential for
between-group differences was addressed in the pretest assessment that resulted in no
statistically significant difference in group means between the four participating classes.
There was, however, a slightly higher mean for the two treatment classes as compared
with the comparison classes. Due to the lack of random selection of the classes, there
may have been other factors not identified in the pretest assessment that influenced the
study’s outcome due to the nature of the course being comprised of self-selected students.

The second limitation, again, is associated with the design of the study. The study was implemented in a limited educational setting with only one school of study participating in the research. The school’s setting is one of ethnic and economic diversity with a large population of international immigrants. Due to this unique demographic make-up and potential differences in educational experiences, this study would be difficult to recreate in another geographic or other educational settings.

The third design limitation is associated with the extent of time between laboratory sessions and the length of the study. There were 16 weeks between the start of the study and the posttest assessments. This time period allows for a great deal of ameliorating factors that may influence student understanding of the chemistry units. The original intention of this study was to add to the body of literature around the effect of time on the use of the SWH compared with the traditional laboratory format; however, the results indicate that time and repeated exposure to the laboratory format may not be a factor in the effectiveness of the SWH.

The fourth design limitation is the effects of time on the students’ perceptions of themselves in a study. The students were notified in writing and in person about their participation in a study. They were informed about the general elements of the study during these notifications. The awareness of being part of a study may have caused a Hawthorne effect if students self-identified as being part of a treatment group. The data do not necessarily support this limitation because there was no statistically significant difference between treatment and comparison groups in the study. There were, however, higher means on the posttest CA and posttest WA favoring the treatment group.
The fifth limitation is the potential effect of measurements implemented in the study with questionable reliability. The reliability of the pretest, SWH student questionnaire, and the traditional student questionnaire were all computed to have low Cronbach coefficient alpha values. The low reliability values indicate a low internal consistency, and inherently, may have items that have peculiarities about them. The pretest and questionnaires each had 10 items or fewer, which may reduce the overall internal consistency Cronbach coefficient alpha when computed.

The sixth limitation is one of implementation of the treatment by the teachers. The chemistry teachers willingly expressed their interest in participating in the study’s design and implementation. Both teachers received training on how the SWH was to be implemented based on the laboratory design. This training took place one week prior to the beginning of the study. The actual implementation, however, varied between teachers as Teacher A did not follow the SWH design with fidelity. The treatment student laboratory reports for this teacher had several missing areas including missing experimental questions that should have been developed at the partner, group, and class level. This lack of co-construction of experimental questions may have had an influence on the overall results of the study, which was supported by subsequent data analyses with a statistically significant difference in posttest scores on the WA between Teacher B’s treatment group and Teacher A’s comparison group. Additionally, there were two laboratory reports that indicated a statistically significant difference in scores favoring Teacher B’s treatment class.

The seventh limitation is the data collection and analysis of the laboratory report scores. The scores were analyzed as an indication in growth in writing; however, there
were several rubric items that were not associated with just the writing growth over time. The analysis likely would have been stronger with only having used the specific rubric scale components that were addressed at the writing within the laboratory report. Additionally, the rubric scales may have not been sensitive enough to detect differences in student performance and understanding of chemistry through their writing.

The eighth limitation is in the administration of the student-perceptions questionnaire to Teacher B’s treatment class. The questionnaire link was not sent by the researcher in time for the students to complete immediately following their posttest. The questionnaire subsequently was sent to the students to complete outside of class, which resulted in only 11 students completing the questionnaire. This omission by the researcher to administer properly the questionnaire likely had an influence on the student-perceptions questionnaire-data results. Additionally, the student-perceptions questionnaire was all self-reported thoughts on the laboratory setting. If a student was struggling with the chemistry concepts, he or she may generalize this sentiment toward the laboratory write-up that may have influenced the validity of their perceptions. The converse also may hold true that if a student perceived the SWH as being more challenging than the traditional laboratory format, the students may have reported lower ratings toward the SWH due to its potential effect on the students’ grade.

The ninth limitation is around the lack of data collection in the traditional laboratory scores. The data on the student-perceptions questionnaire is limited in generalizability without being able to contextualize the responses based on students’ laboratory experience with grading. Had the research study included a comparative measurement between the SWH laboratory scores and the traditional laboratory scores
over groups, this comparison may have provided additional insight into why students had varied perceptions toward each laboratory format.

The tenth limitation in the study’s design includes the lack of formative feedback for students in the SWH laboratory write-ups. One of the study’s research questions centered around the change in time over repeated exposure to the SWH laboratory format. The student laboratory scores, however, were not assessed until after the research study had concluded that limits the students’ opportunities to receive feedback about their performance on the laboratory write-ups and then subsequent improvement in their write-ups.

Last, the researcher’s position at the school of study is a limitation of this research because the researcher is an Assistant Principal who worked with the science department as part of her responsibilities. The researcher worked at the school of study for 6 years and was well connected to staff, students, and families at the time of the research.

**Discussion of Findings**

This study set forth to identify the effectiveness of using the Science Writing Heuristic as a laboratory format to increase scientific literacy. Scientific literacy was being assessed through a posttest content assessment and a posttest written assessment. The study, additionally, was designed to assess the effectiveness of the use of the Science Writing Heuristic over time and student perceptions of the usefulness of the heuristic. The findings of the study indicate that both methods of laboratory format equally were effective in developing student’s conceptual knowledge of chemistry and in developing written communication and vary in student perceptions of usefulness of the laboratory format. The lack of statistical difference in the academic measurements were not
consistent with research on the effectiveness of the SWH and academic achievement (Balgopal et al., 2009; Bullock, 2006; Hand, Wallace, & Yang, 2004; Hand et al., 2009; Saul, 2004; Wellington et al., 2001).

The study’s findings were not consistent with previous research regarding student’s development of conceptual understanding using the SWH laboratory format as compared with the traditional laboratory format. Previous studies have found a statistically significant difference in posttest content-assessment measurements following the varied laboratory formats (Greenbowe et al., 2007; Hand et al., 2002; Keys et al., 1999; Nam et al., 2011). The results favored the treatment group for achievement on the posttest measurements, but they did not reach statistical significance.

The laboratory results were being assessed over time to identify whether there was student growth in his or her ability to synthesize scientific evidence through writing. The results were varied, and there was some indication of growth between laboratory reports, but there was not a clear positive linear trend indicating overall growth. These varied laboratory scores over time are not consistent with previous research results. Previous research has indicated an increase in students’ ability to synthesize and write about scientific phenomenon through the SWH laboratory format (Greenbowe et al., 2007; Keys et al., 1999). This research design most closely modeled Nam et al.’s (2010) research design of running the study over a course of a semester. The Nam et al.’s (2010) research included four laboratories in the course of the semester with results indicating statistically significant differences in student writing scores over time. Memis and Seven (2015) conducted five SWH laboratories over the course of one 6-week unit. These results indicated a statistically significant difference in student posttest measures as well
as writing scores.

The student-perceptions questionnaire indicated that the students consistently were not in favor of the use of the SWH as a laboratory report tool. The students indicated that, overall, they were positive about WTL activities helping them understand chemistry. The comparison group that did not use the WTL laboratory format perceived writing as a method to help them make deeper curricular connections more so than the treatment group, which is not a positive perception trend when thinking about the overall implementation of the SWH and WTL activities and students’ perceptions of their usefulness. The majority of students reported that the SWH took them longer, on average, to complete than the traditional laboratory report. This extra time may have had an effect on the overall likability of the SWH as compared with the traditional format.

The study’s implementation limitations reported under the Limitations section likely factored into the lack of statistically significant results in the posttest content assessment and posttest written assessment between groups. Teacher A did not administer the laboratory format with fidelity and the process of developing the beginning questions within the lab groups and the larger class was omitted. The additional findings through post-hoc data analyses suggested that the teacher differences and compromised implementation fidelity played a role in the results of the study.

**Implications for Research**

There is some evidence in this research that suggests a positive effect of the SWH as a useful WTL activity in developing scientific literacy. The model of research and methodology have implications for future research addressing the use of SWH in developing scientific literacy. Research should continue to investigate the overall efficacy
of the SWH as a laboratory format that effects scientific literacy.

The methodology of this research was aligned closely with a typical general-chemistry course at the 10th-grade level. In order to extend this research model and identify the effectiveness of the SWH, a more robust study with additional schools and varying demographics would be an essential component in identifying scientific-literacy development. The current research assessed the effectiveness of the SWH within a single-setting.

The effects of the teacher implementation fidelity and overall teaching efficacy is important to isolate in research on the SWH. Future research should identify elements of teaching that pair well with teacher use of the SWH. Teachers who have a high level of efficacy in facilitating classroom discussion and allowing students to participate in the direction of the classroom work would likely pair better with the SWH laboratory format. Teachers who are not comfortable with allowing students a voice in developing the classroom laboratory procedures and guiding questions may not pair well with the SWH format that may be an additional area of research to investigate. Paired with the teacher implementation and overall teaching-efficacy research, a study including a teacher-observation feedback loop embedded in the research design would likely be beneficial towards the overall success of the heuristic implementation.

Current research has focused on the effectiveness of the SWH from the eighth grade through college years. Identifying the age range that students may be able to handle cognitively the structure of the SWH is important in identifying ways in which science curricula may be able to scaffold this work at younger grade levels. Research, additionally, focusing on each of the elements of the SWH and how the seven
components may be developed in students over time would inform teachers practices when they vertically articulate their curriculum.

This research design was implemented in a 16-week timeframe. A research study investigating the effectiveness of the SWH through a longitudinal design ranging from 2 to 4 years would add to the literature in terms of the effects of a whole-course sequence (e.g., biology, chemistry, physics, etc.) making a shift to this laboratory format. There is evidence to suggest that this laboratory format is effective in supporting students’ development of scientific literacy. The cumulative effects of students learning within one laboratory framework for their high-school science coursework may have an added benefit to their scientific-literacy development. Keys et al. (1999) indicated that with repeated exposure to the SWH students were able to draw stronger conclusions through the protocol than preliminary writing samples.

This research assessed the effectiveness of the laboratory work over several laboratory settings. Additional research around the development of student proficiencies in writing within the framework of the SWH is important in order to better understand the SWH and its development of scientific literacy. Additional research regarding the work of scaffolding these writing assignments in order to maximize student learning would be a positive addition to the literature regarding SWH implementation. A research protocol that included specific practices associated with analyzing data and writing within a claim, evidence, reasoning format for students to practice their writing skills associated with science content may add to the overall literature regarding science literacy.

Brown, Ryoo, and Rodriguez (2009) have researched and developed the notion of disaggregate instruction in effort to separate the conceptual science learning from the
discursive identity and language components of science. Further research around
discursive identity and disaggregate instruction with the SWH would provide additional
insight into the effectiveness of the SWH as a learning tool when highlighting cultural
identity and language development.

This research was implemented in a general-chemistry class. Additional research
about the effectiveness of the SWH in a biology, honors chemistry, physiology, physics,
environmental science, and advanced-placement science courses would add to the
literature around the effectiveness of the SWH and its practical implications. A
comparative study between an honors-level and general-level science course and the
SWH effectiveness also would add to the literature around the SWH.

The SWH is a writing-based format for students to process the experimental data
and guiding questions they co-construct. Due to the format being a writing-intensive
design, research around the effectiveness of the SWH and its administration in a English
Language Learner (ELL) and Special Education science course would add to the
literature around the effectiveness of this WTL format. This research was implemented in
a general-education class that was not designed specifically to address the needs of ELL
or special education students.

The student-perceptions questionnaire assessed student opinions from a general
level regarding WTL activities and the SWH. These perceptions questionnaire data are
important in the discussion around classroom activities in order to assess student
engagement and their attitudes toward class work. Further investigation around student
perceptions of the SWH with more specific prompts about the each component of the
SWH may be helpful in teachers’ use of the SWH in their science classes.
Last, the focus of the SWH is developing the students’ scientific-literacy skills through writing. A missing component of this research and the SWH literature is the professional development or training program that best trains teachers to develop their facilitation skills to help them negotiate beginning questions with students, to provide support for writing claims using evidence, and to develop the process of reflection. This research included two one-hour trainings around the use of the SWH. A more extensive training might include three or four one-hour trainings in order to process the information over time and have an opportunity to practice the implementation of the laboratory format. Akkus, Gunel, and Hand (2007) investigated the effects of teacher implementation following a 2-day training on teacher implementation of the SWH. The study found that teacher implementation of the SWH has a large effect on student achievement on posttest measurements. Teachers likely would benefit from a training program that included a model instruction component through video-taped lessons and an opportunity to practice the facilitation of the beginning question development as this area was a challenge in implementing this research. Results of Balgopal et al. (2013) research suggest a lack of teacher preparation to develop literacy skills while also developing content knowledge in their students. A research study identifying the key elements of a training process and teacher-preparation program training of the SWH would add to the body of literature around the effectiveness of the SWH.

**Implications for the Practice of Teachers**

Scientific literacy is an essential skill for developing students’ abilities to process data, connect to scientific phenomenon, and make a cogent argument in society (DeBoer, 2000). The SWH was designed to increase scientific literacy through the use of
laboratory experiments that require the use of a collaborative process at both a small-group level and a larger classroom level that is commensurate with the 21st-century skills needed to be successful in the workforce. The research conducted in this study around the effectiveness of the SWH had several implications for classroom practice. The first implication for teaching practice is the positive effect of developing teacher facilitation of the SWH protocol. Teachers who use the protocol have identified valuable areas in the collaborative laboratory protocol that build agency with students and create an investment in the laboratory work. Teacher B reported that students took ownership of the laboratory work after being part of the development process in creating the beginning question and that they subsequently were more engaged in the chemistry they were learning.

Given the higher means of each of the treatment groups on every academic measure, there is evidence to suggest that the SWH helps students develop their understanding of chemistry concepts. There is no evidence to suggest that the traditional laboratory format promotes better student academic achievement. Therefore, teachers should consider the shift toward the use of the SWH laboratory format as the structure by which students engage in laboratory work.

There is evidence to suggest that the SWH is an effective laboratory format to develop student’s scientific literacy as seen in the post-hoc comparison on the posttest WA. These post-hoc data analyses suggest that students who practice WTL activities over time will develop their writing abilities and use of an evidence-based writing structure that is a large component of the development of scientific literacy given the need for students to be able to analyze evidence and use it to make an argument. Teachers
should consider the development of this skill set over time and implement a planned, repeated practice process to this writing protocol.

The heuristic implementation may be more robust when paired with support for student writing and processing information through a claim, evidence, reasoning format. Scaffolding student writing and how to write evidence-based analyses is part of the NGSS implementation and thus, the heuristic may be better paired with student writing and analyses in the future when students are trained to use this format of writing and analyses.

Teachers should consider the results of this SWH research when designing a laboratory format for their students. Teachers and students would benefit from ongoing research and implementation assessment of the SWH in varying levels and content of science. The professional development needs of teachers to implement the SWH properly should be considered by district and site administration when providing teachers research-based curricular development opportunities.

**Summary**

Students in the United States repeatedly are outranked in international science achievement measures indicating a need for additional emphasis in schools on developing scientific literacy (Kena et al., 2015). The science writing heuristic is a research-based laboratory format designed to include a writing-to-learn format that requires students to develop collaboratively a beginning question, conduct an experiment, collect data, and then develop a claim based on the data as evidence. The heuristic, additionally, includes an opportunity for students to reflect on their learning and reaffirm their growth.

Previous research has identified the SWH as an effective laboratory format in
increasing science achievement and developing scientific literacy (Akkus et al., 2007; Cronje et al., 2013; Keys et al., 1999; Nam et al., 2011). In an effort to understand the effects of the SWH over time through several laboratory experiments, this research study compared the effects of the SWH treatment group with a traditional laboratory setting on a writing assessment, content assessment, and a student-perceptions questionnaire. The results of this study were not consistent with previous research (Akkus et al., 2007; Cavagnetto, 2010; Cronje et al., 2013; Greenbowe et al., 2007; Hand et al., 2002; Harmon et al., 2012; Nam et al., 2011; Rudd et al., 2007) with statistically significant achievement outcomes. This research resulted in higher means on each academic treatment measure, but the results were not statistically significant.

These findings were limited, however, by inconsistencies in teacher implementation of the SWH laboratory format. Additional evidence of the effectiveness of the SWH as a teaching tool over time should continue to be researched in a setting with teachers who have received adequate professional development on the use of the SWH as a laboratory format.
References


Appendix A

Table 1: Traditional Laboratory Report Format Versus SWH Format
Table 1

Traditional Laboratory Report Format Versus SWH Format

<table>
<thead>
<tr>
<th>Traditional Science Laboratory Format</th>
<th>Science Writing Heuristic (SWH) Format</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Title and purpose</td>
<td>1. Beginning questions- What are my questions about this experiment?</td>
</tr>
<tr>
<td>2. Outline and procedure</td>
<td>2. Tests— What tests will I do or what procedure will I follow to help me answer my questions?</td>
</tr>
<tr>
<td>3. Data and observations</td>
<td>3. Observations- What did I observe? What did I find?</td>
</tr>
<tr>
<td>4. Discussion</td>
<td>4. Claims— What can I claim to answer my beginning question(s) or the class beginning question(s)?</td>
</tr>
<tr>
<td>5. Balanced equations, calculations, and graphs</td>
<td>5. Evidence—How do I know? Why am I making these claims?</td>
</tr>
<tr>
<td></td>
<td>6. Reflections—How do my ideas compare with other ideas? How have my ideas changed?</td>
</tr>
</tbody>
</table>

*Note: Adapted from Burke, Greenbowe, and Hand (2006)*
Appendix B

Letter to Parents of Student Participants in Study
September 14, 2016

Dear Parents/Guardians of General Chemistry Student:

My name is Denae Nurnberg and I am a graduate student in the School of Education at the University of San Francisco. I am sending this letter to explain why I would like for your child to participate in my research project. I am studying writing in science and would like to see if a change in the laboratory format for General Chemistry results in increased scientific literacy.

With your permission, I will ask your child to take a 10-item pretest, participate in a randomly assigned laboratory setting, complete their final exam, and complete a survey on their laboratory experience. The 10-item pretest, the laboratory assignment, and the final exam will be administered regardless of your child’s participation in this study as these are required by the course instructor.

Your child’s participation in this study is completely voluntary and will not affect his or her grades in any way. Your child may quit this study at any time by simply saying “I do not wish to participate” or sending me an e-mail and his or her data will not be part of the research.

The study will be conducted during your child’s chemistry course and doesn’t require any additional time outside of class other than regularly assigned homework. There are no known risks involved in this study and your child will not receive any compensation for his or her participation. To protect your child’s confidentiality, your child’s name will not appear on any record sheets. The information obtained will not be shared with anyone, unless required by law. The records will be maintained by me. If you have any questions, please contact me at XXX-XXXX-XXXX or via email.

This letter will serve as a consent form for your child’s participation and will be kept in the office at Homestead High School. If you have any questions about your child’s rights as a participant, you may contact the University of San Francisco IRB at IRBPHS@usfca.edu.

Should you decide that you would like to remove your child from this study, please sign this form below and bring it to the Main Office at XXX High School no later than September 30. By removing your child from the study, his or her data won’t be collected by the researcher. This won’t exempt him/her from the class work assigned by the teacher. If you would like to view the study materials, please let me know and I will make them available for viewing.

Sincerely,

Denae Nurnberg
Assistant Principal
Appendix C

Content Validity Rubric for Pretest
Validity Rubric for Expert Panel – SWH Pretest Assessment

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Score</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>YES</td>
</tr>
<tr>
<td></td>
<td>NO</td>
</tr>
<tr>
<td><strong>Readability</strong></td>
<td></td>
</tr>
<tr>
<td>Text is clear</td>
<td>1</td>
</tr>
<tr>
<td>Word choice is appropriate for a 10-11th grade student</td>
<td>1</td>
</tr>
<tr>
<td>Academic language use is same language taught in class</td>
<td>1</td>
</tr>
<tr>
<td><strong>Reflection between text and picture</strong></td>
<td></td>
</tr>
<tr>
<td>Graphics are clear</td>
<td>1</td>
</tr>
<tr>
<td>Graphics that accompany text reflect content</td>
<td>1</td>
</tr>
<tr>
<td><strong>Additional Concerns/ Questions</strong></td>
<td>Total Score:</td>
</tr>
</tbody>
</table>

**Objectives:**

1. Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties.
2. Use mathematical representations to support the claim that atoms, and therefore mass, are conserved during a chemical reaction.
3. Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms.
4. Develop models to illustrate the changes in the composition of the nucleus of the atom and the energy released during the processes of fission, fusion, and radioactive decay.

<table>
<thead>
<tr>
<th>Test Question</th>
<th>Objectives Addressed</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Some of the molecules found in the human body are ( \text{H}_2\text{CO}_2\text{OH} ) (glycine), ( \text{C}_6\text{H}_12\text{O}_6 ) (glucose), and ( \text{CH}<em>3\text{CH}</em>{2}\text{COOH} ) (stearic acid). The bonds they form are:</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>2. Why are enormous amounts of energy required to separate a nucleus into its component protons and neutrons even though the protons in the nucleus repel each other?</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>3. Generally, how do atomic masses vary throughout the periodic table of the elements?</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>4. When a metal is heated in a flame, the flame has a distinctive color. This information was eventually</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Question</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>-------------------------------------------------------------------------</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>5. The reason salt crystals, such as KCl, hold together so well is because the cations are strongly attracted to</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>6. Which of the following is an observable property of many acids?</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>7. When cations and anions join, they form what kind of chemical bond?</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>8. This chemical equation represents the combustion of propane. When correctly balanced, the coefficient for water is C₆H₁₆ + O₂ → CO₂ + H₂O</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>9. The above picture shows a light bulb connected to a battery with the circuit interrupted by a solution. When dissolved in the water to form a 1.0 molar solution, all of the following substances will complete a circuit allowing the bulb to light except</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>10. Why is cobalt (Co) placed before nickel (Ni) on the periodic table of the elements even though it has a higher average atomic mass than nickel?</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>
Appendix D

SWH Laboratory Scoring Rubric
<table>
<thead>
<tr>
<th>Section</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>1—Beginning Questions</td>
<td>The purpose of the lab or the question to be answered during the lab is not shown and/or cannot be tested by the investigation.</td>
<td>The purpose of the lab or the question to be answered during the lab is not clearly identified and stated and cannot be tested by the investigation.</td>
<td>The purpose of the lab or the question to be answered during the lab is clearly identified and stated and can be tested by the investigation.</td>
<td></td>
</tr>
<tr>
<td>2—Tests/Experiments</td>
<td>Procedures do not accurately list the steps of the investigation.</td>
<td>Procedures are listed in a logical order, but steps are not numbered and/or are not in complete sentences. Procedures may be hard to follow.</td>
<td>Procedures are listed in clear repeatable steps. Each step is numbered and is a complete sentence.</td>
<td></td>
</tr>
<tr>
<td>3—Observations</td>
<td>Data are not shown OR are inaccurate.</td>
<td>Some representation of data in graphs or tables is presented. Graphs and tables are not labeled and may be missing elements.</td>
<td>Accurate representation of the data in tables and/or graphs. Graphs and tables are labeled and titled.</td>
<td></td>
</tr>
<tr>
<td>4—Claims</td>
<td>Claim is not made or inferred.</td>
<td>Claim is inferred but may not be based on data/observations collected. Claim may not answer the question.</td>
<td>Claim is inferred and is based on the data/observations collected. Claim answers the question.</td>
<td></td>
</tr>
<tr>
<td>5—Evidence</td>
<td>Claim is not supported by discussion of evidence.</td>
<td>Claim is somewhat supported through analyzed and interpreted data. No references are made about patterns, trends or predictions are made based on the data.</td>
<td>Claim is supported and discussed through analyzed and interpreted data. References are made to the data collected, patterns, trends are discussed.</td>
<td></td>
</tr>
<tr>
<td>6—Reflection</td>
<td>No reflection of learning is included.</td>
<td>Some reflection of learning is included but may not refer back to the question. No successes and challenges are included.</td>
<td>Reflection of Learning is included and refers back to the question. Successes and challenges are included.</td>
<td></td>
</tr>
<tr>
<td>7—Work Cited</td>
<td>Claim is not supported with information from outside sources. Information may not be cited.</td>
<td>Claim is somewhat supported with information from outside sources. Information may not be cited.</td>
<td>Claim is supported with information from outside sources. The information is cited.</td>
<td></td>
</tr>
</tbody>
</table>

Total: /21
Appendix E

Posttest Content Assessment
Content Assessment Questions- Laboratory Content (1 point each)

1. Emission of light from an atom occurs when an electron ___________.
   a. drops from a higher to a lower energy level
   b. jumps from a lower to a higher energy level
   c. moves within its atomic orbital
   d. falls into the nucleus

2. Which of the following quantum leaps would be associated with the greatest energy of emitted light?
   a. n=5 to n=1   c. n=2 to n=5
   b. n=4 to n=5   d. n=5 to n=4

3. When a metal is heated in a flame, the flame has a distinctive color. This information was eventually extended to the study of stars because:
   a. the color spectra of stars indicate which elements are present.
   b. a red shift in star color indicates stars are moving away.
   c. star color indicates absolute distance.
   d. It allows the observer to determine the size of stars.

4. Which of the following elements is classified as a metal?
   a. Bromine       c. sulfur
   b. helium        d. lithium

5. Atoms of elements that are in the same group have the same number of
   a. protons.      c. neutrons.
   b. valence electrons. d. protons and neutrons

6. In Mendeleev’s periodic table, elements in each column had similar
   a. atomic masses.   c. properties.
   b. atomic numbers  d. symbols.

7. Based on the Periodic Table, which of these elements probably has physical and chemical properties most similar to Boron (B)?
   a. magnesium (Mg) c. neon (Ne)
   b. aluminum (Al)  d. chlorine (Cl)

8. Which pair of elements would most likely have a similar arrangement of outer electrons and have similar chemical behaviors?
   a. boron and aluminum c. helium and fluorine
   b. carbon and nitrogen d. chlorine and oxygen
9. $\text{C}_3\text{H}_8(\text{g}) + \text{O}_2(\text{g}) \rightarrow \text{CO}_2(\text{g}) + \text{H}_2\text{O}(\text{g})$

What type of reaction is the above equation?

a. Combustion  
   b. Single-replacement  
   c. Combination  
   d. Double replacement

10. Which of the following are the products for the combustion of ethanol (CH$_3$CH$_2$OH)?

   a. $\text{CO}_2 + 2\text{H}_2\text{O}$  
   b. $2\text{CO}_2 + 3\text{H}_2\text{O}$  
   c. $2\text{CO}_2 + 3\text{H}_2\text{O}$  
   d. $3\text{CO}_2 + 2\text{H}_2\text{O}$

11. ____ $\text{NH}_3(\text{g}) + ____ \text{O}_2(\text{g}) \rightarrow ____ \text{N}_2(\text{g}) + ____ \text{H}_2\text{O}(\text{g})$

When the equation above is completely balanced, the coefficient for $\text{NH}_3$ will be

a. 2  
   b. 3  
   c. 4  
   d. 6

12. What are the products for the decomposition of $\text{H}_2\text{O}_2$?

   a. $\text{H}_2(\text{g}) + \text{O}_2(\text{g})$  
   b. $2\text{H}(\text{g}) + \text{O}_2(\text{g})$  
   c. $\text{O}_2(\text{g}) + 2\text{H}_2\text{O}(\text{g})$  
   d. $\text{H}_2(\text{g}) + 2\text{O}(\text{g})$

13. One molecule of carbon dioxide has what mass?

   a. $28 \text{ g}$  
   b. $44 \text{ g}$  
   c. $1.7 \times 10^{-21} \text{ g}$  
   d. $7.3 \times 10^{-21} \text{ g}$

14. How many moles are there in $2.4 \times 10^{24}$ atoms of He?

   a. $2.4 \times 10^{24} \text{ mol}$  
   b. $2.0 \text{ mol}$  
   c. $4.0 \text{ mol}$  
   d. $6.0 \text{ mol}$

15. 4.0 moles of $\text{H}_2\text{O}$ would have what mass?

   a. $45 \text{ g}$  
   b. $23 \text{ g}$  
   c. $18 \text{ g}$  
   d. $72 \text{ g}$

16. What is the mass of one mole of $\text{AuCl}_3$?
17. What type of reaction is the following: \( \text{Mg} + \text{CuCl}_2 \rightarrow \text{MgCl}_2 + \text{Cu} \)
   a. Combination  
   b. Double-displacement  
   c. Single-replacement  
   d. Combustion

18. What type of reaction is the following: \( \text{C}_4\text{H}_8 + 5\text{O}_2 \rightarrow 3\text{CO}_2 + 4\text{H}_2\text{O} \)
   a. Combination  
   b. Decomposition  
   c. Combustion  
   d. Double-replacement

19. Which is the correct general form for single replacement reactions?
   a. \( \text{AB} + \text{C} \rightarrow \text{A} + \text{CB} \)  
   b. \( \text{A} + \text{B} \rightarrow \text{AB} \)  
   c. \( \text{AB} + \text{CD} \rightarrow \text{AD} + \text{CB} \)  
   d. \( \text{A} + \text{BC} \rightarrow \text{AB} + \text{CB} \)

20. In a combustion reaction, what elements/compounds can be reactants?
   a. Oxygen gas (\( \text{O}_2 \)) and a hydrocarbon  
   b. Oxygen gas and a metal  
   c. Both of the above two answers are correct  
   d. None of the above answers are correct
Appendix F

Content Validity Rubric for Posttest Content Assessment
### Validity Rubric for Expert Panel – Instructional Materials for SWH Content Assessment

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Score</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Readability</td>
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<td></td>
</tr>
<tr>
<td>Text is clear</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Word choice is appropriate for a 10-11th grade student</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Academic language use is same language taught in class</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Reflection between text and picture</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Graphics are clear</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Graphics that accompany text reflect content</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Additional Concerns/Questions</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Objectives:**

1. Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties.

2. Use mathematical representations to support the claim that atoms, and therefore mass, are conserved during a chemical reaction.

3. Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms.

4. Develop models to illustrate the changes in the composition of the nucleus of the atom and the energy released during the processes of fission, fusion, and radioactive decay.

<table>
<thead>
<tr>
<th>Test Question</th>
<th>Objectives Addressed</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Emission of light from an atom occurs when an electron ____________________.</td>
<td>1</td>
<td>2 3 4</td>
</tr>
<tr>
<td>2. Which of the following quantum levels would be associated with the greatest energy of emitted light?</td>
<td>1</td>
<td>2 3 4</td>
</tr>
<tr>
<td>3. When a metal is heated in a flame, the flame has a distinctive color. This information was eventually extended to the study of stars because:</td>
<td>1</td>
<td>2 3 4</td>
</tr>
<tr>
<td>4. Which of the following elements is classified as a metal?</td>
<td>1</td>
<td>2 3 4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>5. Atoms of elements that are in the same group have the same number of:</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>6. In Mendeleev’s periodic table, elements in each column had similar:</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>7. Based on the Periodic Table, which of these elements probably has physical and chemical properties most similar to Boron (B)?</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>8. Which pair of elements would most likely have a similar arrangement of outer electrons and have similar chemical behaviors?</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>
| 9. \( \text{Ca}_{(s)} + \text{O}_{2(g)} \rightarrow \text{CO}_{2(g)} + \text{H}_{2}\text{O}_{(g)} \)  
   The chemical equation above represents the combustion of propane. When correctly balanced, the coefficient for water is: | 1 | 2 | 3 | 4 |
| 10. Which of the following is a balanced equation for the combustion of ethanol (\( \text{C}_2\text{H}_5\text{CH}_3\text{OH} )\)? | 1 | 2 | 3 | 4 |
| 11. \( \_\_\_\text{NH}_3_{(g)} + \_\_\_\text{O}_{2(g)} \rightarrow \_\_\_\text{N}_2_{(g)} + \_\_\_\text{H}_2\text{O}_{(g)} \)  
   When the equation above is completely balanced, the coefficient for \( \text{NH}_3 \) will be: | 1 | 2 | 3 | 4 |
| 12. Which of the following is a balanced equation representing the decomposition of hydrogen peroxide? | 1 | 2 | 3 | 4 |
| 13. One molecule of carbon dioxide has what mass? | 1 | 2 | 3 | 4 |
| 14. How many moles are there in \( 2.4 \times 10^{17} \) atoms of He? | 1 | 2 | 3 | 4 |
| 15. 4.6 moles of \( \text{H}_2\text{O} \) would have what mass? | 1 | 2 | 3 | 4 |
| 16. What is the mass of one mole of \( \text{AsCl}_3 \)? | 1 | 2 | 3 | 4 |
| 17. What type of reaction is the following: \( \text{Mg} + \text{CuCl}_2 \rightarrow \text{MgCl}_2 + \text{Cu} \)? | 1 | 2 | 3 | 4 |
| 18. What type of reaction is the following: \( \text{C}_2\text{H}_4 + 3\text{O}_2 \rightarrow 3\text{CO}_2 + 3\text{H}_2\text{O} \)? | 1 | 2 | 3 | 4 |
| 19. Which is the correct general form for single displacement reactions? | 1 | 2 | 3 | 4 |
| 20. In a combustion reaction, what elements/compounds can be reactants? | 1 | 2 | 3 | 4 |
Appendix G

Posttest Writing Assessment
**Krypton’s Ionization Energy CER**

The table below lists physical data for the noble gases. Use the information in the data table, the grid below, and the CER graphic organizer on the back of this page to help you answer the following Guiding Questions:

a) How can you estimate the ionization energy of krypton given a table of physical data of the noble gases?  
b) What is your estimated value of krypton’s ionization energy?

**Table 1: Noble Gases Physical Data**

<table>
<thead>
<tr>
<th>Element</th>
<th>Period No.</th>
<th>Atomic Mass (amu)</th>
<th>Ionization Energy (kJ/mol)</th>
<th>Density (g/cm³)</th>
<th>Melting Point (K)</th>
<th>Boiling Point (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Helium</td>
<td>1</td>
<td>4.00</td>
<td>2372</td>
<td>1.8 x 10⁴</td>
<td>---</td>
<td>4.2</td>
</tr>
<tr>
<td>Neon</td>
<td>2</td>
<td>20.18</td>
<td>2080</td>
<td>9.0 x 10⁴</td>
<td>24.6</td>
<td>27.1</td>
</tr>
<tr>
<td>Argon</td>
<td>3</td>
<td>39.10</td>
<td>1520</td>
<td>1.8 x 10³</td>
<td>83.8</td>
<td>87.2</td>
</tr>
<tr>
<td>Krypton</td>
<td>4</td>
<td>83.80</td>
<td>???</td>
<td>3.7 x 10³</td>
<td>115.9</td>
<td>119.7</td>
</tr>
<tr>
<td>Xenon</td>
<td>5</td>
<td>131.30</td>
<td>1170</td>
<td>5.9 x 10³</td>
<td>161.3</td>
<td>165.0</td>
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<td>Radon</td>
<td>6</td>
<td>222</td>
<td>1037</td>
<td>9.7 x 10³</td>
<td>202</td>
<td>211</td>
</tr>
</tbody>
</table>

**Krypton’s Ionization Energy CER**

**GUIDING QUESTIONS:**

a) How can you estimate the ionization energy of krypton given a table of physical data of the noble gases?

b) What is your estimated value of krypton’s ionization energy?

**CLAIM:**

**EVIDENCE** | **REASONING**
---|---

**SOURCES OF DATA:**

---

Appendix H

Content Validity Rubric for Posttest Writing Assessment
### Validity Rubric for Expert Panel – SWH Writing Assessment

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Score</th>
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<tbody>
<tr>
<td></td>
<td>YES</td>
<td>NO</td>
</tr>
<tr>
<td><strong>Readability</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Text is clear</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Word choice is appropriate for a 10-11th grade student</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Academic language use is some language taught in class</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td><strong>Reflection between text and picture</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Graphics are clear</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Graphics that accompany text reflect content</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td><strong>Additional Concerns/Questions</strong></td>
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<td></td>
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</tr>
</tbody>
</table>

**Objective:** Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms.

<table>
<thead>
<tr>
<th>Is the objective being addressed by the writing prompt?</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
</table>
Appendix I

Scoring Rubric for Posttest Writing Assessment
<table>
<thead>
<tr>
<th>Section</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observations</td>
<td>Data are not shown OR are inaccurate.</td>
<td>Some representation of data in graphs or tables are presented.</td>
<td>Accurate representation of the data in tables and/or graphs.</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Graphs and tables are not labeled and may be missing elements.</td>
<td>Graphs and tables are labeled and titled.</td>
<td></td>
</tr>
<tr>
<td>Claims</td>
<td>Claim is not made or inferred.</td>
<td>Claim is inferred but may not be based on data/observations</td>
<td>Claim is inferred and is based on the data/observations</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>collected.</td>
<td>collected.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Claim may not answer the question.</td>
<td>Claim answers the question.</td>
<td></td>
</tr>
<tr>
<td>Evidence</td>
<td>Claim is not supported by discussion of evidence.</td>
<td>Claim is somewhat supported through analyzed and interpreted</td>
<td>Claim is supported and discussed through analyzed and interpreted</td>
<td>Total:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>data.</td>
<td>data.</td>
<td>9</td>
</tr>
</tbody>
</table>
Appendix J

Validity Rubric for Student Questionnaire
### Survey/Interview Validation Rubric for Expert Panel - VREP©
By Marilyn K. Simon with input from Jacquelyn White

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Operational Definitions</th>
<th>Score</th>
<th>Questions NOT meeting standard (List page and question number) and need to be revised.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clarity</td>
<td>• The questions are direct and specific.</td>
<td>1=Not Acceptable (major modifications needed)</td>
<td>Please use the comments and suggestions section to recommend revisions.</td>
</tr>
<tr>
<td></td>
<td>• Only one question is asked at a time.</td>
<td>2=Below Expectations (some modifications needed)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• The participants can understand what is being asked.</td>
<td>3=Meets Expectations (no modifications needed but could be improved with minor changes)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• There are no double-barreled questions (two questions in one).</td>
<td>4=Exceeds Expectations (no modifications needed)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 2 3 4</td>
<td></td>
</tr>
<tr>
<td>Wordiness</td>
<td>• Questions are concise.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• There are no unnecessary words</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Negative Wording</td>
<td>• Questions are asked using the affirmative (e.g., Instead of asking, “Which methods are not used?”, the researcher asks, “Which methods are used?”)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overlapping Responses</td>
<td>• No response covers more than one choice.</td>
<td></td>
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<tr>
<td></td>
<td>• All possibilities are considered.</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>• There are no ambiguous questions.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Balance</td>
<td>• The questions are unbiased and do not lead the participants to a response. The questions are asked using a neutral tone.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Use of Jargon</td>
<td>• The terms used are understandable by the target population.</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>• There are no cliches or hyperbole in the wording of the questions.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Appropriateness of Responses</td>
<td>• The choices listed allow participants to respond appropriately.</td>
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<tr>
<td>List Item</td>
<td>Description</td>
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</tr>
<tr>
<td>----------</td>
<td>------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Use of Technical Language</td>
<td>The use of technical language is minimal and appropriate. All acronyms are defined.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Application to Praxis</td>
<td>The questions asked relate to the daily practices or expertise of the potential participants.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relationship to Problem</td>
<td>The questions are sufficient to resolve the problem in the study. The questions are sufficient to answer the research questions. The questions are sufficient to obtain the purpose of the study.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Measure of Construct A: Perception of Learning</td>
<td>The survey adequately measures this construct. (Students perceive their learning being enhanced by the use of the laboratory protocol including thinking critically and improving their writing skills) Questions: 4, 5, 6, 7, 8, 10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Measure of Construct B: Perceived Ease of Learning Tool</td>
<td>The survey adequately measures this construct. (The student perceives the laboratory protocol as being accessible in terms of their learning such that they try their best and are able to accomplish each of the assigned tasks with ease) Questions: 1, 2, 3, 9</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Permission to use this survey, and include in the dissertation manuscript was granted by the author, Marilyn K. Simon, and Jacquelyn White. All rights are reserved by the authors. Any other use or reproduction of this material is prohibited.*
Appendix K

SWH Laboratory Student-Perceptions Questionnaire for Pilot
Part I: Statement Response

This section of the survey is asking you to share your opinion on the SWH/laboratory writing assignment you have completed during the first semester in this class. Using the options provided, please indicate with a check in the box provided whether you consider the statement to be “1=Not at all true,” “2=A little true,” “3=Somewhat true,” “4=Very true.”

| 1. I understood how to complete the SWH laboratory assignment given by my teacher. | 4 | 3 | 2 | 1 |
| 2. I tried my best on the SWH/laboratory assignments. | 4 | 3 | 2 | 1 |
| 3. I completed every portion of the SWH laboratory assignment during the first semester. | 4 | 3 | 2 | 1 |
| 4. The SWH laboratory writing assignments helped me understand chemistry better. | 4 | 3 | 2 | 1 |
| 5. The SWH laboratory assignments were not useful for helping me learn chemistry. | 4 | 3 | 2 | 1 |
| 6. While writing the SWH laboratory response, I had to think critically about chemistry. | 4 | 3 | 2 | 1 |
| 7. The SWH laboratory write-up helped me learn the information better than traditional lab write-ups we do in this class. | 4 | 3 | 2 | 1 |
| 8. The SWH laboratory write-ups were just as effective in helping me learn as traditional labs we complete in this class. | 4 | 3 | 2 | 1 |
| 9. The SWH write-ups took me longer, on average, to complete than the traditional labs we complete in this class. | 4 | 3 | 2 | 1 |
| 10. The SWH laboratory write-ups helped me prepare for the chemistry final examination. | 4 | 3 | 2 | 1 |
Part II: Demographics

Please complete each question below to the best of your knowledge.

1. Your gender:  □ Male  □ Female

2. Your 1st semester grade in chemistry: A □  B □  C □  D □  F □

3. Please indicate your ethnicity (mark all that apply):
   □ Asian American  □ Caucasian American  □ Hispanic or Latino  □ Filipino American  □ African American

5. Is English your first language?  □ Yes  □ No

6. Please indicate your student ID #: _____________________
Appendix L

Comparison-Group Student-Perceptions Questionnaire
**Part I: Statement Response**

This section of the survey is asking you to share your opinion on the SWH/laboratory writing assignment you have completed during the first semester in this class. Using the options provided, please indicate with a check in the box provided whether you consider the statement to be “1=Not at all true,” “2=A little true,” “3= Somewhat true,” “4=Very true.”

<table>
<thead>
<tr>
<th></th>
<th>1=Not at all true</th>
<th>2=A little true</th>
<th>3= Somewhat true</th>
<th>4=Very true</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. I understood how to complete the laboratory assignment given by my teacher.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. I tried my best on the laboratory assignments.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. I completed every portion of the laboratory assignments during the first semester.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. The laboratory writing assignments helped me understand chemistry better.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. The laboratory writing assignments were not useful for helping me learn chemistry.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. While writing the laboratory responses, I had to think critically about chemistry.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. The laboratory write-ups helped me prepare for the chemistry final examination.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Part II: Demographics**

Please complete each question below to the best of your knowledge. There is no identifying information requested so all responses remain anonymous.

1. **Your gender:**  
   - [ ] Male  
   - [ ] Female

2. **Your 1st semester grade in chemistry:**  
   - [ ] A  
   - [ ] B  
   - [ ] C  
   - [ ] D  
   - [ ] F

3. Please indicate your ethnicity (mark all that apply):
   - [ ] Asian American  
   - [ ] Caucasian American  
   - [ ] Hispanic or Latino  
   - [ ] Filipino American  
   - [ ] African American

4. **Is English your first language?**  
   - [ ] Yes  
   - [ ] No

5. Please indicate your student ID #:__________________________
Appendix M

PowerPoint® for SWH Treatment-Group Laboratory
Appendix N

Sample SWH Laboratory Write-Up
Flame Test Lab SWH

Name_________________________ Period____________________ ID #_________________________

Chemistry Teacher_________________________

NGSS Standard:
1. Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost
electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties.

2. Apply scientific principles and evidence to provide an explanation about the effects of changing the
temperature or concentration of the reacting particles on the rate at which a reaction occurs.

Pre-Reading:
Have you ever wondered why a candle flame is yellow? Or what gives fireworks display its bright lavender,
red, green, yellow and blue colors? When elements are heated to high temperatures, some of their electrons are
excited to higher energy levels. These excited electrons then fall back to lower energy levels, releasing the
absorbed energy in packages of light called photons, or light quanta.

Flame colors are produced from the movement of the electrons in the metal atoms found in the compounds. For
example, a sodium atom in the ground state has the electron configuration:

$$1s^22s^22p^63s^1.$$  

When you heat it, the electrons gain energy and can jump into any of the empty orbitals at higher levels - for
example, into the 7s or 6p or 4d or whatever, depending on how much energy a particular electron happens to
absorb from the flame.

Because the electrons are now at a higher and more energetically unstable level, they tend to fall back down to
where they were before - but not necessarily all at one time.

An electron which had been excited from the 2p level to an orbital in the 7 level, for example, might jump back
to the 2p level in one go. That would release a certain amount of energy which would be seen as light of a
particular color.

However, it might jump back in two (or more) stages. For example, first to the 5 level and then back to the 2
level. Each of these jumps involves a specific amount of energy being released as light energy, and each
corresponds to a particular color.

The color of the emitted light depends on its energy. Blue light is more energetic than red light, for example.
When heated, each element emits a characteristic pattern of light energies which are useful for identifying the
element. The characteristic colors of light produced when substances are heated in the flame of a gas burner are
the basis of flame tests for several elements. In this experiment, you will perform flame tests for several
metallic elements.
Section 1: Beginning Questions *What are my questions about this experiment?*

After reading the lab handout, write questions that can be answered by doing the lab.

---

Section 2: Tests (procedures and safety considerations) *What tests will I do or what procedure will I follow to help me answer my questions?*

This is where you write the steps of the lab. All lab equipment and amounts of chemical used should be incorporated into the procedure. Safety considerations need to be included as part of your plan.

**Procedures:**

1. 

2. 

3. 

4. 

5. 

6. 

7. 

8. 

9. 

10. 

<table>
<thead>
<tr>
<th>Safety Considerations:</th>
</tr>
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<tbody>
<tr>
<td>1.</td>
</tr>
<tr>
<td>2.</td>
</tr>
<tr>
<td>3.</td>
</tr>
<tr>
<td>4.</td>
</tr>
<tr>
<td>5.</td>
</tr>
<tr>
<td>6.</td>
</tr>
<tr>
<td>7.</td>
</tr>
<tr>
<td>8.</td>
</tr>
<tr>
<td>9.</td>
</tr>
<tr>
<td>10.</td>
</tr>
</tbody>
</table>
**Section 3-Observations:** *What did I observe? What did I find?*
This section contains any and all tables and graphs with data you collected. You should also include all observations that occurred during the lab.

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
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<td>unknown 1</td>
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<td></td>
</tr>
<tr>
<td>unknown 2</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>unknown 3</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**Section 4-Claim:** *What can I claim to answer my beginning question(s) or the class beginning question(s)?* This is where you answer the beginning questions and you give your results of the experiment. Your claim should be one or two sentences long.

<p>| |</p>
<table>
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<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
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</tbody>
</table>

**Section 5-Evidence:** *How do I know? Why am I making these claims?*
This is where you use your data to back up the claim you made. Justify why you made your claim. This involves analyzing your data tables, internal and external sources to back up your claim.

My claim based on evidence:

---

**Section 6-Reflection:**
*How have my ideas changed?*

---

How does this tie in with what you learned in class?

---
<table>
<thead>
<tr>
<th>How can you connect this lab to something outside of the classroom?</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Are there any new questions you have about the lab?</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tbody>
</table>

**Section 7-Work Cited:** Where did I get my information from? Am I giving credit to my source? Use APA style.
Appendix O

Sample Traditional Laboratory Write-Up
IDENTIFICATION OF METALS USING A FLAME TEST

INTRODUCTION
Have you ever wondered why a candle flame is yellow? Or what gives fireworks display its bright lavender, red, green, yellow and blue colors? When elements are heated to high temperatures, some of their electrons are excited to higher energy levels. These excited electrons then fall back to lower energy levels, releasing the absorbed energy in packages of light called photons, or light quanta.

The origin of flame colors
Flame colors are produced from the movement of the electrons in the metal atoms found in the compounds.

For example, a sodium atom in the ground state has the electron configuration 1s²2s²2p⁶3s¹.

When you heat it, the electrons gain energy and can jump into any of the empty orbitals at higher levels - for example, into the 7s or 6p or 4d or whatever, depending on how much energy a particular electron happens to absorb from the flame.

Because the electrons are now at a higher and more energetically unstable level, they tend to fall back down to where they were before - but not necessarily all at one time.

An electron which had been excited from the 2p level to an orbital in the 7 level, for example, might jump back to the 2p level in one go. That would release a certain amount of energy which would be seen as light of a particular color.

However, it might jump back in two (or more) stages. For example, first to the 5 level and then back to the 2 level.

Each of these jumps involves a specific amount of energy being released as light energy, and each corresponds to a particular color.

The color of the emitted light depends on its energy. Blue light is more energetic than red light, for example. When heated, each element emits a characteristic pattern of light energies which are useful for identifying the element. The characteristic colors of light produced when substances are heated in the flame of a gas burner are the basis of flame tests for several elements. In this experiment, you will perform flame tests for several metallic elements.
OBJECTIVES
1. To observe the colors emitted by various metal ions.
2. To evaluate flame testing as a method of detection of metals.
3. To understand the cause of excited state atoms.

MATERIALS (per lab group)
Safety glasses for each member
Bunsen burner
Test tubes containing the following salt solutions and a wire loop:
- 1 M potassium nitrate, KNO₃
- 1 M calcium nitrate, Ca(NO₃)₂
- 1 M strontium nitrate, Sr(NO₃)₂
- 1 M lithium nitrate, LiNO₃
- 1 M copper(II) nitrate, Cu(NO₃)₂
- 1 M sodium nitrate, NaNO₃
- 1 M barium nitrate, Ba(NO₃)₂
- 1 M lead(II) nitrate, Pb(NO₃)₂
- unknown solutions 1, 2, 3

SAFETY FIRST!
- Wear your safety goggles at all times during the lab.
- In this lab, you will be using an open flame. Tie back loose hair and any loose clothing. Avoid burns by not touching the flame or any items that may be hot.
- Never leave a flame unattended. One person from your group must be assigned to watch the flame at all times.
- The solutions you will be using contain potentially harmful & irritating materials. Avoid skin contact with these chemicals. If you get any chemicals on your skin, rinse with lots of water.
- Do not taste any of the substances or touch them with your hands.
- Return or dispose of all materials according to your teacher's instructions.
PRE-LAB QUESTIONS
1. List the safety precautions associated with using a Bunsen burner.

2. What is a quantum of energy? (see p. 128 of your Chemistry text)

3. List the colors of the visible spectrum, starting with the lowest energy color first and finishing with the highest energy color (see p. 139 of your Chemistry text).

PROCEDURE
1. Set-up your Bunsen burner by closing both air and gas valves on the burner.
2. Open the gas valve 2 turns and open the air valve 1 turn.
3. Attach the rubber hose to a gas outlet.
4. Each group should pick-up a test tube containing a salt solution.
5. Teacher will go to each group and light the Bunsen burner.
6. Place the wetted wire loop from the flask into the flame tip. Observe and record the color of the flame above the wire loop in your data table.
7. If needed you can repeat the flame test.
8. When finished, remain seated. Teacher will tell you when to pass the salt solution to the next group.
9. Repeat steps 6-8 until you’ve conducted a flame test on all the salt solutions.
10. Turn off your Bunsen burner by closing the lever at the gas valve.
ANALYSES AND CONCLUSIONS

1. Which particle in an atom is responsible for the production of colored light?

2. What is the reason for heating the chemicals in the flame?

3. In terms of the electron's energy level, explain why light is emitted when the metal salt solution is placed in a Bunsen burner (see p. 141 of your Chemistry text).

4. Using your answer to Pre-lab question #3 and the colors of the flames, list the elements in order of increasing energy of the light emitted.

5. Does the flame test give results that are qualitative or quantitative? Explain.

6. Aerial fireworks contain gunpowder and chemicals that produce colors. What element would you include to produce red? yellow? purple? green?
Data Table 1. Metals Flame Test Observations

<table>
<thead>
<tr>
<th>Compound</th>
<th>Metal</th>
<th>Metal Electron Configuration</th>
<th>Flame Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>Formula</td>
<td>Name</td>
<td>Name</td>
<td>Symbol</td>
</tr>
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<tr>
<td>unknown 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>unknown 3</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

7. Identify what metal was present in your unknown samples. Explain how you came to this conclusion.

8. Make a drawing of atomic orbitals that show what is taking place when the electron in a metal atom absorbs energy then releases that energy. Include and label the following details:
   - ground state
   - excited state
   - excited electron
   - absorbed energy
   - emitted energy
   - incoming photon or heat energy
   - emitted visible light