Effects of stepwise guided inquiry on students' attitudes and depth of knowledge from written lab reflections in high school chemistry

Melissa Rae Campbell Johnson

University of Northern Iowa

Copyright ©2021 Melissa Rae Campbell Johnson

Follow this and additional works at: https://scholarworks.uni.edu/grp

Recommended Citation
Johnson, Melissa Rae Campbell, "Effects of stepwise guided inquiry on students' attitudes and depth of knowledge from written lab reflections in high school chemistry" (2021). Graduate Research Papers. 1757.
https://scholarworks.uni.edu/grp/1757
Effects of stepwise guided inquiry on students' attitudes and depth of knowledge from written lab reflections in high school chemistry

Abstract
Many teachers find it challenging to embed guided inquiry into high school chemistry courses. Although guided inquiry provides excellent opportunities for students to engage in data analysis, misconceptions and loss of class time are teacher stated problems with guided inquiry. A stepwise inquiry project can slowly introduce students to the inquiry process of data analysis in high school chemistry.

This stepwise inquiry project examined three different inquiry labs designed around the anchoring phenomenon, “Which toothpaste protects our teeth the best?” Each lab progressed in inquiry level. Lab one was written at inquiry level one, confirmation. The second lab was written at level two structured inquiry and the third lab was written as a guided inquiry lab.

Three research questions were examined:

1. What is the effect of the stepwise inquiry project on the attitudes towards chemistry?
2. What is the effect of the stepwise inquiry project on the depth of knowledge in written lab reflections of high school chemistry students?
3. What is the correlation between attitude toward chemistry labs and depth of knowledge of written lab reflections?

The success of this stepwise inquiry project was measured using the Attitude Toward Chemistry Lesson Scale (ATCLS) and Depth of Knowledge (DOK) levels on student written lab reflections. Pre/post survey results from the ATCLS measured the change in attitude towards chemistry from the start of this stepwise project to the end. Student lab reflections were scored based on how their responses matched up with the DOK levels used on Hess’ Cognitive Rigor Matrix.

This stepwise inquiry project had mixed findings. Attitude toward chemistry labs slightly improved. The DOK levels for written lab reflections increased slightly from lab 1 to lab 3. Although both DOK levels and attitudes toward chemistry improved, there appeared to be a moderate negative correlation between attitude towards chemistry labs and increase in DOK levels for written student lab reflections.
Effects of Stepwise Guided Inquiry on Students’ Attitudes and Depth of Knowledge from Written Lab Reflections in High School Chemistry

Non-Thesis Curriculum Development Project for the Master of Arts in Science Education

University of Northern Iowa

Presented by

Melissa Rae Campbell Johnson

Spring 2021
This paper by: Melissa Rae Cambell Johnson

Entitled: Effects of Stepwise Guided Inquiry on Students' Attitudes and Depth of Knowledge from Written Lab Reflections in High School Chemistry

has been approved as meeting the non-thesis requirement for the

Degree of Master of Arts

Date: 4/1/2021  Dr. Dawn Del Carlo, Advisor

Date: 4/1/20/21  Dr. Jody Stone, Outside Reader
Abstract

Many teachers find it challenging to embed guided inquiry into high school chemistry courses. Although guided inquiry provides excellent opportunities for students to engage in data analysis, misconceptions and loss of class time are teacher stated problems with guided inquiry. A stepwise inquiry project can slowly introduce students to the inquiry process of data analysis in high school chemistry.

This stepwise inquiry project examined three different inquiry labs designed around the anchoring phenomenon, “Which toothpaste protects our teeth the best?” Each lab progressed in inquiry level. Lab one was written at inquiry level one, confirmation. The second lab was written at level two structured inquiry and the third lab was written as a guided inquiry lab.

Three research questions were examined:

1. What is the effect of the stepwise inquiry project on the attitudes towards chemistry?

2. What is the effect of the stepwise inquiry project on the depth of knowledge in written lab reflections of high school chemistry students?

3. What is the correlation between attitude toward chemistry labs and depth of knowledge of written lab reflections?

The success of this stepwise inquiry project was measured using the Attitude Toward Chemistry Lesson Scale (ATCLS) and Depth of Knowledge (DOK) levels on student written lab reflections. Pre/post survey results from the ATCLS measured the change in attitude towards chemistry from the start of this stepwise project to the end.
Student lab reflections were scored based on how their responses matched up with the DOK levels used on Hess' Cognitive Rigor Matrix.

This stepwise inquiry project had mixed findings. Attitude toward chemistry labs slightly improved. The DOK levels for written lab reflections increased slightly from lab 1 to lab 3. Although both DOK levels and attitudes toward chemistry improved, there appeared to be a moderate negative correlation between attitude towards chemistry labs and increase in DOK levels for written student lab reflections.
Table of Contents

Acknowledgements...........................................................................................................9

Chapter 1: Introduction ..................................................................................................10

Chapter 2: Literature Review .......................................................................................17

  Inquiry Instruction ...........................................................................................................17

  Levels of Inquiry ............................................................................................................18

  Inquiry and the NGSS ....................................................................................................20

Concerns with Inquiry Instruction ..................................................................................22

  Time ...............................................................................................................................22

  Safety .............................................................................................................................23

  Inconclusive Data ..........................................................................................................24

  Problems with Answers ..................................................................................................25

  Teacher Questioning ......................................................................................................25

Depth of Knowledge .......................................................................................................27

  Level 1- Recall and Reproduction ................................................................................28

  Level 2- Skills and Concepts ........................................................................................28

  Level 3- Strategic Thinking ..........................................................................................28

  Level 4- Extended Thinking ........................................................................................29

Solutions to Inquiry Implementation ...............................................................................30

Attitude ............................................................................................................................31

  Defining Attitude ..........................................................................................................31

  Choosing an Attitude Scale ..........................................................................................33

  Attitudes and Performance .........................................................................................34
## List of Tables

<table>
<thead>
<tr>
<th>TABLE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Levels of Inquiry: Teacher vs. Student Roles</td>
<td>19</td>
</tr>
<tr>
<td>2. Attitude Toward Chemistry Lesson Scale</td>
<td>33</td>
</tr>
<tr>
<td>3. DOK Scoresheet for Written Lab Reflections</td>
<td>47</td>
</tr>
<tr>
<td>4. Updated DOK Scoresheet for Written Lab Reflections</td>
<td>52</td>
</tr>
<tr>
<td>5. Results of Paired t-test for Pre/post Attitude Surveys Toward Chemistry</td>
<td>50</td>
</tr>
<tr>
<td>6. Sample Scores for Written Lab Reflection</td>
<td>53</td>
</tr>
<tr>
<td>7. Results of ANOVA for Scored Written Lab Reflections</td>
<td>55</td>
</tr>
<tr>
<td>8. Analysis of ANOVA for Each Criterion for Scored Written Lab Reflections</td>
<td>55</td>
</tr>
<tr>
<td>9. Post Hoc Analysis t-tests for Questions 3 and 4 from Written Lab Reflections</td>
<td>57</td>
</tr>
</tbody>
</table>
# List of Figures

<table>
<thead>
<tr>
<th>FIGURE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Frequency of DOK Levels for Written Lab Reflection for Criterion 3</td>
<td>58</td>
</tr>
<tr>
<td>2. Frequency of DOK Levels for Written Lab Reflection for Criterion 4</td>
<td>58</td>
</tr>
<tr>
<td>3. Correlation of Difference in Pre/post Attitude Toward Chemistry Surveys and Depth of Knowledge of Written Lab Reflections Using Average of All Lab Reflection Criteria</td>
<td>59</td>
</tr>
<tr>
<td>4. Correlation of Difference in Pre/post Attitude Toward Chemistry Surveys and Depth of Knowledge of Written Lab Reflections for Criterion 1</td>
<td>60</td>
</tr>
<tr>
<td>5. Correlation of Difference in Pre/post Attitude Toward Chemistry Surveys and Depth of Knowledge of Written Lab Reflections for Criterion 2</td>
<td>60</td>
</tr>
<tr>
<td>6. Correlation of Difference in Pre/post Attitude Toward Chemistry Surveys and Depth of Knowledge of Written Lab Reflections for Criterion 3</td>
<td>61</td>
</tr>
<tr>
<td>7. Correlation of Difference in Pre/post Attitude Toward Chemistry Surveys and Depth of Knowledge of Written Lab Reflections for Criterion 4</td>
<td>61</td>
</tr>
<tr>
<td>8. Correlation of Difference in Pre/post Attitude Toward Chemistry Surveys and Depth of Knowledge of Written Lab Reflections for Criterion 5</td>
<td>62</td>
</tr>
</tbody>
</table>
Acknowledgements

I have had immense support throughout this project both professionally and personally from many people. A “special” thank you should be expressed to each.

First to my husband Michael who not only supported my three year journey but also assisted in organizing my raw data for my non-thesis project. I appreciate your analytical methodology. It compliments my more feely views of chemistry.

Secondly my advisor Dawn who has been patient with my endless questions and always pointed me in the right direction for extra assistance when needed. This whole process would not run smoothly without you.

All the members of the science education program at the University of Northern Iowa have helped shape my new found confidence as a secondary teacher. I am especially thankful for Kyle’s willingness to explain the intricacies of small scale statistics and Jody’s straightforward interpretation of the NGSS. After this experience, I am prepared to start teaching on a higher level to change my methods from teaching equations to learning how to figure something out and make science more accessible for all students.
Chapter 1: Introduction

As a chemistry teacher, I often notice students struggle to answer higher order thinking questions during lab. Students wait for the teacher to pose a question. Then ask the teacher how they should answer that question. Students seem programmed to think that teachers want only one answer. Worse yet, students fear these answers are the only ones to earn top grades. Chemistry teachers should encourage deep thinking through inquiry instruction.

Inquiry instruction allows students to investigate a phenomena instead of learning about a topic. In a chemistry classroom, inquiry instruction involves exploring the physical world through asking questions and hands-on investigations. These questions come from natural curiosity about the world and drive the investigations. Being curious about the world leads chemists to seek out answers to their own questions through hands-on explorations. Sometimes these explorations lead to discoveries such as Avogadro's number or Dalton's law of partial pressures. Humans naturally want to explore their world through questioning. Inquiry science instruction taps into this natural curiosity and allows students to question natural phenomena. Question asking through inquiry instruction is encouraged by the Next Generation Science Standards (NGSS).

The NGSS emphasize three-dimensional science instruction starting with an anchoring phenomenon (NGSS Lead States, 2013). Anchoring phenomena are complex, puzzling events and/or processes that in order to understand, require exploration through several scientific investigations. These phenomena lead students to explore something in order to explain how and why it is happening. This differs from starting science units with terminology and knowing the scientific principles prior to the
investigations (McNeil & Reiser, 2018). Grounding curricula with an anchoring phenomenon encourages students to ask questions about a real-world concept. These questions spark student interest and engagement. Teachers carefully consider student generated questions that arise from the anchoring phenomenon in order to construct a storyline (unit plan) which skillfully incorporate the target Performance Expectations (PEs), Disciplinary Core Ideas (DCIs), Crosscutting Concepts (CCCs), and Science and Engineering Practices (SEPs).

DCIs, one of the three dimensions of the NGSS, are “normal” science concepts that are traditionally thought of as science content. For example, DCIs in physical science fall into the broad categories of matter and interaction, motion and stability, forces and interaction, energy, and waves and applications (NGSS Lead States, 2013). Unlike traditional science concepts of the past, the DCI’s are big ideas. NGSS recommends these big ideas be taught in bits and pieces with lesson level phenomena and relating back to the anchoring phenomenon. Students get so wrapped up in the lesson level phenomena that they do not realize they are learning new concepts such as molecules are made of atoms or balanced equations to show mass is equal on both sides of a chemical reaction. In a well constructed unit, these new concepts are constructed by the student and become a part of their own knowledge.

The next dimension, SEPs, actively involves students throughout their investigation of the anchoring phenomenon and lesson level phenomena. The SEPs are the inquiry part of implementing the NGSS. While engaged in SEPs students ask questions, design and use models, plan and carry out investigations, and analyze and collect data. Using the SEPs allows students to work collaboratively, asking questions
and diving deeper in the science concepts. The third dimension of the NGSS (CCCs) can be seen throughout the unit since it provides a common thread from start to finish.

The CCCs are seen in all science disciplines and include patterns, scale and proportion, and cause and effect (NGSS Lead States, 2013). Throughout each lesson level phenomena, students use the SEPs to build understanding of the DCIs and make connections across subjects using the CCCs. The three dimensions of the NGSS can be combined into a cohesive storyline starting with an anchoring phenomenon. Historically it took many years to develop the NGSS as national standards. While the foundation for effective implementation of NGSS is dependent on science teachers having a deep understanding of the ideals of inquiry teaching, there is evidence that many science teachers do not have a clear understanding of what inquiry entails.

When 571 high school chemistry teachers in the U.S. were surveyed, 45.5% reported no inquiry labs in their classroom (Deters, 2005). Part of the problem lies is the definition of inquiry. Inquiry science instruction can mean different things to different people. Some teachers interpret inquiry to mean students completing any lab activity. This can range from a “cookbook” lab to a student created lab procedure. As long as students are engaged in lab work then some teachers consider this practice “inquiry.” Other teachers insist that inquiry only occurs when students write their own research questions and then investigate those research questions themselves. The inquiry investigation can be hands-on, but does not have to be. The word investigate, in this case, can simply be researching the answer in Google and reporting the solution to the class in a slide show or conducting a full scale hands-on lab project. These two
definitions of inquiry science instruction are so strikingly different that it is no wonder there is confusion about the ideas of inquiry for both teachers.

Bell et al. (2005) provides a four part tiered rubric to guide teachers in the creation of inquiry instruction. The four levels are level one: confirmation, level two: structured inquiry, level three: guided inquiry, and level four: open inquiry. Most traditional labs are written at a confirmation or structured inquiry level. These labs are considered “cookbook” labs because the research questions, procedures, data tables, and analysis questions are all provided for the student (Bell et al., 2005). Guided inquiry science instruction allows students to be more involved with the process of investigation. During guided inquiry labs, students are more engaged collecting their own data (Cheung, 2008).

Problems during guided inquiry instruction arise when students have to analyze their own data (Furtak, 2006). Students seem lost and ask teachers to provide sentence stems for analysis assistance. Teachers can feel frustrated. If teachers directly answer student questions about how to do the lab and perform calculations, then students are no longer engaged in inquiry. After watching the students engage in data collection, teachers must sustain engagement through the analysis process. Teachers need instructional resources that use different levels of inquiry to feel more confident implementing inquiry based instruction. Whereas, students need labs that build their confidence in scientific practices.

Chemistry teachers state several reasons for not using inquiry lab instruction in their classrooms: inquiry labs take too long to implement and grade, too much content to cover each year, unsafe lab practices involved with inquiry labs when student groups
perform different labs simultaneously, lack of availability of adequate inquiry instructional materials, lack of professional development for inquiry instruction (Cheung, 2008; Costenson & Lawson, 1986; Deters, 2005). Cheung (2008) presented solutions to these problems for secondary chemistry teachers in Hong Kong. He created seven guided inquiry chemistry labs, offered professional development, and designed an attitude scale to measure the success of his work. As a result, Cheung concluded high schoolers are most successful during guided inquiry lab instruction that focuses on real world problems without predictable results. This is similar to how an NGSS storyline builds cohesion between the three dimensions by starting with a real world anchoring phenomenon. Cheung (2008) also suggested student groups should present their procedures orally to the class prior to the experiment. This creates a student-made class consensus lab procedure that the whole class can follow reducing safety issues. Finally teachers should grade lab reports with a rubric to ensure consistency (Cheung, 2008). The rubric used for this project is based on Webb’s Depth Of Knowledge (DOK).

The purpose of this study is to measure the change in attitude toward chemistry and change in DOK in written lab reflections throughout the stepwise project. The term stepwise explains how students progress through a series of three distinct inquiry labs which are connected through the anchoring phenomenon. Students will slowly progress through activities that increase in inquiry levels as they progress through the stepwise project. This project slowly introduces students to guided inquiry instruction by using lab practices learned from step 1 and step 2 for lab 3’s guided inquiry practice of student written procedures.
By providing high levels of inquiry based high school chemistry lab instruction, teachers prepare students for logical decision making needed to be successful in life in general. Inquiry lab instruction increases a student’s ability to ask their own questions and think for themselves. Students who engaged in inquiry are more likely to ask higher order thinking questions (Hofstein et al., 2005). College students who engage in inquiry lab practices showed positive gains in student motivation, critical thinking, and designing investigations (Brown et al., 2006).

This study will use Cheung’s Attitude Toward Chemistry Lessons Scale (ATCLS) and expand one of his guided inquiry labs into a stepwise project starting with a real-world phenomenon. The ATCLS consists of four dimensions; liking for chemistry lessons, liking for chemistry laboratory work, evaluative beliefs about chemistry, and behavioural tendencies to learn chemistry (Cheung, 2009b). Attitude surveys will be administered prior and post the stepwise project to build a cohesive picture of the students’ attitudes toward chemistry labs. Almost all research on attitudes and chemistry used an attitude scale to measure change in attitude (Cheung, 2009b; Ozden, 2008; Salta & Tzougraki, 2004; Xu & Talanquer, 2013).

The change in attitude will be compared with the written lab reflections to provide a comprehensive understanding of students’ attitude toward chemistry labs. Xu & Talanquer’s (2013) lab reflection questions based on the Science Writing Heuristic (SWH) template will be implemented at the conclusion of each inquiry lab. Student reflections’ for each level of inquiry will be scored on a rubric scale based on Webb’s DOKs.
This research is trying to figure out whether students increase their attitude toward inquiry chemistry labs when they are introduced to increasingly difficult levels of inquiry in a stepwise project. The gap this research hopes to fill is to provide teachers with a stepwise project around a real-world topic to engage students in inquiry chemistry labs. This engagement will be measured during the stepwise project through the analysis of students’ written lab reflections scored on a DOK rubric and measuring pre/post attitude scales toward chemistry labs. This research hopes to find a correlation between attitude toward chemistry lab and DOK levels using a stepwise project.
Chapter 2: Literature Review

Inquiry Instruction

Inquiry chemistry instruction looks different in various classrooms. Inquiry has been defined many times by different people all associated with science teaching. It is no wonder teachers have trouble identifying and distinguishing effective inquiry instruction. Within my own research I found eight different ideas held about inquiry:

- Science should be taught that is “hands-on” and “minds-on” (Lawson, 2000, p. 641).

- “In inquiry based learning students engage in hands-on activities that allow them to discover new concepts and develop new understandings” (Thibaut et al., 2018, p. 6).

- The National Research Council (NRC) states that “inquiry refers to diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work” (National Research Council, 1996, p. 23).

- The “teacher becomes a participant in the exploration rather than the focus of student attention” during inquiry instruction (Baker et al. 2002 p. 248).

- Inquiry occurs when “learners investigate the natural world, propose ideas, explain and justify assertions based on evidence and in the process, sense the spirit of science” (Hofstein et al., 2005, p. 30). This is agreed on by (Brown et al., 2006).
• “Inquiry instills higher understanding than simply following step-by-step instructions on a series of lab book pages” (Lord & Orkwiszewski, 2006, p. 342)

• Inquiry is present when “students write their own procedures-regardless of where the purpose, problem or question originated” (Deters, 2005, p. 1178). Cheung (2008) agrees.

• Students must be engaged in “active learning that emphasizes questions, data analysis, and critical thinking” during inquiry instruction (Bell et al., 2005, p. 30).

Based on all these ideas, one can see the confusion. For the purpose of this project, Bell et al. (2005) inquiry instruction definition will be used. Inquiry instruction is when students are actively engaged in learning with emphasis on questioning and data analysis.

Levels of Inquiry

In order for lab instruction to be considered inquiry it must start with a research question and have students analyze data with the use of critical thinking skills (Bell et al., 2005). There are four levels of inquiry. Level one: confirmation, provides students with the research question and procedure. Students collect and analyze data to confirm a known scientific principle (Bell et al., 2005). Students finding the specific heat of a known metal using a calorimeter from a teacher prepared procedure and data table is an example of a confirmation lab activity. Structured inquiry (level two) is similar to level one. Students collect data from a given research question and scripted procedure. However, the results are not expected. The specific heat of a known metal lab activity
could become a level 2 structured inquiry lab if students were asked to collect and record their own data of an unknown metal. Then students would need to compare the unknown metal's specific heat with that of known values to determine its identity. Both level one and level two labs are considered “cookbook” labs. These labs are most often found in textbooks (Bell et al., 2005). At level three: guided inquiry, students generate a procedure from a teacher provided research question. After the teacher has approved their procedure, students collect their data and analyze it (Bell et al., 2005). An example of guided inquiry is where students are asked how to determine the specific heat of an unknown object. It would be up to the students to design the lab procedure, determine how to collect and record data, and then analyze their data. Level four is called open inquiry because all aspects of scientific research are left up to the student. Students generate the research question, write the procedure, collect and analyze the data, and communicate the results. Some consider open inquiry similar to a full-scale research project and too difficult for most high school students (Bell et al., 2005). An example of open inquiry is if a teacher asks a student to research a real world example of specific heat. The student would need to design a way to show energy transfer as well as to determine how to calculate heat loss. Here the student would have to research how to answer their own question, how to model this in a lab setting, how to collect and record data, and finally how to analyze that data. The engagement among student and teacher at each level of inquiry can be seen in Table 1.

Table 1
Levels of Inquiry: Teacher vs. Student Roles

<table>
<thead>
<tr>
<th>Type of Inquiry</th>
<th>1- Confirmation</th>
<th>2- Structured</th>
<th>3- Guided-inquiry</th>
<th>4- Open-inquiry</th>
</tr>
</thead>
</table>
Inquiry and the NGSS

Today, inquiry chemistry instruction is guided by the Next Generation Science Standards (NGSS). The NGSS provide chemistry teachers with guidance on what students should know and be able to do with that scientific knowledge (NGSS Lead States, 2013). Using the NRC (2012) Framework for Science Education as a foundation, the NGSS integrates a three-dimensional design. The three dimensions are the Disciplinary Core Ideas (DCIs), Crosscutting Concepts (CCCs), and Science and Engineering Practices (SEPs).

DCIs provide key ideas which are grouped into four broad categories of science. These categories are physical, life, engineering and earth and space science. Under physical science are the subcategories of matter and its interactions, motion and stability, energy, and waves and their applications. Life science is divided into the subcategories of ecosystems, from molecules to organisms, heredity, and biological evolution. Earth and space science explores the topics of earth’s place in the universe,
earth's systems, and earth and human activities. Each of these subcategories of DCIs start as general concepts in elementary and build in complexity as students progress through secondary school. The limited number of DCIs allows students to deepen their understanding over time (NGSS Lead States, 2013).

As students progress through the DCIs, they are exposed to the similarities that all science disciplines have in common. These are the CCCs. The CCCs are common themes of science and allow students to integrate the different science disciplines. This integration makes connections to real world experiences. The real world is not just life or earth or physical science. The real world is interconnected by cause and effect, patterns, systems, matter and energy, scale, and stability and change. All of these are examples of the CCCs (NGSS Lead States, 2013).

While the DCIs provide the broad science content and the CCCs connect all the sciences together, the SEPs describe how to undertake science. The SEPs are the skills and processes scientists and engineers use as they investigate the natural world and/or problem solve. These practices include asking questions, developing models, planning and carrying out investigations, using mathematics and computational skills, constructing explanations and designing solutions, obtaining, and evaluating and communicating information. Students use these practices to do science in the classroom. In doing so, students learn the creative endeavor that scientists and engineers are involved in on a regular basis (NGSS Lead States, 2013). By repeated use of these practices, students will develop critical thinking skills and a lifelong appreciation of science.

NGSS ties the DCIs, CCCs, and SEPs together into Performance Expectations (PE). Instead of being composed of benchmarks or daily learning goals, the three
dimensions of the NGSS are expressed as PEs. The PEs are what students should be able to do by the end of the unit (NGSS Lead States, 2013). In Iowa (where this project takes place), only the NGSS’s PEs are required to be explicitly taught. For this project PE HS-PS1-5 will be used. It states that students must “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” (NGSS Lead States, 2013). The DCI for this PE is chemical reactions, particularly how chemical reaction rates change when new molecules are formed, bonds are broken, and thermal energy is added or removed from a reaction. The CCC is patterns which means looking for changes at different scales to provide evidence that the reaction occurred. The SEP asks students to apply scientific principles by constructing an explanation and designing a solution to how changing the temperature or concentration affects the rate of the reaction (NGSS Lead States, 2013). Since PEs combine all three dimensions of the NGSS, they are not accomplished until the end of the unit.

Although PEs combine all three dimensions of the NGSS, they are completely different from the benchmarks/standards from the 1990s. Instead of being told what to teach, teachers are given what students will learn by the end of the unit. Teachers have voiced concerns for how to implement the PEs in their classroom especially the SEPs, the dimension closely related to inquiry instruction practices.

**Concerns with Inquiry Instruction**

**Time**

Teachers give several reasons for not using inquiry labs. One is time. Inquiry labs take too much class time especially when students write their own procedure (Backus,
2005; Brown et al., 2006; Cheung, 2008; Costenson & Lawson, 1986; Deters, 2005; Keith-Lucas, 2001). It can take two to three times longer for students to write their own procedures than for teachers to use the procedure given from the textbook (Deters, 2005). It also takes more time to grade inquiry labs. The teacher must evaluate evidence applied to reasoning instead of accuracy matched to textbook answers (Cheung, 2008).

Since it takes more class time for inquiry investigations, some teachers would rather teach the topics planned out in a textbook. Teachers' are overwhelmed by their course schedules and there is administrative pressure to cover massive amounts of course material (Rissing & Cogan, 2009). Inquiry instruction takes more time to dive deeper into big ideas. Teachers are afraid they will have to cut out important parts of their old curriculum. Also, inquiry labs require extra teacher effort to set up. These labs may also need extra class time for student trial and error (Lanni, 2014). Finally, students may be performing different experiments at the same time. Therefore teachers must set up more than one lab for the same period. Extra time is something most educators say they do not have (Backus, 2005; Baker et al., 2002; Cheung, 2008).

**Safety**

Safety is another major concern for teachers (Backus, 2005; Baker et al., 2002; Cheung, 2008). Student designed inquiry labs make it difficult for teachers to manage potential hazards. Students might mix dangerous chemicals or use the wrong equipment. To avoid this, a teacher would examine student procedures prior to executing the lab work. This creates additional work for the teacher. There can be different safety concerns in the classroom lab at the same time if different students are performing different lab work at the same time (Cheung, 2008).
**Inconclusive Data**

Another teacher concerns with some forms of inquiry is that student created procedures will lead to mixed results. Student created lab procedures can fail or provide inconclusive data. Although this is a natural part of data collection, it can be frustrating for a student. Teachers fear that students will dislike chemistry if their lab procedures do not “work” (Deters, 2005). Lawson (2000) discourages telling students there is a “correct” answer to any lab activity. Scientific knowledge has not been created only by authorities knowing the answer (Lawson, 2000). If students feel that there is only one answer, it can lead to more problems such as students not asking questions because the teacher holds all the answers. This leaves the teacher feeling helpless. The teacher does not know how to help the student deal with inconclusive data without doing the data analysis for them or providing a “cookbook” lab.

Most of teachers’ concerns with inquiry revolve around student generated procedures. Student generated procedures can take more than one class period to complete. These same procedures can lead to inconclusive data and unknown safety concerns. Teachers have become comfortable with well tested “cookbook” labs that show the predicted results and safety precautions that teachers fear letting students design their own labs. As Bell et al. (2005) points out, inquiry instruction contains many levels which allows both teacher and student to become comfortable with inquiry techniques that do not have to involve student generated procedures. There can be benefits from student generated procedure. Backus (2005) eased herself and her students into inquiry lab instruction by simply removing the procedures from old “cookbook” labs. She found that although the labs took more time her students learned
not just chemistry but also how to approach a new problem, draw conclusions, and analyze their findings (Backus, 2005).

**Problems with Answers**

Teachers also feel more comfortable answering student questions directly, rather than with more questioning (Bruck & Towns, 2009). The real change from the "cookbook" labs of science past is how inquiry investigation requires students to construct new knowledge through open-ended questions. Gone are the days of lectures and fill in the blank notes. Student questions drive true scientific inquiry instruction. In order for students to take ownership of their own learning, teachers have to stop providing direct answers and allow students to think through solutions to their own questions. Some teachers avoid direct answers, but end up causing more confusion instead of scaffolding student understanding. Furtak (2006) found three different ways teachers avoid direct answers to student questions. Some teachers play the game of “evil scientist.” Only the teacher knows the correct results. The students must investigate to figure out what the teacher already knows. Other teachers state that anything goes. In order to make students comfortable, these teachers state there are no wrong answers and fail to correct the students' misconceptions during science investigations. Still other teachers give students a false “I don’t know” in response to their questions in hopes to encourage the student to investigate on their own (Furtak, 2006). None of these approaches encourage students to think critically about their own learning.

**Teacher Questioning**

Questioning plays a critical role in all levels of inquiry. Teachers can use student answers to scaffold student thinking. Chin, (2007) found that teachers use four different
questioning strategies to encourage students to construct their own scientific knowledge.

Socratic questioning uses a series of questions to encourage more inquiry. Socratic questioning includes pumping, verbal toss, and constructive challenge (Chin, 2007). Pumping is when the teacher restates the student's question and follows up with another question to point out the next step in the investigation. An example of a verbal toss or constructive challenge is when a teacher redirects a student question to the whole class instead of answering directly. The difference between verbal toss and constructive challenge is that during the constructive challenge the teacher knows that the student's question is misleading (Chin, 2007).

Verbal jigsaw is another type of questioning that can be useful in inquiry instruction (Chin, 2007). Verbal jigsaw uses student language to connect science vocabulary or key terms. This strategy works with the CCCs of the NGSS by connecting different branches of science with common terms such as cause and effect, patterns, scale proportion and quantity. Teachers use the CCCs to help students build relationships between their real world ideas. For example examining the relationship between reaction rate and the effectiveness of toothpaste brands. Making a connection to something students already know like toothpaste through the CCC of patterns will help students understand the scientific concept of reaction rates. Students will be able to grasp how quickly teeth decay and apply that to chemical reactions. Verbal jigsaw is a questioning strategy that can be used to enhance inquiry instruction.

Another type of questioning useful in inquiry is to rephrase from a different angle or use multimodal thinking called semantic tapestry (Chin, 2007). The same example of toothpaste and reaction rate can be linked together using multimodal thinking. It might
be easier for some students to understand reaction rates using a visual model. Others might need to read about it. Still others might like to see a symbolic chemical equation of Le Chatelier's principle to show how change in concentration affects reaction rates. Finally others might just need to hear how concentrations change due to different factors such as the concentration of fluoride to be able to investigate the concept. The last type of questioning that can be used in inquiry instruction is framing. Framing is when a teacher takes a student's question and rephrases it to show the relationship between it and the bigger picture (Chin, 2007). An example of framing is when a student asks how toothpaste can remove stains from one liquid, but not from another. A teacher would frame this student question back to the student and ask what is different about the two liquids. This would help the student think about the chemical properties of the liquids and how that affects the interaction between the different liquids and the toothpaste.

**Depth of Knowledge**

Teachers use different types of questionings to encourage depth of knowledge during inquiry instruction. Webb established four levels of depth of knowledge (DOK) to measure student cognition during assessments (Webb, 1997). DOK levels were used in the alignment of some state standards by subject (Hess, 2010b). The fourth level, extended thinking, requires complex cognitive connections within the content area and beyond. Most assessment tasks do not include this level of depth due to the time required for students to obtain mastery (Webb, 2002). In science the word “knowledge” can refer to both knowledge of scientific content and the knowledge of scientific processes (Webb, 2002). DOK levels are meant to be a “ceiling” not a target (Hess, 2010a). This allows teachers to measure the cognitive levels a student is currently at.
Therefore some assessments might fall under more than one DOK level depending on the student's ability.

**Level 1- Recall and Reproduction**

DOK level 1 is called recall and reproduction due to the simple one step task required of the student. A student response at this level is a simple right or wrong answer. If a student does more than automatically respond to a question then that response is beyond DOK level 1 (Hess, 2010a; Webb, 2002). Key verbs used by students at this level are “identify,” “recall,” “recognize,” “use,” “calculate,” and “measure” (Webb, 2002, p. 5). An example of a DOK level 1 assessment task is to perform a scripted procedure to determine the density of an unknown object.

**Level 2- Skills and Concepts**

DOK level 2 actions require more than one step tasks such as selecting and performing a procedure based on specific criteria to make an object sink, float, and hover. This level is more complex since it requires students to decide how to solve a problem. Keywords used at this level are “classify,” “organize,” “estimate,” “make observations,” “collect,” “display data,” and “compare data” (Webb, 2002, p. 6). Students need to provide details in their answers for why they selected the specific criteria. Using words such as “explain,” “describe,” or “interpret,” could be categorized as a higher level of DOK depending on complexity of the action (Webb, 2002, p. 6). As a comparison, it would be considered DOK level 2 to interpret data from a given graph, but DOK level 3 to create a graph from experimental data.

**Level 3- Strategic Thinking**
At DOK level 3, students use evidence to reason and plan out their thinking. This level of complexity does not come from multiple answers, but from the cognitive demands on the student (Webb, 2002). One example of a DOK level 3 task would be drawing conclusions from experimental data. Here the student must justify why they got the results they did and how that connects to the research question asked. The question might seem simple, but the answer given should describe the student’s thinking and provide evidence that relates the data to the experiment. Drawing conclusions from experimental data is an example of when DOK levels can be used as a ceiling instead of a target. If level 3 is the teacher’s “target”, then the student loses points for not fully explaining their answer. The student might not cognitively be able to connect the experimental data to the research question yet. If level 3 is the teacher’s “ceiling” instead of the target, then the student can reach level 2 by explaining the data they got from the lab given the specific conditions. The teacher can then provide the student with feedback on how to connect the data with the research questions to reach for the “ceiling” level 3 next time.

**Level 4- Extended Thinking**

Level 4 tasks require students to use complex reasoning within or among content areas (Hess, 2010; Webb, 2002). These assessment tasks require experimental design, planning, and usually an extended period of time. Most on demand tasks cannot require the cognitive demands of DOK level 4. Assessment goals can be worded to extend student thinking in a way to address parts of level 4 (Webb, 2002). One example is asking students to conduct an experiment after identifying a problem/phenomenon. Then designing and carrying out the experiment. Finally collecting data and analyzing the
results. Webb (2002) points out complex reasoning occurs when students conduct an experiment over an extended period of time. This project's final goal of planning and conducting a guided inquiry experiment around the anchoring phenomenon, “Which toothpaste protects our teeth the best?” should be reaching for DOK level 4. Therefore, by the end of this project some students may show elements of complex reasoning related to DOK level 4.

**Solutions to Inquiry Implementation**

With practice, students can develop mastery, learn to communicate, pay attention to details, increase engagement and develop error analysis during inquiry instruction (Deters, 2005). Sophomores at a private urban high school self-reported that designing their own chemistry labs made them feel more confident. They no longer relied on the textbook, understood construction of data tables, and found lab work more enjoyable. Students reflected that writing their own lab procedures gave them clarity toward future labs. Knowing the details a lab writer goes through, made students more conscientious of lab procedures given to them (Deters, 2005). High school students who performed a year's worth of chemistry experiments without being provided the experimental procedures were better able to engage in critical analysis of data and were able to hypothesize how to approach new problems. These students enthusiastically repeated their experiments after discussing student error analysis through peer review (Backus, 2005).

Anderson (2002) compiled research that focused on inquiry approaches. He found that students who practiced inquiry made cognitive gains, increased scientific literacy and increased conceptual understanding through inquiry approaches. Some
students found inquiry chemistry labs challenging. Serafin & Priest (2015) designed an organic chemistry guided inquiry lab for college students to determine products using spectroscopic lab techniques. Although the 200 undergraduate students were challenged by this organic chemistry lab, they also found it more engaging due to its puzzle-like nature. Anchoring phenomena provide a puzzle-like experience that can only be solved through inquiry investigations and student questions. These phenomena are focused on real world problems, connect to students’ life, and can draw students to inquiry chemistry. Inquiry chemistry investigation should focus on a variety of activities at each inquiry level driven by answering student questions. According to Cheung (2008), in a high school setting, inquiry should never exceed guided inquiry. Open inquiry requires students to create their own research questions. Cheung (2008) believe’s student led research is beyond the cognitive skills of most high school students. Guided inquiry provides the opportunity for student groups to present their procedures to the class to critique which saves class time and provides the same safety practices for all students. Next, the student groups collaborate and create a consensus procedure for the next day’s lab (Cheung, 2008). This allows the teacher to facilitate only one procedure and the procedure is student written. During the presentation, students engage in critical thinking skills ironing out missing safety and lab practices from each other’s procedures (Cheug, 2008). The presentations give students confidence to perform the student created guided inquiry lab because they discussed it as a class. Student confidence can lead to an increase in attitudes toward chemistry with future guided inquiry lab projects.

Attitude

Defining Attitude
Attitude is defined as the positive or negative response toward an object (Attitudes, 2020). The object can be anything. In this case attitude will be measured toward inquiry chemistry instruction. The attitude that is formed can be through one of the following dimensions: affective, behavioral, cognitive. Affective process is the feelings and emotion a person has towards an object. A person’s attitude affects their feelings about the object (like or dislike). For example, does a person like or dislike chemistry. Behavioral processes are how a person acts and responds toward an object based on their attitude. For example, a student with a negative attitude toward chemistry will demonstrate the behavior of not paying attention in class versus a student with a positive attitude toward chemistry who willing answers questions during class. Finally, cognitive processes can affect a person’s beliefs or knowledge about an object. For example, if a student has heard chemistry is a hard class that will affect their attitude toward chemistry versus a student who was told chemistry is an easy class. All three dimensions of attitude are connected. A student not liking a class (affective) can lead to the same student not paying attention in that class (behavioral) which leads to the student thinking this class is too hard (cognitive).

In order to measure each of these dimensions, a study must allow participants the opportunity to express their behavioral, cognitive, and affective attitudes. Behavioral responses can be measured through observations or self-reporting on an attitude survey. For example behavioral responses on an attitude survey would include “I would like to become a chemist” “I would like to have fewer chemistry lessons”. Affective responses can be measured through self-reported feelings on an attitude scale or written responses. Examples of affective questions on an attitude survey are “It is interesting
doing chemistry experiments” or “I hate doing chemistry experiments”. Cognitive responses can be measured through interviews or surveys that allow students to write statements about beliefs. Examples of cognitive responses on an attitude survey are “Chemistry knowledge is worthwhile” “Chemistry is a necessary subject that should be taught to all students” (Cheung, 2009b; Kind et al., 2007). This study uses both an attitude scale and written lab reflections to measure the three dimensions of attitudes.

Choosing an Attitude Scale

Attitudes in science can be measured in two ways: attitudes toward science (i.e. interest in science) and scientific attitudes (i.e. skepticism, honesty) (Gardner, 1975). In attitude toward science, the focus is on the scientific object such as - in this study - the subject of chemistry. A scientific attitudes study would focus on the scientific trait such as open mindedness. Cheung (2009b) used Gardner’s framework for attitudes toward science when he created the attitude toward chemistry lesson scale (ATCLS) (Table 2). Cheung administered the eight question ATCLS to 954 students ages 16-19 in 6 different schools in one month. His study indicated that males enjoyed chemistry lessons more than females in Secondary 4 and 5, but over time males declined in their appreciation for chemistry whereas females did not. Cheung found the ATCLS easy to administer and reliable. The Cronbach’s alpha for the items on the ATCLS ranged from 0.76-0.86 (Cheung, 2009a). He recommended its use to all secondary teachers in Hong Kong to assess how students value inquiry-based laboratory work in chemistry (Cheung, 2009b).

Table 2

<table>
<thead>
<tr>
<th>Attitude Toward Chemistry Lesson Scale (ATCLS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strongly Disagree</td>
</tr>
<tr>
<td>--------------------</td>
</tr>
</tbody>
</table>
1. Chemistry experiments are interesting 1 2 3 4 5 6
2. What I do in chemistry experiments is related to my daily life. 1 2 3 4 5 6
3. I have learned from chemistry experiments that there is often more than one way to solve a problem. 1 2 3 4 5 6
4. Chemistry experiments are important to chemistry students. 1 2 3 4 5 6
5. I like doing laboratory work in which I have a chance to plan the procedure. 1 2 3 4 5 6
6. Chemistry experiments are a good way for me to apply chemical knowledge and practical skills. 1 2 3 4 5 6
7. Chemistry experiments are challenging because I need to decide how the data should be presented and analyzed. 1 2 3 4 5 6
8. Overall, I like it when the teacher tells me what to do in a chemistry experiment. 1 2 3 4 5 6

Note: Student responses are to mark one answer to each question on a scale of 1 to 6, with 1 = strongly disagree and 6 = strongly agree. Adapted from: "Inquiry-based laboratory work in chemistry: Teacher’s guide." by Derek Cheung, 2006, Department of Curriculum and Instruction, The Chinese University of Hong Kong.

**Attitudes and Performance**

Attitudes towards science can affect class performance. Weinburgh (1995) found a correlation between attitude in science and scientific achievement. Girls had a stronger correlation between science attitude and achievement than boys at 0.55 to 0.50. This suggests girls are more likely to achieve if they like the subject matter (Weinburgh,
In Greece, chemistry is taught theoretically without hands-on lab activities. Salta & Tzougraki (2004) suggested this practice causes students’ disinterest in chemistry. Their study found a low positive correlation between achievement and attitude toward chemistry. If a student perceived chemistry was difficult they did poorly (Salta & Tzougraki, 2004). High school chemistry students in Hong Kong only showed a slightly positive attitude toward chemistry practices (Cheung, 2008). It seems high school students take chemistry as a requirement; not for enjoyment. As a chemistry instructor, making chemistry more enjoyable for students is a priority to improve student achievement.

**Student Attitude Toward Inquiry Instruction**

“Tell Me and I Forget. Teach Me and I Remember. Involve Me and I Learn” is an often used quote from an unknown source (Quote Investigator, 2019). Inquiry lab instruction requires students to be active participants. Students enjoy hands-on lab activities (Cheung, 2009a; Okebukola, 1986). The problem arises when students are asked to create their own procedures, data tables, and analyze the hands-on lab. Inquiry can seem too challenging for students who become easily frustrated. They are fearful of making mistakes in the lab and reflect that designing their own lab is challenging. Degininging labs made students fear being in control. Students self-reported that they normally follow the lab directions and found guided inquiry labs difficult when they were responsible for the procedure. Also, if the whole lab process is not designed properly, it can lead to mistakes down the road (Deters, 2005). Since guided inquiry lab designs require active students, unfamiliar situations arise. Some students lack the requisite skills to generate possible solutions to the inquiry questions presented (Baker et al.,
2002). Students have been trained that only teachers know the answer and rely on teachers to solve all their problems (Bruck & Towns, 2009). During guided inquiry the teacher takes the role of facilitator. The facilitator avoids answering direct student questions. Instead, the facilitator guides students through open-ended questions that allow students to answer their own questions. Students initially feel frustrated assuming the teacher is purposely not helping them (Bruck & Towns, 2009).

**Theoretical Foundation**

When asked, 1,638 11th grade chemistry students ranked attitudes toward chemistry as the number one factor related to their performance in the laboratory (Okebukola, 1986). Attitude is a measure of the internal state that affects a person’s behavior toward another person, object, or event. Since attitude happens internally within a student, it is best to measure attitude change over time through self-reported surveys. This allows students to make specific choices affected by specific occurrences.

Attitudes can be changed through direct methods such as reinforcement, conditioned response, or success and indirect methods such as a human role model (Gagne et al., 1992). Gagne thought role models influenced positive attitudes since learners enacted the role model’s behavior. A role model affects both internal and external conditions of attitude. Internal conditions included respect for the role model. A teacher role model could provide praise and impartially for all students. This establishes trust between the teacher and the students. This could lead to a change of attitude toward the subject. For example if the students feel they can trust the teacher’s teaching practices then students are more likely to have a good attitude toward the subject taught. Other internal conditions are the role model’s intellectual skills and knowledge of
behavior wanted to establish (Gagne et al., 1992). If students feel like the teacher is knowledgeable about the subject being taught, the students are more likely to imitate the role model's behavior.

External conditions affecting attitude change are how the model is presented, how the learner recalls the applications of the model, communication/demonstration of the model, and that the final outcome of the model is satisfactory (Gagne et al., 1992). Although Gagne et al. (1992) insists on a human role model, in science education a model is a representation of a process/system that describes part of the phenomenon. Models are a visual way to communicate explanations of complex data (Pokapū Akoranga Pūtaiao, 2018). Looking at the external conditions from a scientific models perspective, then student attitude change occurs when the anchoring phenomenon model is presented. Students learn how to apply this model to level 1 and level 2 inquiry labs. Finally student attitude change is measured after the final outcome of the level 3 guided inquiry lab that returns to solving the anchoring phenomenon. The attitude change is measured using two methods (attitude scale and written lab reflections) to check for consistency.

This mixed method stepwise inquiry project will engage high school chemistry students in a real world phenomenon in order to measure their attitude toward chemistry labs and DOK levels of their written lab reflections. The stepwise inquiry project will consist of three labs set at different levels of inquiry: confirmation (level 1 inquiry), structured (level 2 inquiry), and guided inquiry (level 3). As the students move through each lab, they will slowly be instructed on all the steps needed to create a lab procedure for the guided inquiry lab. This should reduce frustration students feel during guided
inquiry labs. The purpose of this study is to measure student attitude change toward chemistry labs, measure the DOK levels of written lab reflections, and examine the correlation between the two during this stepwise project. No other study could be found that compared attitude scales with DOK levels of written lab reflections during a stepwise chemistry project.

This mixed method study examined the following research questions:

1. What effects does a stepwise inquiry lab project have on the attitudes towards chemistry labs of high school chemistry students?
2. What effect does the stepwise inquiry lab project have on the depth of knowledge in written lab reflections of high school chemistry students?
3. Is there a correlation between attitude toward chemistry labs and depth of knowledge of written lab reflections?
Chapter 3: Methods

Population and Sample

Data was collected from high school students enrolled in a year long chemistry course attending a private, Midwestern high school. The elective chemistry course for 10th and 11th grade students met 4 days a week. Three of those days the class is 45 minutes long. One day of the week the class is 70 minutes long. The 70 minute class was preferred for laboratory work since it allowed for an uninterrupted block of time to complete longer experiments. There were 2 sections of chemistry with a total of 21 students. One section had 14 students. The other only had 7 students. Students worked in lab groups of 3 to 4 students per unit. Students were in the age range of 16-18 years old.

Stepwise Inquiry Project Design

The data was collected during one unit consisting of three inquiry labs in a stepwise inquiry project. The first lab was at level one confirmation. The second lab was at level two structured inquiry. The third lab was a guided inquiry lab. To provide consistency for the students, all the labs revolved around the same anchoring phenomenon. The student handouts for all three labs are located in Appendix A.

The stepwise inquiry project began with the introduction of the anchoring phenomenon of: “Which toothpaste brand protects our teeth the best?” (adapted from Cheung, 2006, p. 29). Students generated answers to this question and recorded their initial models about this real-world problem in their lab notebooks. The teacher used semantic tapestry to present the anchoring phenomenon (Chin, 2007). Students presented both words and pictures for how they thought toothpaste worked to protect
their teeth. This type of scientific model building helped students build a deep meaningful connection with the anchoring phenomenon. This information was not graded since its intent was to engage the students.

Next, students began the first inquiry lab at level one confirmation (Bell et al., 2005). The teacher generated the research question, “Which ingredients of toothpastes are most effective in removing a stain from ceramic and porcelain tiles?” (adapted from Riley, 2016). This lab instructed students to determine how well toothpaste cleans teeth and to compare different brands of toothpaste. Students were provided a written procedure and blank data table. Throughout the lab, the teacher used two inquiry question strategies: framing and pumping (Chin, 2007). These strategies helped the students understand the relationship between anchoring phenomenon and the tile lab. Students confirmed their predictions of how the active ingredients in the toothpastes affect the two different tiles and how it relates to the function of toothpaste. These answers were written in their lab reflections with their feedback on how the lab went and improvements for next time. This lab was related to the NGSS’s SEP “analyzing and interpreting data” (NGSS Lead States, 2013).

The second inquiry lab moved students to level two: structured inquiry. Students were provided the research question, “What effect do sugary drinks have on teeth?” (adapted from Busboom et al., 2012). Students received a teacher made procedure but constructed their own data table (Bell et al., 2005). In this lab, students compared the staining of different types of sugary drinks on chicken egg shells. During the lab, the teacher used verbal jigsaw to help students understand how the patterns in their data related to real world phenomena (Chin, 2007). Here the written lab reflection contained
evidence of how the student collected data related to the research question, what they learned from the lab, sources of error, application of the lab to real life, and feedback on how the lab went. This lab is related to the NGSS CCC patterns. Students looked for patterns in the different amounts of staining on teeth (egg shells) due to different reactions with sugary drinks (NGSS Lead States, 2013).

At the third level of inquiry students participated in a guided inquiry lab. Combining the knowledge gained from the last two labs, the students used the guided inquiry lab to answer the anchoring phenomenon, “Which toothpaste brand protects our teeth the best?” They relied on the practices learned in level one and level two labs to create their own procedures in response to the anchoring phenomenon. The teacher also provided three other questions to guide the students through this inquiry practice: “How will you measure the rate of tooth decay for each brand of toothpaste,” “What variables need to be kept constant in this investigation,” and “How will the proposed procedure be feasible and safe?” (adapted from Cheung, 2006, p. 29). These questions were connected to the NGSS PE, HS-PS1-5. It states, “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.” While completing this inquiry lab, students used the CCC of patterns to find the best brand of toothpaste. Students designed a solution and constructed an explanation for the difference of reaction rates of eggs covered in different toothpastes soaked in different acidic solutions (Bell et al., 2005; Cheung, 2006; NGSS Lead States, 2013). Therefore students engaged in all three dimensions of the PE.
Students wrote procedures in lab groups of three to four students. The teacher held individual conferences with each lab group to discuss their procedure. During the student lab group conferences the teacher went over supplies needed and safety precautions. The teacher used framing to help students determine how they wanted to collect their own data (Chin, 2007). Since each lab group had chosen a similar procedure with minimal changes, groups were allowed to complete their own procedures without creating a class consensus procedure. Each student group also decided how to collect and record their data (Bell et al., 2005; Cheung, 2006; NGSS Lead States, 2013).

**Quantitative Attitude Study**

Cheung’s (2006) ATCLS was chosen to measure students’ attitudes toward chemistry for the following reasons: ATCLS was based on a theoretical framework, was multidimensional, led to the creation of a new chemistry curriculum, and has a short set of questions and scale of responses. Cheung (2009b) administered his pilot survey of the ATCLS to 777 students, the final version to 954 students. As a result of his attitude study, Cheung (2011) created a new secondary chemistry curriculum consisting of 10 guided inquiry labs.

Student interviews were used to check the validity of the ATCLS. Cheung (2009b) randomly interviewed 10 chemistry students to gather data while writing his chemistry attitude scale. Students shared they did not enjoy chemistry when it was “chalk-and talk” (Cheung, 2009b, p. 2194). Instead, students prefer chemistry to connect to their daily life. Students enjoyed chemistry when they found the pH of Coca-Cola, found the amount of ethanol in a bottle of red wine, and discussed how the presence of Thalidomide inhibited the growth of the limbs of babies (Cheung, 2009b).
Previous attitude scales lacked theoretical frameworks (Cheung, 2009b). Attitude by definition is based on behaviors and experiences. Without a theoretical basis, attitude scales cannot give a complete impression of how students experience chemistry. The ATCLS uses the theoretical framework of Oskamp & Schultz (2004) based on the latent viewpoint of attitude (Cheung, 2011). Cheung proposed that attitudes are hidden processes brought out in a chemistry classroom. Since this latent attitude can be triggered by anything, a chemistry educator must carefully plan and implement lab instructions to meet these latent views (Cheung, 2011).

Another problem with other attitude scales, was the lack of multidimensionality. The confirmation of an attitude scale has seldom been tested by multidimensionality (Cheung, 2009b). Validity of attitude scales was hard to measure. Several attitude scales measured their validity based on Cronbach’s alpha which only measures an instrument’s internal consistency. This measured each item in the set to see if each behaves the same way. Even if none of the questions are giving a true impression of student attitudes, then the attitude scale could still produce a valid Cronbach’s alpha (Kind et al., 2007). Alternate ways to measure validity include using a theoretical framework and using student responses from open ended questions. Cheung used both a theoretical framework and open ended student questions to create the ATCLS.

ATCLS was easy to give to students since there is a set number of questions (8) and a set number of responses (6 points). Interviews and open-ended questionnaires are difficult to get high school students to complete and may introduce unintentional biases from the researcher/teacher. Data analysis was easily performed with the ATCLS.
and the researcher remained unbiased. Also this researcher analyzed the ATCLS and DOK levels on the written lab reflections to look for a correlation.

**ACTLS Administration**

To measure the change in attitude the ATCLS was administered (Cheung, 2009a). Students completed the pre survey using the ATCLS prior to introduction to the anchoring phenomenon of the stepwise project. Table 2 shows the items and scales of the ATCLS that were administered. These surveys were collected using Google forms. As a Google school, these surveys were sent out and collected by the school secretary until the end of the semester. Google surveys allowed for collection of email addresses to easily match pre/post survey results. At the conclusion of the stepwise inquiry project, post surveys using the same ATCLS administered the same way as the pre-surveys. IRB approval was requested and obtained (Appendix B).

The ACTLS measured if the stepwise project produced a change in student attitudes toward chemistry labs over time. Using Gagne et al.’s (1992) attitude framework, students needed to overcome four external conditions in order to change their attitude towards chemistry labs. First, the model needed to be presented in a way to engage student interest. Since the anchoring phenomenon was about protecting teeth it was interesting to most students. Secondly, the learner needed to apply applications of the model to a new situation. This occurred throughout the stepwise project. During the level one confirmation lab, students were slowly introduced to the importance of inquiry methods. Then they took more control of the lab writing process moving from level one to level two structured inquiry. By level three guided inquiry, students applied the learned inquiry skills to writing their own procedure to figure out the anchoring phenomenon. The
third external condition to overcome attitude change was communication and demonstration of the model. During the level 1 confirmation and level 2 structured inquiry lab students demonstrated parts of the final model. Throughout the stepwise project, the teacher guided students with socratic questions to make connections between the individual labs and the anchoring phenomenon (Chin, 2007). Finally the fourth external condition to overcome was to produce a satisfactory final outcome. It was predicted that if students feel successful with the level 3 guided inquiry lab then their attitude toward chemistry would become more positive. To confirm the validity of student attitudes, this study compared quantitative attitude surveys with qualitative student written lab reflections.

Lab Reflections

The format for the lab reflection for each of the 3 labs followed Xu & Talanquer’s Science Writing Heuristic (SWH) template (2013). Their study measured the effects of inquiry levels on written lab reflections in college level general chemistry. The SWH template provided both a guideline for writing student lab reports and a teaching tool to guide lab instruction (Burke et al., 2006). The seven sections of an SWH lab report included the following: beginning questions, safety considerations, procedures and tests, data, calculations and representations, claims, evidence and analysis, and reflections and additional questions (Burke et al., 2006; Xu & Talanquer, 2013). The qualitative data for this project focused on the last section of the SWH template called reflections and additional questions. The following were used as guiding questions for the student written reflections for all 3 labs in this project:

What did you learn in this lab?
What did you not completely understand?
How have your ideas changed as a result of this lab?
How does this lab relate to what is being discussed in class and/or real life?
What sources of errors occurred during the lab?
How would you improve what you did?
What new questions do you have about the anchoring phenomenon?

(Burke et al., 2006; Xu & Talanquer, 2013.)

Xu & Talanquer (2013) compared their written lab reflections to Bloom’s taxonomy, however this project used Webb’s DOK levels. Webb (2002) provided guidelines to determine when science work is at each of his four DOK levels. In order to be considered a level one (recall & reproduction), students must have recalled or answered yes or no to a posed question (Hess, 2010a; Webb, 2002). If a student simply answered the question without explaining then it was registered as level one. At level two (skills & concepts), students organized, specified, described and explained their answers (Hess, 2010a; Webb, 2002). A student had reached level two when their answers interpreted the information but did not begin to draw any conclusion. Once the student drew conclusions or provided reasoning for the phenomenon, then the student had moved to level three (strategic thinking). In level three, students used abstract and complex thinking to justify the results they had collected (Hess, 2010a; Webb, 2002). The difference between level three and level four thinking was that level four required additional time and analysis of multiple sources of evidence using complex/abstract themes. At level four, students showed high cognitive development by providing
generalization of the results obtained and making connections across several variables. They connected the current lab with previous lab work (Hess, 2010a; Webb, 2002). Level four students understood the fundamental relationship between the scientific principles that founded the experiment and connected them together along with a real world application (Table 3).

**Table 3**

*DOK Scoresheet for Written Lab Reflections*

<table>
<thead>
<tr>
<th>Criteria</th>
<th>DOK Level 1</th>
<th>DOK Level 2</th>
<th>DOK Level 3</th>
<th>DOK Level 4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Written Lab Reflection</strong></td>
<td>What is knowledge?</td>
<td>How can this knowledge be used?</td>
<td>Why can the knowledge be used?</td>
<td>How else can this knowledge be used?</td>
</tr>
<tr>
<td>1. Make conclusions that are well supported by the data. (learned/did not understand)</td>
<td>Recall &amp; Reproduction</td>
<td>Skills &amp; Concepts</td>
<td>Strategic Thinking</td>
<td>Extended Thinking</td>
</tr>
<tr>
<td>2. Uses scientific ideas to try to explain. (connection to class/real world application)</td>
<td>Recall &amp; Reproduction</td>
<td>Skills &amp; Concepts</td>
<td>Strategic Thinking</td>
<td>Extended Thinking</td>
</tr>
<tr>
<td>3. Identifies major sources of error and explains their effects on results.</td>
<td>Recall &amp; Reproduction</td>
<td>Skills &amp; Concepts</td>
<td>Strategic Thinking</td>
<td>Extended Thinking</td>
</tr>
<tr>
<td>4. Identifies possible improvements in the experimental design.</td>
<td>Recall &amp; Reproduction</td>
<td>Skills &amp; Concepts</td>
<td>Strategic Thinking</td>
<td>Extended Thinking</td>
</tr>
<tr>
<td>5. Extension of research (new questions/change of ideas)</td>
<td>Recall &amp; Reproduction</td>
<td>Skills &amp; Concepts</td>
<td>Strategic Thinking</td>
<td>Extended Thinking</td>
</tr>
</tbody>
</table>

Chapter 4: Analysis/Results

Data Analysis

The research questions for this study were to measure the effect of attitudes towards chemistry labs, measure the levels of DOK from written lab reflections of high school chemistry students during a stepwise project and to measure the correlation between the two. In order to measure these, t-tests, one-way ANOVAs and Pearson correlation were conducted. Students took the same ATCLS prior to the stepwise inquiry lab project (pre survey) and after completing the guided inquiry lab (post survey). The ATCLS was measured on a Likert scale from strongly disagree to strongly agree on a numerical scale from 1 to 6 (Table 2). The Likert scale data was measured using the numerical value that corresponds to the same degree. A t-test compared the change in attitude from the post survey to the pre survey.

Written lab reflections were collected from each inquiry lab (three in all). Analysis was scored using a rubric that is based on Webb’s DOK levels (Table 3) (Hess, 2010b; Webb, 2002). The written lab reflections were coded using predetermined codes corresponding to the 4 levels of DOK using Hess’ Cognitive Rigor Matrix (Table 4). Hess’ Cognitive Rigor Matrix blends Webb’s DOK levels to Bloom’s Cognitive progresses (Hess, 2010b). DOK level 1 answers the question, “What is knowledge?” At this level, student reflections simply stated how the lab went. DOK level 2 student reflections answered the question, “How can this knowledge be used?” Student reflections explained how data was found and what they did or did not learn. “Why can the knowledge be used?” is the question at DOK level 3. Here student reflections explained how the data supported or refuted their hypothesis. At DOK level 4 student reflections
extend their learning by relating the lab to a new lab and answering the question, “How else can this knowledge be used?” (Francis, 2019). Once a written lab reflection was scored 1-4 on the rubric the data was transformed into numerical form using the average scores from the 5 criteria. The numbers were used in one-way ANOVA, t-test, and to calculate Pearson correlation. The one-way ANOVA compared the change in levels of DOK between the confirmation lab, structured lab, and guided inquiry lab. The t-test compared statically significant results Post Hoc to find out which two labs were statically significant. A Pearson correlation was calculated to determine the association between change in attitude and change in levels of DOK of written lab reflections throughout the stepwise project.

**Results of the Attitude Surveys**

Prior to the start of the first lab in the stepwise project, students took a pre attitude survey via a Google form. Students were offered 5 points extra credit for completing the survey in a timely manner. Following the third lab in the stepwise process, students were sent the post attitude survey via a different Google form. Again students were offered 5 points extra credit (for a total of 10 extra credit points) for completing the post attitude survey in a timely manner. The Google form pre/post attitude surveys were sent to the high school chemistry students by the high school secretary. Surveys were collected by the secretary until the end of the semester. After pairing the pre and post survey responses, student names and email addresses were removed and changed to unassociated numbers by an uninvolved party before data analysis.
Unpaired student results were eliminated leaving 8 out of a possible 21 chemistry students in the class. Student responses were written on a scale from strongly disagree to strongly agree. These words were changed to numbers i.e. strongly disagree representing 1 to strongly agree representing 6 for questions 1-7. Question 8 data was changed to strongly disagree representing 6 and strongly agree representing 1 (i.e. reverse scored). This question asked students if they liked non-inquiry labs which held the opposite meaning of the original question from the ALCS. The mean and standard deviation were calculated for both pre/post attitude surveys (Table 5). To compare students’ scores on the pre/post attitude survey, a paired t-test was calculated. There was statistical significance between the pre/post attitude scale, t(8) = 4.41, p < 0.001. In order to calculate effect size, Hedges’ g was chosen over Cohen’s d due to the small sample size (Glen, 2016). Cohen’s d can be biased when sample sizes are too small. The effect size (0.67) using Hedges’ g was in the medium range. Therefore, there was a moderate effect of the stepwise project on the attitude toward chemistry labs of the high school students who submitted their attitude surveys. It should be qualified that these results may not be accurate due to the small sample size.

Table 5

<table>
<thead>
<tr>
<th></th>
<th>M</th>
<th>SD</th>
<th>p</th>
<th>g</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre</td>
<td>4.00</td>
<td>0.51</td>
<td>0.017</td>
<td>0.67</td>
</tr>
<tr>
<td>Post</td>
<td>4.41</td>
<td>0.54</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Results of the Student Written Lab Reflections

As a part of their chemistry class students were required to keep a laboratory notebook. This notebook was graded based on eight sections:

1) Title
2) Purpose/Scope
3) Materials
4) Safety
5) Procedure
6) Data
7) Calculations
8) Summary and Results

For this project, the last section (summary and results) was collected from the high school chemistry students for each of the three stepwise labs. On the lab notebook rubric, students were asked to include their final results and answer seven reflection questions in their own words using complete sentences. Prior to scoring, these seven reflection questions were put into five criteria (Table 4). Using Hess’ Cognitive Rigor Matrix: Applying Webb’s Depth-of-Knowledge Levels to Bloom’s Cognitive Process Dimensions-Math/Science, each criterion was matched with one of Bloom’s taxonomy heading (Hess, 2010a). Hess’s Cognitive Rubric Matrix matched Bloom's taxonomy learning objectives with the four DOK levels (Hess, 2010b). Based on the scientific principle of the criterion, the written lab reflections were scored using parts of Hess’s Cognitive Rigor Matrix. Each criterion was matched with the Bloom’s Taxonomy learning
objective it demonstrated. Then Hess's Cognitive Rigor Matrix's DOK level was assessed for that Bloom's Taxonomy learning objective.

Criteria 1 was matched with Bloom's taxonomy learning objective Analyze. This included questions 1 and 2 of the written lab reflection which asked students to make conclusions supported by the data. Questions 3 and 4 were included in Criteria 2 which matched Bloom's taxonomy learning objective Understand. Criteria 2 required students to construct meaning from the lab and make connections to classwork and/or the real world. Bloom's taxonomy Apply was selected for Criteria 3 and Criteria 4. For Criteria 3, students identified experimental error sources by answering Question 5 on the written lab reflection. Whereas in Criteria 4, students identified improvements to their experimental design to answer Question 6 of the written lab reflection. Finally Criteria 5 matched Bloom's taxonomy’s learning objective Create. This related to Question 7 of the written lab reflection where students asked new questions, generated new hypotheses and synthesized information from their data sets.

Table 4

*DOK Scoresheet for Written Lab Reflections*

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Bloom’s Taxonomy</th>
<th>DOK Level 1</th>
<th>DOK Level 2</th>
<th>DOK Level 3</th>
<th>DOK Level 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Written Lab Reflection</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Make conclusions that are well supported by the data. (learned/did not understand)</td>
<td>Analyze</td>
<td>Recall &amp; Reproduction</td>
<td>Skills &amp; Concepts</td>
<td>Strategic Thinking</td>
<td>Extended Thinking</td>
</tr>
</tbody>
</table>
The written lab reflections were color coded based on these preassigned criteria.

Then each criteria was scored from 1-4 based on its DOK Level in that criteria using Hess’s Cognitive Rubric Matrix. A score of 1 meant the student showed the lowest level of DOK Recall and Reproduction for that criterion. A score of 4 meant the student showed the highest level of DOK Extended Thinking for that criterion. If a student did not answer the reflection question(s) represented by a criterion, a score of NR (no response) was given. NR did not count against the average. No zeros were given. Scores for each criterion were averaged to give one score for each written lab reflection per lab in the stepwise project. This method was used to score all the student written lab reflections for the stepwise inquiry lab project. Table 6 provides an example of a scored written lab reflection. For more details about how written lab reflections were graded see Appendix C.
### Table 6

**Sample Scores for Written Lab Reflection**

<table>
<thead>
<tr>
<th>Lab #1 Minerals</th>
<th>Sample #18</th>
</tr>
</thead>
<tbody>
<tr>
<td>Criteria</td>
<td>DOK Level-Bloom’s Taxonomy</td>
</tr>
<tr>
<td></td>
<td>Learning Objective</td>
</tr>
<tr>
<td>1.</td>
<td>Level 3- Analyze</td>
</tr>
<tr>
<td></td>
<td>(the more NaF, the faster mark goes away)</td>
</tr>
<tr>
<td>2.</td>
<td>Level 1- Understand</td>
</tr>
<tr>
<td></td>
<td>“My ideas have grown”</td>
</tr>
<tr>
<td></td>
<td>and relate to class discussion “which toothpaste is best”. But they don’t make any conclusions.</td>
</tr>
<tr>
<td>3.</td>
<td>Level 1- Apply</td>
</tr>
<tr>
<td>4.</td>
<td>Level 2- Apply</td>
</tr>
<tr>
<td>5.</td>
<td>Level 3- Create</td>
</tr>
</tbody>
</table>

Average Score for Sample #18 = 2

Note: Average scores for written lab reports were used to determine the overall DOK Level for each lab in the stepwise project.

There were seventeen written lab reflections for each of the three labs in the stepwise project. The average scores for each lab were compared using a one-way ANOVA. A one-way ANOVA was chosen because it is designed to test equality between three or more means. A two way ANOVA would not have worked since it tests two independent variables which this project does not have. The findings from the one-way
ANOVA were statistically significant, $F(1.17) = 24.31, p = <0.001$. Separate t-tests were then calculated for each of the three labs Post Hoc to find which pair(s) exhibited significant differences between them. The significant difference was found between lab 1 and lab 3, $t(17) = 6.74, p = <.001$. The effect size using Hedge's $g$ was 0.23 (Table 7).

**Table 7**

*Results of ANOVA for Scored Written Lab Reflections (N = 17)*

<table>
<thead>
<tr>
<th></th>
<th>M</th>
<th>SD</th>
<th>$p$</th>
<th>g</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lab 1</td>
<td>1.99</td>
<td>0.43</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>Lab 2</td>
<td>1.88</td>
<td>0.34</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Lab 3</td>
<td>2.75</td>
<td>0.41</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post Hoc</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lab 1 vs. Lab 2</td>
<td>-</td>
<td>-</td>
<td>0.48</td>
<td></td>
</tr>
<tr>
<td>Lab 1 vs. Lab 3</td>
<td>-</td>
<td>-</td>
<td>&lt;0.001</td>
<td>0.23</td>
</tr>
<tr>
<td>Lab 2 vs. Lab 3</td>
<td>-</td>
<td>-</td>
<td>0.48</td>
<td></td>
</tr>
</tbody>
</table>

To determine whether any of the five criteria were more significant than the others, individual one-way ANOVA were calculated for each criteria (Table 8). This eliminated some of the misleading averages due to no responses by students who did not answer all the questions. Only criteria 3 and 4 were statistically significant, $F(1,13) = 85.62, p = <0.001, F(1,12) = 40.71, p = <0.001$.

**Table 8**

*Analysis of ANOVA for Each Criterion for Scored Written Lab Reflections*

<table>
<thead>
<tr>
<th></th>
<th>M</th>
<th>SD</th>
<th>p</th>
<th>g</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lab #1</td>
<td>2.59</td>
<td>0.87</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Lab #2 | 2.24 | 0.83 | 0.15 | -
Lab #3 | 2.82 | 0.88 |

**Criterion 2**  
(N=13)

| Lab #1 | 1.92 | 0.86 |
| Lab #2 | 1.93 | 0.27 | 0.08 | - |
| Lab #3 | 2.38 | 0.51 |

**Criterion 3**  
(N=12)

| Lab #1 | 1.15 | 0.38 |
| Lab #2 | 1.50 | 0.52 | <0.001 | - |
| Lab #3 | 3.00 | 0.00 |

**Criterion 4**  
(N=11)

| Lab #1 | 1.82 | 0.40 |
| Lab #2 | 1.64 | 0.50 | <0.001 | - |
| Lab #3 | 3.09 | 0.30 |

**Criterion 5**  
(N=9)

| Lab #1 | 1.89 | 0.60 |
| Lab #2 | 1.82 | 0.60 | 0.07 | - |
| Lab #3 | 2.50 | 0.85 |

In order to find where the statistical significance was in criteria 3 and 4, three separate t-tests were calculated in a Post Hoc analysis (Table 9). For criterion 3, the finding showed a statistical significance between lab 1 and 3 and lab 2 and 3, \( t(12) = 17.00, p = < .001 \), \( t(12) = 9.95, p = < .001 \). The effect size using Hedge’s g for criterion 3 was 8.55 and 5.00. The finding also showed statistical significance between lab 1 and 3 and lab 2 and 3 for criterion 4, \( t(11) = 9.04, p = < .001 \), \( t(11) = 9.24, p = < .001 \). The
effect size for criterion 4 using Hedge’s g was 0.35 and 3.14 for lab 1 and 3 and lab 2 and 3.

**Table 9**

*Post Hoc Analysis t-tests for Questions 3 and 4 from Written Lab Reflections*

<table>
<thead>
<tr>
<th>Criterion 3</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>(N=12)</td>
<td>p</td>
<td>g</td>
</tr>
<tr>
<td>Lab 1 vs. Lab 2</td>
<td>0.068</td>
<td></td>
</tr>
<tr>
<td>Lab 1 vs. Lab 3</td>
<td>&lt;0.001</td>
<td>8.55</td>
</tr>
<tr>
<td>Lab 2 vs. Lab 3</td>
<td>&lt;0.001</td>
<td>5.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Criterion 4</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>(N=11)</td>
<td>p</td>
<td>g</td>
</tr>
<tr>
<td>Lab 1 vs. Lab 2</td>
<td>0.44</td>
<td>-</td>
</tr>
<tr>
<td>Lab 1 vs. Lab 3</td>
<td>&lt;0.001</td>
<td>0.35</td>
</tr>
<tr>
<td>Lab 2 vs. Lab 3</td>
<td>&lt;0.001</td>
<td>3.14</td>
</tr>
</tbody>
</table>

Since criteria 3 and 4 were statically significant, the student written lab reflections were analyzed for frequency of DOK level for these two criteria. For criterion 3, in Lab 1 there were 10 written lab reflections at DOK level 1 and 2 at level 2. In lab 2 written lab reflections were evenly scored for DOK levels 1 and 2 with 6 each. For lab 3, all 12 written lab reflections were scored at DOK level 3 (Figure 1). Of the 11 written lab reflections for lab 1, 2 were at DOK level 1 and 9 were at DOK level 2 for criterion 4. For lab 2, 5 written lab reflections were at DOK level 1 and 6 were at a DOK level 2 for criterion 4. This is a decrease in DOK level from lab number 1. For lab 3, 10 students were at DOK level 3 and 1 student was at DOK level 4 for criterion 4. (Figure 2).
Figure 1

*Frequency of DOK Levels for Written Lab Reflection for Criterion 3 (N =12)*

Figure 2

*Frequency of DOK Levels for Written Lab Reflection for Criterion 4 (N =11)*

**Pearson's Correlation**

In order to measure if there was an association between the attitude toward chemistry and the depth of knowledge of written lab reflections, a Pearson correlation test was conducted. The difference of the means for the post/pre attitude scale was
compared to the difference of the means of the third from the first written lab reflection in
the stepwise inquiry project. The two variables were moderately negatively correlated
\[ r(8) = .50 \] (Figure 3).

Since there was a statistically significant difference overall for the written lab
reflections, a Pearson correlation was conducted for each criteria to determine if one
criteria was more statistically significant than the others. Figure 2 shows that Criterion 1
had a slight positive correlation \[ r(8) = .38 \] (Figure 4). Criteria 2, 3, and 4 showed little to
no correlation (Figure 5-7). Criteria 5 showed low positive correlation \[ r(8) = .17 \] (Figure
8).

**Figure 3**

*Correlation of Difference in Pre/post Attitude Toward Chemistry Surveys and Depth of
Knowledge of Written Lab Reflections Using Average of All Lab Reflection Criteria (N=8)*
**Figure 4**

Correlation of Difference in Pre/post Attitude Toward Chemistry Surveys and Depth of Knowledge of Written lab Reflections for Criterion 1 (N=8)

**Figure 5**

Correlation of Difference in Pre/post Attitude Toward Chemistry Surveys and Depth of Knowledge of Written Lab Reflections for Criterion 2 (N=8)
Figure 6

Correlation of Difference in Pre/post Attitude Toward Chemistry Surveys and Depth of Knowledge of Written Lab Reflections for Criterion 3 (N=8)

![Graph](image1)

Figure 7

Correlation of Difference in Pre/post Attitude Toward Chemistry Surveys and Depth of Knowledge of Written Lab Reflections for Criterion 4 (N=8)

![Graph](image2)
Figure 8

Correlation of Difference in Pre/post Attitude Toward Chemistry Surveys and Depth of Knowledge of Written Lab Reflections for Criterion 5 (N=8)

Research Question #1- Attitude Surveys

The first research question asked, “What effect does a stepwise inquiry lab project have on the attitudes of high school chemistry students towards chemistry labs?”. This stepwise inquiry lab project slightly increased the attitudes of high school chemistry students toward chemistry labs. There was an increase of +0.41 for the mean scores of the eight students who completed both the post/pre attitude surveys. This suggests a slight increase in attitude for these students. Their mean pre attitude survey score was a 4. They had an overall “sorta positive attitude” toward chemistry labs before beginning the stepwise project. Their post attitude survey mean score was 4.41. Therefore their attitude increased to become more positive following the stepwise project, t(8) = 4.41, p
< 0.001. The effect size using Hedges’ g was in the medium range (Table 5). It should be noted that having a small sample size (N=8) could make these numbers unreliable.

This stepwise inquiry project allowed students to be slowly introduced into writing their own lab procedure. This gave students the opportunity to feel comfortable with data interpretation before asking them to work independently. Although students were slightly positive toward the chemistry lab prior to this stepwise inquiry lab project, their positive attitude increased after the project ended. This suggests that the experience of the stepwise project was a positive one.

**Research Question #2- Written Lab Reflections**

The written lab reflections contained seven student questions that were scored based on five criterias. Each criteria from the three labs were analyzed using a one-way ANOVA (Table 8). Although students did not always achieve the depth of knowledge associated with the level of inquiry for each lab in the stepwise inquiry project, there was improvement from lab 1 to lab 3. The decrease in average DOK level for Lab 2 might have been due to how the lab prompt was written. From lab 1 to lab 3 students increased their depth of knowledge on average from 1.82 to 3.09. This can be attributed to the increased freedom of experimental design allowed in the guided inquiry lab (lab 3). By lab 3, students wrote and carried out their own lab procedure based on their results from labs 1 and 2. In the written lab reflection students acknowledged that they could have improved on their experimental design by changing certain aspects of their own lab. They would not have much to improve on lab 1 which was written by the teacher.
Lab 1 was written as a level one confirmation lab. Students on average scored a 1.99 on DOK which is above confirmation. Lab 2 was set up as a level two structured inquiry lab. On average students scored a 1.88, lower than the level 1 lab. The final lab was written as a guided inquiry lab which should have helped students achieve level 3. On average students only scored 2.75 on their DOK (Table 7).

The second research question was, “What effect does the stepwise inquiry lab project have on the depth of knowledge in written lab reflections of high school chemistry students?” The effect of the stepwise inquiry lab project on the depth of knowledge in written lab reflections of high school students was limited to criteria 3 (sources of error) and 4 (improve procedure).

When the criteria were analysed individually, only criteria 3 and 4 were statistically significant. From the one-way ANOVA and Post Hoc t-tests results, the statistically significant difference was between labs 1 and 3 and labs 2 and 3 for both criteria 3 and 4.

The written lab reflection question for criterion 3 was, “What sources of error occurred during this lab?” During lab 1 students were provided with a teacher written lab procedure. The most common student reflections on error analysis were either about miscounting the number of times they brushed toothpaste on the tile or brushing two ways instead of one way consistently. In Lab 2, students were asked to create their own data tables while following a teacher prepared lab. Half of the students commented “no errors made” (DOK level 1). The other half reflected that they should have measured the mass of the eggs with all the parts after some egg shells had dissolved in the Red Bell solution (DOK level 2). Others commented on the necessity to measure out the same
amount of liquid to cover the eggs (DOK level 2). The final lab required students to write their own procedures. All students scored a DOK level 3 because they suggested design solutions to replicate their results (Figure 1). One student suggested that, “puring the coke on top of the egg may have washed off the toothpaste. To fix this problem I would pour the Cola before putting the egg shell in.” Criterion 3 (identifying sources of error) led right into criterion 4.

Criterion 4 asked students to reflect on, “How would you improve what you did?” In Lab 1, students reflected on possible lab procedure improvement at DOK levels 1 and 2 (Figure 2). They followed simple procedures (DOK level 1) and suggested new procedures (DOK level 2). One student wrote, “a way to improve on this lab would be to stay consistent and measure the length of the line” that was removed with toothpaste (DOK Level 2). Another student suggested, “have two people count and agree on the same number” in order to not lose count while brushing the toothpaste on the tile (DOK Level 2).

Written lab reflections from Lab 2 also remained in DOK level 1 and 2 for criterion 4 (Figure 2). Besides following procedures (DOK level 1) and suggesting new procedures (DOK level 2), students also described how to organize their data (DOK level 2). Some students were concerned about the lab procedure stating, “to improve this lab, I would be extra patient and scoop out all the egg in the Red Bull solution when weighing the results” (DOK Level 2). While others were confused about how to fix the procedure, they wrote, “I would improve this lab by show how making [sic] sure the eggs don’t crack so you can get accurate data (DOK Level 1). Data collection methods were also stated as needing improvements. They wrote, “something I would do to improve...was be more
STEPWISE INQUIRY LAB

Descriptive on the look of the eggshell. This would help to further explain the affect drinks have on our teeth” (DOK level 2). Another student wrote, “I would improve on making my data tables a little more organized and nicer” (DOK Level 2). Finally one student said, “I wouldn’t do anything different” (DOK Level 1). Lab 2 presented a more complicated procedure that allowed the students more freedom with the experimental design. Students chose the different liquids. This may have enticed excitement to see the results that they overlooked how to prepare their solutions and rushed to make data tables.

In the guided inquiry lab 3 students were expected to write their own procedure based on the results from lab 1 and lab 2. All students had improved in their DOK level from lab 2 (Figure 2). Instead of reflecting only on the given lab procedure, students suggested designs for new investigations (DOK level 3). One student suggested that next time use “an egg with no toothpaste, however since we were comparing toothpaste and not with vs. without toothpaste it isn’t that big of a deal nor does it complete the lab, though it [sic] think it would have added a bit of clarifying information” (DOK level 4). This student selected an alternative approach to the presented lab to answer the research question, “which toothpaste is best”. They also explained the pros and cons of using a control egg. Other students suggested putting “toothpaste on the inside (of the egg) too”, “done more trials for it to work better and more efficient”, “apply masking tape to the egg while applying the toothpaste … help seeing the protected part of the egg and the non-toothpaste section” (DOK level 3). The student suggestions were original and showed their engagement with this stepwise lab project. Therefore, this stepwise inquiry lab project was most effective at getting students to reflect on possible improvements needed for their lab procedures.
Research Question #3 - Correlation

The third research question asked, "Is there a correlation between attitude toward chemistry labs and depth of knowledge of written lab reflections?" A moderate negative correlation existed between the attitude toward chemistry labs and depth of knowledge of written lab reflections. For the high school chemistry students in this project, a higher depth of knowledge seemed to be negatively correlated with a more positive attitude towards chemistry labs. These results were unexpected. Students with a more positive attitude toward chemistry decreased in depth of knowledge in their written lab reflection (Figure 3). Students could have enjoyed the chemistry tasks, but not the written reflection portion.

Looking at the correlation for each of the written lab summary questions individually, Criteria 1 and Criteria 5 had a positive low correlation (Figure 4, Figure 8). Criteria 1 focused on two questions: “What did you learn in this lab?” and “What did you not completely understand?”. These two questions utilized Bloom’s taxonomy learning objective Analyze. Students who enjoyed the lab would have been able to analyze their data (Figure 4). Students who did not enjoy the lab did struggle to determine the meaning behind the lab.

Criteria 5 focused on the question, “What new questions do you have about the anchoring phenomenon?” This criteria uses Bloom’s taxonomy learning object Create. It allowed students to generate new hypotheses for future research or ask clarifying questions related to the recently completed lab work. Students with a positive attitude towards chemistry would have been interested in continuing their investigation and proposing new research questions to further their learning (Figure 4).
Discussion

High school chemistry students’ attitudes toward chemistry improved with this stepwise project. Student attitudes could have been affected both internally and externally (Gagne et al., 1992). Externally, students likely developed a relationship of trust with their teacher through this stepwise project. Instead of the teacher demanding a lab procedure from scratch, students were eased into the writing process through labs 1 and lab 2. This likely built trust. Although the students had to write their own procedure for the guided inquiry lab, the process was modeled for them with similar labs written by the teacher.

Student attitudes may have changed internally by becoming more knowledgeable about chemistry through this stepwise project. Skills learned in labs 1 and 2 were used to accomplish lab 3. In lab 1, students learned how to brush toothpaste onto a surface in order to measure its effectiveness, while lab 2 taught students how to compare and contrast the effects of how different liquids stain eggshells. Being able to learn these skills and then apply them to their own lab procedure may have built students’ confidence; unlike students who are asked to write a guided inquiry lab procedure based on general lab skills.

Students were engaged with the real world phenomenon about toothpaste. The anchoring question used multimodal thinking to connect scientific topics to ideas and concepts that students had previously experienced. This made the stepwise project relevant to the students. When students find school work relevant it increases their engagement (McNeil & Reiser, 2018). Students asked questions about the investigations because they were truly interested in the topic. From the day this stepwise project was
introduced, students were excited to get started. In order to introduce the phenomenon, students were asked to jot down which toothpaste brand they used at home. Then students drew a model of how they thought toothpaste protected their teeth. Students shared their models as a class and compared how their models were similar and different. Next students were given time to freely brainstorm any questions they had about the anchoring question, “Which toothpaste protects our teeth the best?”. After the brainstorm, students shared their questions and explained why their home toothpaste brand was the best. All of these activities set the stage for the confirmation lab. Students engaged in debate throughout the confirmation lab about how they knew one toothpaste would be more effective because it was their brand. It was almost like having a favorite football team to cheer for. When the students got unexpected results, they picked that toothpaste brand as their champion. Suddenly there were cheers in the classroom for Crest Kids toothpaste because it was a top performer. If another student tried to argue, a student would open their lab notebook and prove they were right with evidence from the confirmation lab. Socratic questioning was used throughout the first lab encouraging students to develop their own solutions to their questions (Chin, 2007). The teacher transitioned into the role of a facilitator allowing students to feel confident in their lab results.

Historically, problems cited with inquiry instruction included time, safety, inconclusive data, problems with answers, and teacher questioning. This whole project took six class periods. One of which was an extended period or block day (70 minutes). Each of these labs were performed on consecutive days. Labs 2 and 3 took two days for the eggs to sit in the different solutions. One day was given to introduce the real world
phenomenon. There was a day given for students to write up their lab procedure which coincided with Lab 2 results day. Part of the thinking behind this administration was to keep engagement high. The eggs in Lab 2 sat over the weekend in the different solutions. Part of the egg shells broke up in the acidic solutions. Therefore when students wrote their procedures for Lab 3 they chose to analyze the eggs after one day in solution. If this stepwise project was repeated, it might be beneficial for the students to spend more time on data analysis. If an educator wants to save time, this stepwise project did not take long. Lab step up and clean up was easy to manage as well.

Although it was originally planned for all students to complete the same lab procedures for Lab 3, each lab group performed their own procedures. When student groups presented their procedures, each group only changed small details such as the type or amount of liquid used in their experiment. Also, each group provided a valid reason to use their student created procedure therefore it was allowed. It would have been possible to force all the students to use the same procedure for Lab 3. When students develop their own procedures, they have ownership over their experiment which allows them to explore what those procedures lead to.

Safety concerns were low for this stepwise project. There was a general concern about salmonella since raw eggshells were used. If this project was repeated, the raw eggshells could be boiled prior to student handling. Otherwise, all three labs used the same materials. Even if students created different procedures for lab 3 only minor details changed such as type of liquid so safety precautions were easy to monitor as the instructor.
Inconclusive data did occur which led to interesting questions for both the students and teacher. The eggshells that sat in Red Bull produced a weird growth on the outside of the eggshells which was not anticipated. This did not cause the students to have a negative reaction to chemistry though. Instead one student wrote in their lab reflection, “after this lab, I find that Red Bull can not only be harmful to human teeth but the human body as well and plan on avoiding it in the future”. Similarly, Backus (2005) found that after discussing errors with temperatures in her rates of reaction lab, students were willing to repeat the experiment using their classmates’ suggestions for improvement. Therefore inconclusive data can make students want to ask more questions and be more curious in science related topics.

The problems with answers and teacher questioning can frustrate students especially during laboratory work. Students always asked the instructor what to do while they were experimenting and never seemed to appreciate the, “What do you think you should do?” Then the student asked their lab partners what to do hoping they knew. The attitude surveys were on the positive side of the scale for questions even for question 6, “Chemistry experiments are a good way for me to apply chemical knowledge and practical skills.” The students indicated that they knew they should use practical skills in the lab. As Gagne stated students can change their attitude toward a subject (writing their own procedure) if the final model is successful (Gagne et al., 1992). If students practice writing their own procedures, over time they will grow to be more confident. (Backus, 2005).

Going forward any stepwise project can be successful when it is centered around a real world phenomenon that engages students. Everyone has teeth and
therefore these high school students were hooked into this project immediately. This stepwise project increased students’ attitude toward chemistry because it used Level 1 and Level 2 lab data to apply to a Level 3 guided inquiry lab. High school students can write their own procedures if they are given a framework to start with. Using student data from previous labs provided a framework for student created procedures. This stepwise project could be improved with a more scaffolded data analysis discussion. Scaffolded discussion can promote deep understanding of concepts and provide opportunities for students to voice evidence for their claims (Michaels et al., 2008). Xu & Talanquer (2013) found their lab reflections were lacking connections to chemistry concepts. They suggested students needed time to engage in three types of discourse activities: (1) eliciting hypotheses and ideas, (2) sensemaking of the chemistry content of the lab activity, and (3) creating evidence-based explanations based on their results. Students might show an increased depth of knowledge if time was spent in between the labs for these discourse activities. Students should discuss and analyze their results from Lab 1 and Lab 2 before creating their written procedures for Lab 3. By discussing their claims out loud with their classmates, students support, listen to, build on, and critique each other’s scientific understanding using evidence and reasoning (McNeil & Reiser, 2018). These scaffolded discussions can provide sensemaking and coherence making the three stepwise labs fit together.

Future Work
Inquiry chemistry implementation can be enjoyable for both teacher and students. It can take less than 2 weeks to accomplish a finished student product.

This mixed method study could be improved by implementing it with a larger class and/or using the stepwise project at more than one high school. The small class size provided very limited participation numbers. This made the results unreliable and are likely not yet generalizable. In order to know the effectiveness of this stepwise project it should be repeated with a larger class of chemistry students. It would be best to use the stepwise project at 3 different high schools or with different topics to see the effectiveness from varying demographics.

It should be noted that prior to this project high school students were absent from an in-school experience for the final three months of the previous school year due to the outbreak of COVID-19. This may have impacted students' hands-on science experience prior to this project since this project occurred at the start of the next school year. Therefore students may have been more interested in laboratory experiments since they had spent six months without any hand-on science experiences. It may be worth trying this stepwise project when a pandemic is not occurring to see if the results are the same.
References


Busboom, J., Martinez, J., Friedman, N., & Riyaj, I. (2012). *Winning Experiment*
Procedures from the NIH LAB Challenge. NIH K-12 Lab Challenge, Coppell High School, Coppell, Texas.


Chemical Education, 82(8), 1178–1180. https://doi.org/10.1021/ed082p1178


Quote Investigator. (2019, February 27). *Tell Me and I Forget; Teach Me and I May Remember; Involve Me and I Learn* [Online Forum Post]. https://quoteinvestigator.com/2019/02/27/tell/


Appendix A: Lesson Plans

Lab #1: Minerals in Toothpaste
Anchor->Which toothpaste protects our teeth the best?

Toothpaste is used to clean and protect our teeth from cavities. Which brand of toothpaste do you prefer and why? Stop and Jot your answer below:

**How does toothpaste protect our teeth from cavities?** As your dentist might have warned you certain foods and drinks can produce holes or cavities in our teeth over time. Using toothpaste slows down the rate of this chemical reaction.

Imagine you have been hired by a research and development (R&D) company to investigate which brand of toothpaste slows down the rate of the reaction between teeth and certain foods/drinks that cause cavities.

**Brainstorm** your initial ideas related to how toothpaste protects your teeth. Draw a model using pictures/labels to explain your thinking.

**Compare and Contrast** your model with two or more of your classmates. Record your similarities and differences between your models below:

<table>
<thead>
<tr>
<th>Similarities</th>
<th>Differences</th>
</tr>
</thead>
</table>

What questions do you have related to the anchoring phenomenon? Jot them here.

**Background Information:**
Minerals are naturally occurring, nonliving solids with definite chemical structure. One example, halite, NaCl, is the naturally occurring mineral of table salt. Since a mineral is the pure form of an element or compound, they can be found everywhere including toothpaste. The different properties of minerals provide different functions of toothpaste. Ceramic and porcelain tiles are similar in structure/composition to our teeth.
Materials:
- Various toothpaste
- Black Felt-Tipped Marker
- Toothbrush
- Pencil/Pen
- Ceramic Tile
- Beaker with water
- Porcelain Tile

Safety:
PPE.
Do not eat or drink anything in the lab. Materials are for lab use only.

Investigating question:
Which ingredients of toothpastes are most effective in removing a stain from ceramic and porcelain tiles?

Procedure:
1. List the active ingredient in each toothpaste brand in the first column, and the amount (%) of each ingredient (if listed).
2. Make a mark on each ceramic tile with a black felt-tipped marker.
3. Make predictions on how effective each toothpaste brand will be in removing the marker stain. (example: Toothpaste will remove all of the black mark, some of the mark, none of the mark)
4. Put a pea-size amount of the first toothpaste brand onto the toothbrush. Brush one of the marked ceramic tiles in one direction 50 times using the same amount of force for each stroke.
5. Record qualitative (visual) observations in the fourth column.
6. Using the beaker with water, rinse off the toothbrush thoroughly.
7. Repeat with the other brands of toothpaste.
8. Mark the porcelain tile with a black felt-tipped marker.
9. Repeat the procedure with the porcelain tile and each brand of toothpaste.
Data:

**Data Table - Ceramic Tile**

<table>
<thead>
<tr>
<th>Toothpaste Brand</th>
<th>Active Ingredient</th>
<th>Prediction</th>
<th>Observations (qualitative)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Data Table - Porcelain Tile**

<table>
<thead>
<tr>
<th>Toothpaste Brand</th>
<th>Active Ingredient</th>
<th>Prediction</th>
<th>Observations (qualitative)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Results:

<table>
<thead>
<tr>
<th>CLAIM</th>
<th>EVIDENCE (data that supports your claim)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I claim that .....</td>
<td>I claim that because</td>
</tr>
<tr>
<td>(answer to the investigating question written in complete sentences)</td>
<td></td>
</tr>
</tbody>
</table>

Reflection:

Compare your claim to the investigating question. Then answer the following questions in complete sentences in a complete paragraph as they relate to this lab.

What did you learn in this lab?
What did you not completely understand?
How have your ideas changed as a result of this lab?
How does this lab relate to what is being discussed in class and/or real life?
What sources of errors occurred during the lab?
How would you improve what you did?
What new questions do you have about the anchoring phenomenon?
Lab #2-Dental Hygiene Eggsperiment

Background Information:
In this experiment you will compare how different drink choices affect dental hygiene. Chicken egg shells share similar qualities with human teeth. The texture of the tooth enamel and the egg shell are both proactive and calcium-rich. Different foods and drinks might affect teeth differently. You will analyze how three different drinks affect egg shells. Drinks such as water, pop, and kool-aid have different effects on teeth. Students analyze the different effects of these drinks on eggs.

Materials:
- 3 eggs
- 3 cups
- 1 can of Coca-Cola
- 1 bottle of gatorade
- Water
- 3 beakers for measuring 200 mL
- Scale
- Permanent marker

Safety:
PPE.
Do not eat or drink anything in the lab. Materials are for lab use only.

Investigating question:
What effect do sugary drinks have on teeth?

Procedure:
1. Using a permanent marker, mark three eggs as W, C, and G for water, Coca-Cola, and gatorade.
2. Label each of three cups with your group's initials. Place each egg in a cup, and weigh each one. Record the weight and observations about the texture, color, and anything else you notice a data table (you will need to construct one).
3. Pour 200 mL of each liquid (water, Coca-Cola, gatorade) into three separate beakers.
4. Check the label of each egg, and place it into the appropriate beaker of liquid so that it is fully submerged.
5. Let the eggs sit in the beakers for 24 hours.
6. Remove the eggs and record all observations (qualitative), including the color and texture of the eggshell, and the color of the water, in a data table.
7. Weigh the eggs again (quantitative) and record all observations (texture, color, color of water, etc.) in your data table.

Data: (Create a data table to record both your qualitative and quantitative data)
Results: (Make a claim related to the investigating question. Remember to use evidence to support your claim based on your collected data)

Reflection:
Compare your claim to the investigating question. Then answer the following questions in complete sentences in a complete paragraph as they relate to this lab.
What did you learn in this lab?
What did you not completely understand?
How have your ideas changed as a result of this lab?
How does this lab relate to what is being discussed in class and/or real life?
What sources of errors occurred during the lab?
How would you improve what you did?
What new questions do you have about the anchoring phenomenon?
Lab #3-Which toothpaste protects our teeth the best?

Background Information:
Egyptians were among the first to use paste to clean teeth around 5000 BC. Early toothpaste contained ox hooves’ ashes, burnt eggshells, charcoal, oyster shells, ginseng, mints, salt, and pumice. The first toothpastes were actually powders until 1850 when Colgate introduced toothpaste in a jar. It wasn’t until the 1890s that toothpaste made it into its familiar tube. In 1914 fluoride toothpaste was introduced to prevent tooth decay (Colgate-Palmolive Company, 2020).

Now that you have learned more about toothpaste, toothpaste brands and sugary drinks, let us return to your job:

Remember: you have been hired by a research and development (R&D) company to investigate which brand of toothpaste slows down the rate of the reaction between teeth and certain drinks that cause cavities.

It is your lab group’s responsibility to plan and carry out an experiment to compare at least three different brands of toothpaste. Submit your plan to Google Classroom by _________________ (date).

Your group will be presenting on _________________ (date) in front of the R & D representative. You will have 10 minutes to present your plan, followed by 10 minutes in which you will be expected to respond to questions from the representatives. Your presentation needs to answer the following questions:

- How will you measure the rate of tooth decay for each brand of toothpaste?
- What variables will you need to keep constant in this investigation?
- Will the proposed procedure be possible and safe?

Use the following headings in your plan for carrying out your experiment:

Materials: (what materials will you need to complete your experiment? What material will you use to represent teeth?)

Safety: (what safety precautions should you consider while planning and carrying out this experiment?)

Investigating question:
Which toothpaste protects our teeth the best?
Procedure: (Step by step directions of what you will do in order to answer the investigating question and the presentation questions)

Data: (Create a data table to record your observations both qualitatively and quantitatively)

Results:(Once you have collected data, make a claim related to the investigating question. Remember to use evidence to support your claim based on your collected data)

Reflection:
Compare your claim to the investigating question. Then answer the following questions in complete sentences in a complete paragraph as they relate to this lab.
What did you learn in this lab?
What did you not completely understand?
How have your ideas changed as a result of this lab?
How does this lab relate to what is being discussed in class and/or real life?
What sources of errors occurred during the lab?
How would you improve what you did?
What new questions do you have about the anchoring phenomenon?
Appendix B: IRB Letter of Approval

Johnson (Del Carlo): IRB PreK-12 Exempt 1 Determination
4 messages

Todd Evans <todd.evans@uni.edu>
To: johnsmue@uni.edu
Cc: Dawn Del Carlo <dawn.delcarlo@uni.edu>, Sean Parrish <sean.parrish@uni.edu>, Todd Evans <todd.evans@uni.edu>

Dear Investigator(s):

Your study, Effects of Stepwise Guided Inquiry on Students’ Attitudes and Depth of Knowledge from Written Lab Reflections in High School Chemistry, has been determined by the UNI IRB to meet the criteria for Exempt status, category 1. You may begin recruitment, data collection, and/or analysis for your project.

You are required to adhere to the study procedures reported in your IRB form, and to monitor the project to ensure that the rights and privacy of the participants in your study are protected.

If you need to make any changes to the study, you must request approval of the changes before continuing with the research. Requests for modifications should be emailed to the IRB Chair Todd Evans at todd.evans@uni.edu.

Your study will not require annual review or closure.

If during the study you observe any problems or events pertaining to participation in your study that are serious and unexpected, you must pause data collection and report this to the IRB immediately (at least within 10 days) to receive guidance on next steps. Examples include unexpected injury or emotional stress, missteps in the consent documentation, or breaches of confidentiality.

Best wishes for your project success.

Todd Evans
IRB Chair

--
Todd A. Evans, PhD, ATC, LAT
Associate Professor, Athletic Training
University of Northern Iowa
Human Performance Center
2251 Hudson Road
Cedar Falls, IA 50614–0244
(319) 273–6152
todd.evans@uni.edu
Fax number: 273–7623

--
Appendix C: Grading Tools
Lab Notebook Rubric

Chemistry Lab Notebook
The following steps should be included in each of your laboratory experiment notebook. Lab reports should be hand written on notebook paper/or turned into Google classroom. Be clear and concise.

I. TITLE- (2 points)
   Give the experiment a descriptive title.

II. PURPOSE & SCOPE (4 points)
   This should include the objective of the experiment. Give the reason what this experiment is looking for and why the experiment is being performed. This is include a hypothesis or research question

III. MATERIALS (2 points)
   This should include all chemicals and equipment used in the experiment. Just list the materials in columns. Complete sentences are not used.

IV. SAFETY (2 points)
   State all safety precautions that should be taken in order to perform this experiment.

V. PROCEDURE (4 points)
   Write an explanation of each step of the experiment. Be sure to include the precise amounts of chemicals used to complete the experiment. It should be written in past tense. Nothing in the procedure is insignificant. DO NOT write a recipe, explain what happened during the experiment.

VI. DATA (4 points)
   Place all data in neat tables that are labeled, titled and easy to read. Include graphs when necessary.

VII. CALCULATIONS (4 points)
   Includes any calculates performed in the experiment. Does not have to be a labeled section. All calculations are checked for accuracy and that the numbers make sense with data presented.

VIII. SUMMARY AND RESULTS (8 points)
   Include the final results obtained whether they were observational or mathematical.
   Also include these reflection questions:
   What did you learn in this lab?
   What did you not completely understand?
   How have your ideas changed as a result of this lab?
   How does this lab relate to what is being discussed in class and/or real life?
   What sources of errors occurred during the lab?
   How would you improve what you did?
   What new questions do you have about the anchoring phenomenon?

   Answer any questions from the lab sheet here in YOUR OWN WORDS using complete sentences and restating the questions. Do NOT just write the question numbers.

   Total = ______________________/30
<table>
<thead>
<tr>
<th>Section</th>
<th>Limited</th>
<th>Inconsistent</th>
<th>Adequate</th>
<th>Well Done</th>
</tr>
</thead>
<tbody>
<tr>
<td>TITLE</td>
<td>There is a title. (0.5 points)</td>
<td>Title describes the experiment. (1 point)</td>
<td>Title contains either an adjective or a verb to describe the experiment. (1.5 points)</td>
<td>Title contains an adjective and verb to describe the experiment and list all chemicals used by name. (2 points)</td>
</tr>
<tr>
<td>PURPOSE &amp; SCOPE</td>
<td>Neither a full purpose or a full hypothesis is state. (1 points)</td>
<td>Purpose of the lab or hypothesis is stated. (2 point)</td>
<td>Purpose of the lab is mostly explained and experiment might make a guess on what might happen. (3 points)</td>
<td>Purpose explains the objective of the experiment and what the experimenter predicts might happen. Any pre-lab is listed here. (4 points)</td>
</tr>
<tr>
<td>MATERIALS</td>
<td>Half of all the materials necessary to perform the lab. (0.5 points)</td>
<td>Some of all materials necessary to perform the lab. (1 point)</td>
<td>Most of all materials necessary to perform the lab including the quantity of chemicals and size of the glassware is included. (1.5 points)</td>
<td>All materials necessary to perform the lab including the quantity of chemicals and size of the glassware is included. (2 points)</td>
</tr>
<tr>
<td>SAFETY</td>
<td>Half of all safety measures needed for the lab are noted. (0.5 points)</td>
<td>Some of all safety measures needed for the lab are noted included PPE (1 point)</td>
<td>Most of all safety measures needed for the lab are noted included PPE (1.5 points)</td>
<td>All safety measures needed for the lab are noted included PPE. (2 points)</td>
</tr>
<tr>
<td>PROCEDURE</td>
<td>Plaque with mistakes explanation (1 points)</td>
<td>Several mistakes with explanation: not in past tense, missing steps, or recipe style. (2 points)</td>
<td>Written explanation of what the experimenter did is either not in past tense, missing several steps or recipe style. (3 points)</td>
<td>Written explanation of what the experimenter did in past tense is stated not in recipe style. (4 points)</td>
</tr>
<tr>
<td>DATA</td>
<td>Missing more than 4 labeling errors or data info (1 points)</td>
<td>Missing 2-3 parts or data info (2 points)</td>
<td>Missing 1 part of labeling or data table/graph (3 points)</td>
<td>Neat tables are labeled, titles, and easy to read. Graphs used when needed have title and axis labels. (4 points)</td>
</tr>
<tr>
<td>CALCULATIONS</td>
<td>Over 5 Calculation accuracy and labels errors (1 points)</td>
<td>3-4 calculation accuracy errors. (2 points)</td>
<td>Calculations are missing labels or are mismatched with data presented. (3 points)</td>
<td>All calculations are performed with accuracy and make sense with data presented. Numbers are labeled correctly. (4 points)</td>
</tr>
<tr>
<td>SUMMARY AND RESULTS</td>
<td>Missing over 5 components from well done column (5 points)</td>
<td>Missing 3-4 components from well done column (6 points)</td>
<td>Missing 1-2 components from well done column (7 points)</td>
<td>Include final results obtained. Include opinion of how the experiment went and suggestions to make this lab more efficient or successful. Any mistakes or errors should be explained here. Questions from the lab sheet are answered in complete sentences and in student’s own words. (8 points)</td>
</tr>
</tbody>
</table>
**Written Lab Reflection Analysis**

**Analyzing Level 3**

On this lab, I learned that different toothpastes have different benefits that help different needs. I did not normally understand how ingredients work. However, after this lab result, I find that all toothpaste options are just as effective which I did not expect to happen. This lab can be very important to us because we brush our teeth everyday. During this lab, we made the error of brushing in the same direction, but we went back and did it right. To improve the lab, I would recommend trying out which toothpaste is the most effective and which ingredients work. I still have a question in which toothpaste is the most recommended by dentists for people with basic needs.

**Create Level 7**

Brainstorm idea based on topic.