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A Framework for Pre-Laboratory Instructional Design to Support Student Inquiry in High School Chemistry

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by

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CHAPTER ONE : Introduction

Introduction

Today's society requires that citizens are science literate and can think critically. Research studying science education emphasizes the need for students to be involved in genuine scientific inquiry. The public school system increasingly focuses on explicit content-centered learning outcomes that must be attainable by all students. This project attempts to bridge the gap between these demands to make student-led inquiry feasible in the high school chemistry classroom. This project was created to combine pre-lab demonstration of key laboratory techniques with guided analysis questions modeled after writing to learn pedagogies in order to help high school chemistry students develop appropriate procedures for laboratory experiments so that students can deepen their conceptual understanding of chemistry. The capstone question is: *How can a pre-laboratory instructional framework help high school chemistry students independently design experiment procedures in order to transform inquiry experiments into an effective tool for content learning?*

This introduction walks through my own positive experiences of science education, discusses the roots of my interest in inquiry methods, followed by relevant themes from my teacher education program. I explain the demands placed on the high school chemistry classroom, specifically the laser focus on content standards, and how those demands conflict with the recommendations of the Next Generation Science Standards (NGSS) to utilize inquiry methods. From there, I discuss the unmet needs in my high school chemistry classroom and solutions that have worked in my classroom. This introduction ends with a discussion of the specific challenges of implementing inquiry experiments in high school classrooms, how my students and the field at large would benefit, and finally a preview of the literature that has shaped the solutions I propose in this project.

Personal and Philosophical Background

My formative years were filled with a fabulous array of encounters with science. I can recall crushing plastics in a material engineering lab, listening to a talk by the paleontologist who excavated Sue the T-rex, running polymerase chain reaction to solve a fictional crime, observing dead pigs to understand how insects help us determine the time of death, and hanging on every word of any naturalist that led a nature hike. On many occasions, I posed my own questions to real live scientists. These were a result of my parents' concerted effort to provide their children with enriching experiences (and their own personal love of museums). These rich experiences gave color to all the nitty-gritty science skills I learned in school. When a challenging or boring topic came up in the classroom, I had the advantage of background knowledge to help me through. In addition to their role in instilling me with a life long love of science, these experiences also grounded my vision for the science classroom in joy and curiosity.

Perhaps unsurprisingly, I attended a math and science-focused high school. The roots of this master's capstone project come directly from my junior year at that high school. As a result of my participation in our student facilitated science outreach program, I chose to complete my junior year project on inquiry-based education. While the details of that project have mostly faded from memory, it set in motion gears that are still grinding away in my brain. This followed with my pursuit of teacher training at the college level. My training focused on constructivist theory, reflective practices, and learner-centered classrooms. I have adopted this philosophical perspective. As will become apparent, the practice of guided inquiry labs is built squarely on the importance of students constructing their own knowledge.

Professional Context

Currently, I teach high school chemistry. High school educational philosophy places a strong focus on standards-based practices. This means chemistry is expected to help all students master a defined set of discrete skills and knowledge. Given the current school climate, delivering enriching experiences of the scientific process often comes second to student mastery of the core content. Yet, educational research and the Next Generation Science Standards (NGSS) emphasize the beneficial role of experiencing scientific inquiry in student learning (Next Generation Science Standards, 2013). There may be room for experimentation units in middle school where the primary learning objectives are about the scientific inquiry process itself rather than content standards. However, in high school, that margin for enriching independent experimentation shrinks to near non-existence. My hope is that this project is a first step toward a chemistry curriculum that allows for experimental activities that facilitate both student-led inquiry and content mastery.

Aside from the desire for my professional practices to align with current best practices as established by the NGSS, inquiry experiments also offer the opportunity to attend to the social-emotional and academic needs of the modern student population. I find myself in a moment where my students have a combined disadvantage of limited formal science education, due to an emphasis on reading and math for testing reasons, and limited experience of practical skills in their home life, perhaps due to the mind-altering technologies of the internet and touch screens. For instance, lighting a Bunsen burner is often a student's first experience with fire.

Challenging tasks, like equipment set up for an experiment, often result in a student shutting down with no notion of where to start with a difficult task. They need opportunities to develop autonomy and confidence in their own problem-solving abilities. Students also struggle to take written directions and translate them into physical tasks. Measuring out a specific quantity of liquid requires repeated reminders of which types of glassware are appropriate for measuring volume. Their limited experience with physical processes means that they must pay a great deal of attention to the physical procedure and have little room to contemplate the chemistry that is taking place. Implementing inquiry experiments would benefit my students' practical ability to carry out sequential directions and interpret scientific information. It would also build their sense of autonomy and hopefully give them the tools to take on complex tasks in many areas of life.

As I have explored the research and tried various options in my class, I have had success with POGIL (process-oriented guided-inquiry learning) activities that provide students with sample data or a visual model and guide students through the use of precise, scaffolded questioning to discover core scientific principles (Trout, 2012). This type of activity allows students to build their understanding in a highly contextualized environment that has, as I have observed in my own classroom, helped students gain confidence in their ability to observe and identify patterns. Students often refer back to these activities later in the year, signaling the significant impact of these activities on student learning. Between the success of inquiry on paper and the student needs described above, I am motivated to find a route that will bring inquiry into the chemistry laboratory.

Having made a few attempts at using inquiry techniques in the lab, there are several recurring challenges that have made it a less than satisfactory experience. First, students do not have the practical knowledge of glassware and basic lab techniques to write a procedure from scratch. Several published inquiry-based labs I have attempted to use require students to create procedures from a blank page (Flinn Scientific, 2015; The College Board, 2014). Second, students are often so wrapped up in doing the lab they miss the connection between their activities in the lab and the content on our tests. They do not know where to direct their attention to the most meaningful parts of the lab. Any observation could be as important as the last. Third, students lack the prior knowledge to draw connections between their results and larger chemical principles. This connection is essential for labs to achieve the larger objective of increasing content knowledge. In order for students to successfully design and conduct their own experiments they need substantial scaffolding. I have attempted inquiry labs from at least two publications. Both publications, while useful in theory, failed to provide students with the substantial guidance they needed to navigate experimental design and data analysis (Flinn Scientific, 2015; The College Board, 2014). Every resource I have encountered is, simply put, too general.

Preview of the Literature

The literature reviewed while preparing for this project explores previous research on the instructional strategies that were used to build the instructional framework and templates proposed in this project. The discussion starts with the science writing heuristic. This is a template for guided inquiry in the general science classroom and has been found to improve student learning outcomes when compared with traditional methods (Keys, et al., 1999). The science writing heuristic provides a foundation for the broader sequence of tasks required to complete the full inquiry process. This is followed by a discussion of using writing-to-learn strategies in science classrooms, focusing on chemistry classrooms. Writing-to-learn has also been shown to improve learning outcomes and improve students' ability to incorporate experimental data into their understanding of science phenomena (Klein & Rose, 2010; Lillig, 2008). This section focuses on the components of successful writing to learn strategies, such as peer feedback. After these two broader topics, the review turns to research on pre-lab assignments. While a variety of approaches to pre-lab instruction are presented, they all support the conclusion that when students understand the laboratory process in more detail, they are more likely to learn the associated chemical concepts (Pogacnik & Cigic, 2006; Winberg & Berg, 2007). The review of the literature concludes with a discussion of demonstrations and, in particular, how the instructional approach that is taken when presenting a demonstration affects learning outcomes (Majerich & Schmuckler, 2007). This body of knowledge informed the creation of the instructional framework and templates described in the second half of this capstone. The instructional framework facilitates a demonstration to teach lab techniques and activate prior knowledge, followed by a series of guiding questions to walk students step-by-step through the process of designing an experimental question and a procedure that helps them answer their question.

Summary

My hope is that this project provides scaffolding that could be used by other chemistry teachers and facilitate inquiry-based learning in the laboratory. This project focused specifically on preparing students to design a procedure. Without a procedure, there is no experiment.

How can a pre-laboratory instructional framework help high school chemistry students independently design experiment procedures in order to transform inquiry experiments into an effective tool for content learning?

This introduction has covered my personal background in science education, the current climate in my high school chemistry classroom, challenges and motivations for implementing inquiry experiments, and an overview of the literature that will shape the final project. The following chapter discusses four themes in the literature: the science writing heuristic, writing-to-learn strategies, pre-lab preparations, and demonstration experiments. Each theme evaluates common threads that evidence shows impact student learning. Chapter 3 goes on to discuss the methods for designing an experiment template for high school chemistry. This capstone paper concludes with Chapter 4 which presents my personal reflection on the project. This reflection evaluates the role the literature played in the final framework design, shares my personal learnings from the project, and discusses potential for further research.

CHAPTER TWO : Literature Review

Introduction

This literature review examines teaching pedagogy for laboratory-based learning with a focus on chemistry courses. The review of the literature will begin by exploring the science writing heuristic (SWH), a method for implementing inquiry-based experiments in the classroom. The next section will delve into writing to learn strategies where writing is used to help students develop their understanding of complex topics through the gathering of data and feedback from peers and instructors. The third section examines various approaches to preparing students for laboratory experiments, often termed a *pre-lab*. Finally, the discussion will consider the practices that makes for effective laboratory demonstrations. In each section, essential elements of successful practice will be highlighted and effects on student content learning will be analyzed. This selection of the literature provides essential background for answering the research question: *How can a pre-laboratory instructional framework help high school chemistry students independently design experiment procedures in order to transform inquiry experiments into an effective tool for content learning?*

Science Writing Heuristic

Before delving into alternative frameworks, a clear picture of a standard or traditional lab experiment should be established. A standard high school chemistry course includes a laboratory component (Domin, 1999). A traditional expository lab would start with a short written introduction explaining background information about the chemical processes and include details about any new experimental techniques required. The introduction concludes with a purpose or essential question. The lab would continue on to a step-by-step procedure where the entire process has been prescribed for students to follow exactly. Then, the teacher would provide a series of analysis questions that direct the student on exactly how to process the data collected to fulfill the purpose set out in the beginning. This process relies heavily on the students' understanding of the prompts and requires minimal conceptual understanding of the chemistry to complete. This method, often referred to as the *cookbook-style*, does not align well with the broader purpose of deepening students' conceptual understanding of chemistry. In response to this, some instructors have implemented inquiry instruction. This style requires students to "formulate the problem, relate the investigation to previous work, state the purpose of the investigation, predict the result, identify the procedure, and perform the investigation" (Domin, 1999, p. 544) The science writing heuristic (SWH), which is discussed in detail in the following section, is a specific sequence designed to guide a class through an entire inquiry experiment (Keys et al., 1999).

Initially proposed by British chemist Henry Edward Armstrong in the 1870s, the method of the SWH promotes a setting where students act as discoverers of chemical principals (Rayner-Canham & Rayner-Canham, 2015). He specifically developed the method in response to students whose only desire was to memorize the minimal information required to pass his course. His method turned toward the image of student as scientist. It promoted students conducting their own experiments to answer a larger question about the nature of chemistry. Students completed a series of experiments that would each add a link to their chain of evidence. Unfortunately, like many educational pedagogies, instructors began to overreach, some leaving out all direct instruction. This resulted in a gradual shift away from student-driven experiments and a move toward the lecture method, supported by demonstrations. However, the idea resurfaced in the United States in 1979 under the new term *Inquiry* (Pavelich & Abraham, 1979).

The term *science writing heuristics* reappears in the literature in 1999. Proposed with two components, a teacher template and a student template (Appendix A), the SWH guides students through a framework that promotes the development of claims supported by evidence in the science classroom (Keys et al., 1999). The following section discusses several examples of the SWH found in the literature, highlighting how the student-led design, discussion, and writing embedded in the SWH templates proposed by Keys et al. (1999) increases student content knowledge and supports depth of learning.

In contrast to an expository prescribed format, the SWH improves upon traditional laboratory procedures by facilitating the social construction of knowledge. Four of the eight stages found in the teacher template focus on student negotiation of meaning (Burke, et al., 2006). Negotiation is initiated by the sharing of individual student data with the class. Then, after individual reflection, the students are gathered into a group discussion of claims and evidence. What evidence shows that opportunities to discuss experimental results impact comprehension? In a study of the SWH applied to an 8th-grade stream study (Keys, et al., 1999), interviews and student work demonstrated these activities promoted active meaning generation and metacognitive evaluation of their knowledge. Students were able to both explain their claims and evaluate the justification of that knowledge. The discussion of these results suggested that the social construction of knowledge plays a key role in allowing students to form justifications for their claims which deepens their scientific knowledge. In a study of 7th graders learning about the cell, Hand et al. (2004) found that 83% of students interviewed said that peer group discussions facilitated their learning. A study that surveyed student attitudes during the implementation of the SWH in an AP chemistry course, an older age group working with more complex material, found that students felt they better understood labs that included this group discussion of shared data (Putti, 2011). That survey of student attitudes further emphasizes the value students place on cooperative learning. At the undergraduate level, a study examined students who participated in an SWH lab on equilibrium, where time was set aside for group discussion as students formed initial claims and evidence arguments (Rudd, 2007). These students demonstrated, through test questions requiring evidence-based arguments, a stronger conceptual understanding of the equilibrium systems. Overwhelmingly, studies demonstrate that student discussion of claims and evidence in the negotiation phases of the SWH supports stronger conceptual understanding of science content (Kingir, et al., 2013; Poock et al., 2007; Burke et al., 2006).

In addition to discussion, the SWH facilitates learning by requiring students to articulate their newly obtained knowledge through writing. While the SWH can include writing in each step, it emphasizes writing in negotiation phases 1 and 4 when students articulate their claims and evidence (Burke, et al., 2006). A study of 7th-grade students working on the cell provides evidence of how this impacts learning. Researchers found that the active engagement in drawing connections between evidence and claims positively impacted the conceptual learning of the students (Hand et al., 2004). In addition to the SWH framework, this study asked one student group to write a final report in the form of a textbook explanation of the concept for a peer audience. The researchers found this strategy further increased student performance on conceptual free-response questions on the test. A different study at the undergraduate level also showed that students writing for student audiences resulted in increased conceptual learning after completing the SWH process results in (Rudd et al., 2007). A possible explanation for how writing facilitates this learning is presented by Burke et al. (2006) in a paper discussing the implementation of the SWH in undergraduate labs. These researchers shared several quotes from students who explained that the process of writing after discussing the data brought their thought process back to the initial question. For students, the writing puts the raw data into context. Ultimately, these studies draw a clear link between writing and student learning in the SWH (Rudd et al., 2007).

Importantly, these writing and discussion practices that impact student learning are not done in a vacuum. It should be emphasized that all negotiation of ideas is done with data gathered during student-driven experimentation. The beginning questions phase is critical to the success of the later negotiation phase. All of the studies discussed above started with an experiment where students have directed the questioning and experimental design to varying degrees. Students who have influenced the experimental design are more invested and engaged in the outcome of the experiment (Burke et al., 2006). Putti (2011) noted that students became progressively more invested in their experimental question and that pre-lab discussion resulted in higher student engagement during the actual laboratory process. Overall, studies of the SWH reflect how the student-formulated questions followed by actively negotiating understanding lead to deeper understanding of the instructional content (Burke et al., 2006; Kingir et al., 2013; Poock et al., 2007; Rudd et al., 2007). All this is to say that the SWH creates a synergistic learning experience by combining student-designed experiments, peer discussion of new ideas, and writing to synthesize understanding.

Having established the impactful components of the SWH, it should be noted that the majority of research has been done either at the middle school level or at the undergraduate level. While it is a useful framework, more work needs to be done to adapt and apply it in a high school setting. This project helps fill the gap in practical materials for implementing inquiry at the high school level by exploring the question: *How can a pre-laboratory instructional framework help high school chemistry students independently design lab procedures in order to transform inquiry experiments into an effective tool for content learning?*

The next section takes a broader look at writing to learn strategies. It explores the role that writing assignments can play in helping students assimilate new understandings into their knowledge of science.

Writing to Learn

Writing serves as a mode for synthesizing learning in the guided inquiry lab setting. Writing should allow students to draw clear connections between the experimental design, data collection, and the course content. The SWH is specifically designed with writing exercises at each stage of the scientific investigation. Each of these writing to learn (WTL) activities must also be scaffolded for the learner. This section explores writing and cognitive theory followed by a discussion of the mechanics of effective implementation of WTL strategies. The first half explores how writing facilitates student learning, drawing from works that examine writing in science classrooms specifically. The review then turns toward the mechanics of WTL in the science classroom. Different types of writing activities, ranging from one paragraph summaries to formal undergraduate term papers are explored along with the range of learners and settings in which WTL strategies have been deployed. After outlining the variety of WTL options, the focus changes to the details of implementing WTL, specifically scaffolding writing tasks. Notably, the activities reviewed in the research focus on post-lab writing, whereas the work in this capstone focuses on writing to prepare students for the lab process.

WTL facilitates learning by demanding students organize new understandings and shape them into language. Klein and Rose (2010), in a study examining the development of content literacy through WTL instruction, discussed the knowledge transformation model of writing that utilizes the metaphor of a content space and a rhetorical space. This posits that the writing process demands students first decide what they mean, which may require them to revisit previous knowledge or seek out new information, then the students must determine how to communicate their meaning which leads to a transformation of knowledge. Klein and Rose (2010) also discussed how text revision plays a key role in knowledge transformation, a topic that will be discussed in more detail. When comparing WTL to guided group discussion in an undergraduate setting, Finkenstaedt-Quiin (2017) found that student understanding increased as a result of the writing and revision process. Writing tasks are generally prompt-based and prompts push individual student thinking towards specificity and complexity that may not be demanded by other activities, such as group discussion. The cognitive task of writing facilitates learning by challenging students to organize, connect, and communicate their knowledge (Lillig, 2008; Prain & Hand, 2016).

While writing may be a solitary task, the process of learning through writing benefits from the input of others. Feedback from both peers and instructors plays a central role in the effectiveness of a WTL pedagogy (Klein & Rose, 2010; Kovac & Sherwood, 1999; Lillig, 2008; Prain & Hand, 2016). The cognitive theory presented above might leave the impression that one could assign a writing prompt, students would consider available sources of information, formulate a piece of writing, and *voila,* learning achieved! In a discussion of the Knowledge Transformation Model relative to research in middle grades learnings, Klein (2010) pointed out that “the transformation of content knowledge is itself complex and challenging” (p. 454). Reflecting on the feedback process in an undergraduate setting, Finkenstaedt-Quiin (2017), remarked, “Students typically feel that their initial submission is a polished product and do not recognize how to do revisions” (p. 1615). Establishing a rich understanding of a topic challenges students, and often they are not even aware of the gaps in their understanding. In particular, multiple authors note that feedback provided during the outline stage prompted students to incorporate new evidence or adjust arguments (Klein & Rose, 2010; Lillig, 2008). Receiving early feedback allows students to accommodate new ideas or restructure their writing before investing energy into the rhetorical aspects of writing. In the process of WTL, feedback is essential to facilitating the acquisition of new content knowledge (Vazquez et al., 2012).

Feedback serves the additional purpose of enhancing students’ writing skills. The science teacher might bristle at the obligation to instruct in writing skills, however, students with stronger writing skills benefit more from WTL strategies (Klein & Rose, 2010; Kovac & Sherwood, 1999). WTL requires that students structure their text in ways that reflect their organization of the content. This implies students with stronger writing skills will more clearly express their understanding through WTL. Thus, effective implementation of WTL pedagogy also requires that students grow in their writing skills. Stronger writing skills lead to improved outcomes from individual WTL activities (Klein & Rose, 2010). The mechanics for improving student writing will be discussed later in this section.

With the learning theory behind WTL established, the practical functions of implementing WTL in the classroom must be considered. Research has evaluated the effects of a wide range of writing tasks on learning outcomes. Common at all levels is the explanatory prompt. In some cases, this could be an exam question where students are asked to generate an explanation of a scientific phenomenon (Logan & Mountain, 2018; Visser et al., 2018). In other cases, this may be an assignment to explain specific phenomena using previously taught concepts (Klein & Rose, 2010; Kovac & Sherwood, 1999). Alternatively, students could produce explanations of specific phenomena as resources for other students in the course (Vazquez et al., 2012). At the undergraduate level, WTL has been implemented in the form of a term paper in place of the cumulative exam that would traditionally conclude an undergraduate chemistry course (Lillig, 2008; Parrill, 2000). Finally, undergraduate and K-12 instructors have implemented written lab reports and writing summaries of learning from laboratory activities (Deiner et al., 2012; Nordekvist, 2009). The majority of these applications used writing as a tool to facilitate deeper understanding of previously introduced concepts. In contrast, this project aims to explore how writing can be used to form students' initial understanding of a topic or lab technique.

While each style of writing assignment comes with its own challenges, several key practices appear as common threads throughout the research. Those threads include: clearly defining the writing task, providing writing instruction, building feedback into the writing process, and connecting writing tasks to course objectives. In a paper examining the professional learning community process of high school chemistry teachers who were revising prompts and rubrics for writing based exam questions, Logan and Mountain (2018) discussed how the teachers' use of domain-specific prompts, such as compare and contrast, produced student responses with better causal linkage and evidentiary support. Other effective language prompts may include explain, reason, describe, or justify (Visser et al., 2018). The author noted that this was specifically important for the high school students because their other classes, primarily English, required different styles of writing. Language-specific prompts reminded students to use science-specific styles of writing (Logan & Mountain, 2018). A well-designed assignment specifies the rhetorical form and audience desired from student writing (Kovac & Sherwood, 1999). Another study looking at high school chemistry students utilized a visual checklist of five items that accompanied the writing prompt on exams (Visser et al., 2018). While not part of the language of the writing prompt, it also functioned to remind students to check their writing for specific components needed in an effective answer. Those items were: punctuation, key components, complete reasoning, reference, and connectives.

Along with the verbiage of writing prompts, consideration should be made for the connection between the writing task and the course objectives. A study of the *Writing To Teach* model tasked students with writing explanatory texts of specific exemplars for other students (Vazquez et al., 2012). This group expressed that they felt they did understand specific concepts better, but the assignments did not aid their achievement on course assessments. Students may learn from WTL activities but if the prompt does not connect to course objectives, it may not aid in the desired content learning.

When dealing with longer writing assignments, researchers emphasized the importance of defining each subsection of the assignment for students (Deiner et al., 2012; Parrill, 2000). Deiner et al. (2012) discussed the implementation of a process called *directed self-inquiry*. For each section of the formal lab report, students were provided with a set of guiding questions. Students were asked to write answers to these questions prior to writing each section of the paper. The questions reflected the key information that should be included in that section. This pre-writing activity lead to stronger initial drafts of lab reports. The drafts reflected that students had a stronger understanding of the purpose of each section of a formal lab report by producing drafts with only the necessary information and drafts of appropriate length (Deiner et al., 2012). Additionally, grading criteria provide a resource for students to self-evaluate their writing and provide the most appropriate responses (Parrill, 2000).

Aside from understanding the writing task itself, students need support learning the skill of science writing. One university chemistry department approached the need for writing instruction through launching a program called “Writing Instruction and Training” as a part of their undergraduate program (Stewart et al., 2016). They implemented course components that supported improved writing skills. Then, they trained their teaching assistants (graduate students) in delivering writing instruction and effective feedback. Their TAs provided writing instruction in the form of seminars, presentations, and individual consultations. These individuals also provided students with detailed feedback on written work. All of this instruction culminated in producing students who have produced publishable work (Stewart et al., 2016); an especially remarkable feat when it could be argued that peer-reviewed publications are the form of WTL that facilitates the expansion of the scope of human knowledge. All of this is to say that fully embracing WTL in science classrooms necessitates the systematic instruction in domain-specific writing.

To step from the undergraduate setting into the middle school classroom, Klein and Rose (2010) found that writing instruction enhances students' *content* learning during WTL activities. Students with stronger writing skills learned more content from WTL assignments. When instructing on argumentative and explanatory writing, the teachers used activities including read-aloud followed by discussion and analyzing/evaluating to explore model texts, as well as outlining, drafting, and revising arguments. These practices are not new ways of teaching writing, however, the shift focuses on writing skills that support causal arguments central to science.

While direct instruction sets the groundwork for enhancing students' writing skills, students need feedback on each assignment in order to assimilate those skills. One study found that providing incremental feedback on student term papers improved the lowest graded papers in a cohort from earning 10% to earning 65% (Parrill, 2000). Anecdotally, students respond positively to one-on-one conferencing, using a method that provides one concrete positive, one concrete item to improve, and a general assessment of student achievement (Deiner et al., 2012). In addition to instructor feedback, peer feedback early in the process can be very helpful to enhance how receptive students are to feedback (Kovac & Sherwood, 1999). When students edit others' writing they are exposed to good and bad exemplar texts which also enhances their understanding of genre writing (Finkenstaedt-Quinn et al., 2017; Logan & Mountain, 2018; Visser et al., 2018). Moreover, the feedback that students then receive from those peer edits challenges them to revise their thinking and provide stronger explanative or argumentative writing (Finkenstaedt-Quinn et al., 2017; Kovac & Sherwood, 1999; Vazquez et al., 2012). Implementing a system of peer feedback also addresses the practical reality of the limited time an instructor has to look over each student's work. Asking students to review their peers' work increases the quantity and specificity of input each student receives on any given assignment (Kovac & Sherwood, 1999). This feedback process challenges students to grow both their thinking and their writing (Klein & Rose, 2010; Lillig, 2008). It is most beneficial when provided in a timely manner (Lillig, 2008). Both peers and instructors can provide transformative feedback. While writing tasks focus a student's cognition on the task of learning, feedback may be the secret sauce to student learning through writing. A program that effectively implements WTL in a science setting should include systematic writing instruction, clear writing tasks designed with a clear connection to course objectives, and frequent feedback.

The research provides evidence that language supports improve student learning through writing, however, the formulation of an experimental question requires specific supports that are not addressed in the literature that focuses primarily on interpreting outside sources or previously obtained laboratory data. This project will apply these language supports to the critical thinking required to design a laboratory experiment through addressing the question: *How can a pre-laboratory instructional framework help high school chemistry students independently design experiment procedures in order to transform inquiry experiments into an effective tool for content learning?* The next section explores how preparation before an experiment can impact student learning. In particular, it examines the genres of information students need prior to conducting an experiment.

Pre-Lab Instruction

Pre-lab assignments are a standard part of a chemistry laboratory curriculum. This section discusses several different approaches to preparing students for laboratory-based learning and how those approaches impacted student outcomes. Before that, however, there is the question of why laboratory-based learning requires preparation in the first place.

In a fully successful laboratory setting, students complete a physical process that requires specific step-wise actions, gather specific qualitative and quantitative data, analyze said data through causal links and mathematical processes, and finally assimilate that experience into their larger understanding of chemical phenomena (Klein & Rose, 2010; Winberg & Berg, 2007). A guided inquiry lab includes the additional requirement that students make decisions about the experimental question and procedure (Domin, 1999). Students may get caught up in the tasks required to conduct the experiment and miss the conceptual aim of the experiment (Chittleborough et al., 2007). Kirschner (1992) divided these demands into the substantive (the theoretical knowledge of science) and the syntactic (the habits and skills required to practice science). The process of preparing students for laboratory experiments must reduce the cognitive load required by carrying out the physical tasks of the experiment (Winberg & Berg, 2007). If pre-lab instruction allows students to complete the physical experiment with some automaticity, they will be able to shift their attention to the theoretical aspect of the experiment. That attention shift, as would be predicted, then results in greater conceptual learning as a result of conducting the experiment. This leads to the first essential objective of quality pre-laboratory learning, conceptual learning. Teachers must help students develop familiarity with the materials and techniques required to conduct the experimental process in order to achieve this objective (Rodriguez & Towns, 2018). In addition to understanding the physical processes involved, students who have activated prior knowledge of the theory involved in the experiment and a clear grasp of the aim of the experiment are then able to direct their attention to the most pertinent observations during the experiment and experimental analysis (Winberg & Berg, 2007). In summary, prelab assignments best prepare students when they both familiarize the student with the physical procedures of the lab and explicate the theoretical underpinnings of the experiment, which allows the student to focus on the epistemic question posed by the lab.

How is this done? The following section highlights several approaches to pre-lab preparations, what benefits they convey on students, and what aspects may be most applicable to the high school chemistry guided inquiry setting. To start, two studies that use quizzes as part of their pre-lab preparation are contrasted to show how different focus of the instrument impacts learning outcomes.

A Slovakian university tested an approach that presents a substantial shift from previous practices. In this study, students were provided with an introductory instructional session followed by a test a week later in preparation for subsequent lab work (Pogacnik & Cigic, 2006). As such, students experienced two full weeks of pre-lab preparation. During the introductory session, the theoretical basis for the experiment, basic calculations, and interpretation of the results were discussed. A week later students completed a test consisting of both multiple-choice questions and free-response questions on the introductory session. Instructors were able to use the results of the test to provide targeted feedback on the day of the lab. Notably, the pre-laboratory instruction included minimal practical instruction for the lab. It follows that in the discussion, instructors noted that students' questions regarding the protocol of the lab were not reduced by this pre-lab process. This supported the earlier claim that unless otherwise prepared, students spend a great deal of their mental energy on the physical process of the lab while they are completing the lab, which takes attention away from learning about the chemical phenomenon. Three other findings reported by this team reflect that this method of instruction and testing prior to the lab improves learning. First, students reported greater individual study in preparation for lab. Second, students felt that this time was better used than in lab instruction under the traditional model. Third, the number of students who passed the end of semester laboratory exam increased in all courses and in one course the percentage increased by 33%. These results suggest that shifting the time burden away from post-lab write-ups and towards pre-lab assignments can have a major impact on the learning (Pogacnik & Cigic, 2006).

While no other studies have shifted the format to include a full instructional session prior to lab, several other researchers implemented similar pre-lab tests that have also revealed important benefits to pre-lab learning. For example, in a second-year undergraduate chemistry course, students were provided with a video demonstration of the equipment and techniques (Jolley et al., 2016). This was followed by an online quiz containing guided calculations and multiple-choice questions that students could attempt twice and received feedback on the accuracy of their answers. Again, this method produced positive attitudes from students who felt they learned more from their lab experience. The quiz questions closely modeled the calculations required for experimental analysis which resulted in greater student confidence in their ability to conduct and analyze their own results. The author reflected that students were able to avoid cognitive overload and gained a positive learning experience from the lab. Importantly, completing the prelab work outside of class also freed up time for the instructors so they could provide individual attention to student needs at the start of the lab period. In contrast to the prelab instruction that focused on the underlying theory discussed in the previous paragraph, this study did not note a significant change in student scores on lab reports. The study noted that this may be because the lab reports are not a comprehensive assessment of all desired learning outcomes (Jolley et al., 2016). In either case, it is worth considering that the focus on lab procedures and calculations specific to that experiment may not be sufficient to encourage students to connect a specific experiment with their general knowledge of chemistry.

To further highlight the influence that feedback has on student learning, the next study used an online assignment to guide students through designing their own procedures (Girault & D'Ham, 2014). This is particularly relevant because this intervention has the same aim as the work proposed in this capstone project. First-year university students prepared procedures for an inquiry-based laboratory. In the intervention, students completed a simulation that was equipped with an automated tutor that walked them through the process of designing an experiment. The scaffolding and feedback provided by the computer program meant students produced more detailed and executable procedures. While this study does not assess how this impacted overall student learning, it did show an impact on preparedness for the experiment (Girault & D'Ham, 2014). This result further cements that a well-structured pre-laboratory assignment can improve student preparedness for an inquiry lab situation.

Computer simulations have been used as an additional method to improve the experimental procedure produced by students. They have also been used to broaden students' thinking about an experiment. In another university setting, students engaged in groups with a computer simulation of an experiment while teachers were present (Winberg & Berg, 2007). Similar to the intervention presented by Pogacnik and Cigic (2006), class time was dedicated to laboratory preparations. Students received a series of 15 open-ended and non-computational prompts for discussion during the class period. These prompts focused on the students' conceptual understanding of the chemical processes and were "designed to initiate questioning and discussions rather than asking for explicit answers" (Winberg & Berg, 2007, p. 1116) These concluded with the task of designing a procedure for the following day's open inquiry lab. While the other strategies presented prime students by activating prior knowledge and providing feedback on their understanding, this combination of a computer simulation and small group discussion uniquely focuses students' thought processes on the theoretical crux of the experiment. Post experiment interviews reflected that students had increased knowledge usability and production of theoretical questions about their experiment (Winberg & Berg, 2007).

The research presented overwhelmingly supports the impact of pre-laboratory assignments on improving students confidence during the lab, reducing the cognitive load of carrying out procedures, and improving either student work or learning outcomes (Girault & D'Ham, 2014; Jolley et al., 2016; Pogacnik & Cigic, 2006; Winberg & Berg, 2007). Direct instruction, quizzing, and computer simulations are all useful tools to facilitate learning. Instructors should consider the goal of the prelab assignment, whether it is meant to focus on the technical procedure, the analysis calculations, and/or the larger theoretical context of the experiment. When students know more about the lab experiment, they are able to learn more from it. Their cognitive focus during the experiment can be shaped by the design of the prelab experiment (Winberg & Berg, 2007). By shaping cognitive focus, pre-lab assignments directly enable and direct student learning during an experiment.

Finally, a consideration for the inquiry setting. The previous discussion focused on the format and focus of the pre-lab assignment for experiments with a prescribed procedure. This section considers the specific stages of an experiment that students should be asked to examine in preparation to design an experiment. Pre-labs must be especially rigorous in an inquiry lab situation because designing and conducting an experiment adds another layer of decisions and cognitive load for students. To illustrate, undergraduate students were asked to complete a two-week mini-investigation after four weeks of only experiencing expository labs and no specific preparation for experimental design (Seery et al., 2019). The research noted that "feedback from students indicated that these latter activities were unmanageable, stressful, and very difficult for them to carry out. The jump from expository to inquiry was too great" (Seery et al., 2019, p. 54). As a result, they redesigned the entire progression of instruction for the laboratory aspect of the course to scaffold the inquiry process. While their process was more involved than would be appropriate to expect from a high school student, this evidence does emphasize the importance of appropriate scaffolds when asking students to take on experimental design.

In this niche topic of specific experimental components to be included in a pre-lab to engage students in experimental thinking, there are two notable articles. The first article considers how the reconception of the prelab and post-lab assignments may be adapted to enhance critical thinking (Rodriguez & Towns, 2018). These authors point to the NGSS science practices as guidelines for the type of critical thought students need to engage in. The science practice most relevant to the aims of this project is "planning and carrying out investigations," which the article explains that students must identify what instruments to use, what data is needed, and what techniques allow you to gather said data (Rodriguez & Towns, 2018, p. 2145). However, this list, similar to the previous discussion, could use greater detail. The author went on to present a template for questions that would be addressed in a model pre-lab assignment for engaging students in critical thinking. These are paraphrased below:

i. Explain what methods are used and what data is collected
ii. Explain why these methods & *how* the data is generated
iii. Develop a scientific question that could be answered by this procedure
iv. Identify the chemical components of the experiment at specific points
v. Ask *why* specific calculations are used (Rodriguez & Towns, 2018, p. 2145)

While this is a useful template for instructors the article does not offer evidence of the effectiveness of the template in a classroom.

For a classroom-tested model, this discussion turns to Neber and Anton (2008) who focus their work on guiding students to generate epistemic questions. Drawing from previous research, these authors concluded that students are the most effective learners when they have drawn on prior knowledge to develop an experimental question. The process of drawing up knowledge and framing it into a question best prepares them to restructure existing knowledge based on the experience of the laboratory. The larger challenge is guiding students through the process of developing that question. They propose a five-step process:

I. Observation of a phenomenon
II. Access prior knowledge related to the observations
III. Formulate an epistemic question
IV. Develop anticipated answers
V. Plan to gather evidence to address the question (Neber & Anton, 2008 p. 1804)

With a focus on the third step, the intervention tested in the article helped students develop higher quality questions. The intervention started with asking students to rank their questions according to three dimensions: answerability, relevance to chemistry, and cause-effect relationships. This was supported with direct instruction on the difference between questions for facts and questions for causes (the desired type). Finally, students were given question stems that were pre-structured for conditions or functions. This time spent on developing quality questions resulted in stronger performances in the experiment and demonstration of strengthened cognitive skills (Neber & Anton, 2008). This shows that support structures and clear criteria are needed to develop strong experimental design skills in students.

These articles by Rodrigues and Towns (2018) and Neber and Anton (2008) could be layered together into a full sequence to prepare a student for an inquiry cycle. After developing anticipated answers, students would likely benefit from considering the questions in the template proposed by Rodriguez and Towns (2018) before designing a procedure. Paired together they would activate prior knowledge, establish a theoretical background for the experiment, and familiarize the student with the physical procedure necessary to gather scientific data, which seems to be the thread required to turn a lab experiment into a learning experience. The adaptation to the chemistry classroom requires further support to activate student thinking on a molecular scale. These steps walk students clearly through the experimental design process, however, students need further prompts to connect the macroscale data they collect with the molecular scale claims they will make in their hypothesis. These templates provide the beginning structure for the project that addresses the question: *How can a pre-laboratory instructional* *framework help high school chemistry students independently design experiment procedures in order to transform inquiry experiments into an effective tool for content learning?*

The next section focuses on demonstrations as a more specific technique for learning. The discussion focuses on how the instructional choices made when presenting a demonstration have the potential to take demonstrations from entertainment to active learning experience.

Demonstration Experiments

Demonstrations serve as a common instructional tool in the chemistry classroom. They can be useful tools to help students fully incorporate new concepts into their previous knowledge of chemistry. They can also help make abstract concepts more concrete for students (Black, 2005). However, they have a reputation for providing more entertainment than education (Roadruck, 1993). Demonstrations can be useful tools to help students fully incorporate new concepts into their previous knowledge of chemistry. This section explores three components that transform demonstrations from entertainment into a tool that transforms students' conceptual understanding of chemistry.

First, a well-designed demonstration directs students' attention to the key observations. In a complex demonstration set up, eliminating the noise and directing student attention to the key phenomena is essential to moving their thought process in the right direction (Majerich & Schmuckler, 2007). The physical set up of the equipment can be one way to direct their attention. In fact, one study examined how the Gestalt principles, principles designed to make objects or patterns easier for human vision to perceive, could be used to influence the physical apparatus of a demonstration (Nehring, 2018). These principles include: simplicity, moving from left to right, and symmetry, amongst others. When testing the principles, they found that their use positively impacted student attention and also learning during a demonstration. Aside from physical set up, the instructor should also direct attention to the most relevant observations as they proceed with the demonstration. One study used the term *window boundaries* to communicate the moment and location that students should direct their attention (Majerich & Schmuckler, 2007). The ability of a teacher to direct student attention at a precise observation is an advantage of demonstrations over other forms of laboratory work (Meyer et al., 2003).

Second, demonstrations need to explicitly engage students in sense-making, rather than simply explaining what has happened. This may include involving students in questions, predicting outcomes, clarifying what happened and why it happened, and explaining how specific chemical principles were involved (Meyer et al., 2003; Roadruck, 1993). Eliciting predictions and hypotheses, in particular, may help students draw specific conclusions from their observations (Black, 2005). Instructors may ask students to record their thoughts in a journal. Having students use a common note-taking structure may facilitate further conversation between students (Majerich & Schmuckler, 2007). In addition to the benefit of active questioning to the general student population, the active conversation between the teacher and students uniquely benefits visual learners and verbal processors (Meyer et al., 2003). This interaction between students, prior knowledge of chemistry, and new observations help students draw causal links between events and assimilate their observations into their general chemistry knowledge (Roadruck, 1993).

Third, instructors must scaffold the sense-making process and model scientific thinking. Instructors must adjust the concepts and the processes of the demonstration to the level of the student (Roadruck, 1993). This includes explicit instruction of academic vocabulary (Meyer et al. 2003; Roadruck, 1993). From there the instructor can use discussion during the demonstration to illicit causal thought and structure their questions to verbally scaffold students' thought process (Black, 2005). Much like written sentence stems, the structure of an instructor's questions provides verbal cues for how students should shape their own language and thought process. Aside from the discussion with students and shaping their output, instructors also have the opportunity to explicitly model how a scientist might deal with perplexing information (Meyer et al., 2003; Roadruck, 1993). A demonstration may be concluded with an expert diagram describing the principles embodied in the demonstration (Black, 2005). In fact, the opportunity to hear an expert explanation of a demonstration allows students to revisit and adjust their own understanding and explanation (Deese et al., 2000; Majerich & Schmuckler, 2007).

To further explore how these elements inform student learning, two contrasting research articles will be presented. The first offers insights into the challenges that can arise when teaching using a demonstration (Baddock & Bucat, 2008). The second offers an exemplar for how adjusting the instructional style used during a demonstration can positively impact student learning outcomes (Majerich & Schmuckler, 2007).

The first exemplar took place in the chemistry classroom of year 11 secondary students who are learning about the properties of acids and bases (Baddock & Bucat, 2008). The demonstration is meant to confer the difference between a weak acid and a strong acid, using solutions of varying concentrations, an acid/base indicator, and pH. Students were given four prompts:

I. Describe the demonstration

II. What was the aim of the demonstration

III. Explain the observations

IV. What do you think you have learned? (Baddock & Bucat, 2008, p. 1118)

The demonstration was conducted in three cohorts containing students with different skill levels. In the first cohort, the demonstration was given without explicitly stating the aim. Student responses reveal that students did not recognize the objective of the demonstration. Additionally, observations noted by individual students varied greatly because their attention was undirected. This related directly to point one above, instructors must direct students to the salient observations. In the second cohort, the names and formulas of the acids were provided on the board, and the teacher-facilitated a discussion of the results. In this case, students were able to state the aim and identify the key concept involved. However, they were not able to provide a causal explanation for this observation. While not discussed in the paper, it is possible that an additional demonstration or an expert explanation may have been needed to reach a full explanation. This highlights how demonstrations can function as an introduction of a concept but may not provide enough context or depth of information to generate full explanations for a phenomenon. Uniquely, Baddock and Bucat (2008) reported that the third cohort had a particularly negative reaction to this format of instruction. This cohort also included students that are described as low to average ability. Baddock and Bucat (2008) noted that these students had little experience with being asked to “propose or defend ideas” (p. 1124). This highlights the importance of scaffolding demonstrations for the level and abilities of the participating students. While there were positive outcomes from this instructor’s practices, the report usefully highlights the essential nature of well-developed discussion prompts to pair with a demonstration.

The second exemplar of how instructional design can improve student learning outcomes during demonstration-based instruction took place in a non-major undergraduate chemistry course (Majerich & Schmuckler, 2007). Over the course of the semester, students in this course viewed 102 demonstrations. This project compared two cohorts. The first cohort saw all demonstrations in a traditional mode where, "in brief, the instructor told students what they were going to see, showed them the demonstration, and then told them what they just saw" (Majerich & Schmuckley, 2007, p.62) In the second cohort, an alternative revised method meant to engage students in scientific thought utilized convergent and divergent questions meant to encourage discussion amongst the instructor and students. This strategy exemplifies one approach to actively engage students in sense-making, as discussed earlier. The instructor also used *window boundaries* to direct student attention on specific phenomena and eliminate noise. Intentionally directing student attention was also discussed as a key element of effective instruction during a demonstration. Additionally, students were given a uniform note-taking strategy (a way to classify and organize information as they participated in the lesson) and were asked to compare notes with at least two other students to refine their conclusions. The instructor modeled sense-making through a note-taking structure which is another documented component of effective demonstration instruction. Apart from the demonstration itself, students in the second cohort also took daily quizzes on the previous day's demonstration which was followed by a review of correct responses by the professor. This provided students with an expert model for thinking about the concepts. As a result of these classroom engagement strategies, the second cohort scored higher and recalled more applied knowledge than when compared to the first cohort (Majerich & Schmuckler, 2007). Clearly, when students are actively engaged in analyzing observations from a demonstration and their thought process is properly scaffolded, demonstrations offer an engaging instructional format that does result in students learning chemical concepts (Deese et al., 2000; Majerich & Schmuckler, 2007; McKee et al., 2007; Sever et al., 2010).

Summary

This literature review has presented an overview of the SWH, WTL, pre-lab assignments, and demonstration-based instruction. The SWH provides an outline for supporting student thinking through a full inquiry process. It emphasizes the role of writing and conferring with others to shape ideas about science over time. The WTL section explored a wide variety of ways that writing has been used to support learning in the chemistry classroom, from simple exam questions to full undergraduate term papers. These articles emphasize the importance of clear prompts, feedback throughout the writing process, and instruction on writing skills themselves. They affirm that writing can improve student learning in science but must be structured and supported. The pre-lab section revealed that students need both theoretical background knowledge, as well as, a practical understanding of lab processes in order to fully appreciate the concepts demonstrated by the experiments they conduct. Finally, the demonstration section revealed that demonstration experiments are most useful when students are actively engaged in interpreting the observations from the demonstration. It also reinforced the notion of cognitive overload from the pre-lab section. When students have to spend energy focusing on the lab procedure, they pay minimal attention to the meaning of their results. Students need guidance to see the most salient details of any demonstrated experiment. These details direct students to think about the chemical principles displayed in the demonstration.

While each of these sections reflect best practice, none directly address the use of demonstrations as instruction to prepare students for selecting an experimental question and designing a lab procedure. These methods will be pieced together into a framework that will address the research question: *How can a pre-laboratory instructional framework help high school chemistry students independently design experiment procedures in order to transform inquiry experiments into an effective tool for content learning?*

The next chapter walks through the methods of the template that was developed in this project. It introduces the specific high school setting that this intervention is designed for. In addition, there is a short explanation of the key articles from the literature review that are built upon to develop the scaffolds. Finally, there is a detailed description of the demonstration and guided analysis process proposed by this project. This is followed by Chapter 4 which presents my personal reflection on the project. This reflection evaluates the role the literature played in the final framework design, shares my personal learnings from the project, and discusses potential for further research.

CHAPTER THREE : Project Description

Introduction

This project designed an instructional framework for utilizing a teacher-led demonstration followed by guided analysis questions to facilitate the design of a student-led experiment. This chapter expands upon frameworks described in the previous chapter, and provides details about the specific classroom where the project will be implemented. Combining research-based practices with practical knowledge leads to an answer to: *How can a pre-laboratory instructional framework help high school chemistry students independently design lab procedures for guided-inquiry labs in order to transform inquiry experiments into an effective tool for content learning?*

Current education research suggests that in order to prepare science-literate students, students must participate in genuine scientific inquiry and that the inquiry setting can result in lasting content learning (Blumer & Beck, 2019). Inquiry, at its heart, means that students learn from forming and answering questions. In the chemistry classroom, inquiry centers around the laboratory. This project focuses on guided-inquiry, a format in which, to varying degrees, teachers set boundaries by prescribing available materials and the general topic for the experiment. Students are then asked to design and conduct an investigation. This structure works well in settings where students are using familiar materials for experimentation and variables are easily measured by common tools, like measuring plant growth with a ruler. Unfortunately, the chemistry laboratory is often entirely unfamiliar to students and there are substantial safety concerns that students must be prepared to mitigate. The nature of chemistry requires investigators to connect visible macroscale observations with invisible microscale behavior. The causal chain can pose a substantial challenge for students when designing experiments that will address their formulated question. Aside from the logistical challenges involved in student-designed laboratory experiments, there is pressure on high school chemistry curricula to teach a substantial amount of complex content in a distinctly limited amount of time. Inquiry labs must fit within the time restraints of a chemistry course.

This project aims to fill the gap between prescribed best practices (inquiry-based instruction) and practical concerns (complex techniques, safety concerns, and time) using laboratory demonstrations and guided writing exercises to set students up with the tools and supports needed to properly design an experiment. Laboratory demonstrations serve as a time friendly method of both sparking student interest in a topic and teaching laboratory techniques and procedures. Students are then set with both a conceptual framework and a practical framework to work within. Guiding questions allow students to generate and evaluate experimental questions, and design a step-wise procedure that will address their questions.

Standards and Outcomes

While this project aims to provide a template that could be applied in teaching a wide range of chemistry content, there are specific skill-based outcomes that students who participate will hopefully obtain. Students will

1. Learn to connect macro-scale observations with molecular scale behaviors
2. Improve their experimental design skills
3. Gain confidence in their ability to participate in science and think like a scientist

4. Experience joy and enthusiasm as it relates to successfully conducting an experiment

While multiple science and engineering practices will be involved, this process aims to facilitate students in the NGSS standard: HS - PS-1 - Planning and Carrying Out Investigations - "Students should design investigations that generate data to provide evidence to support claims they make about phenomena" (NGSS Lead States, 2013, Appendix F).

Setting and Participants

The project, while designed with broad flexible use in mind, will be implemented in a public high school setting. The school is in a small midwestern city and has approximately 1,077 students of whom 24% identify as a minority (primarily Hmong and Black) and 30% of whom receive free and reduced lunch (*Central high school school report card detail,* 2019). Students attend from both urban neighborhoods surrounding the school and the nearby rural communities. Students will be 10th and 11th-grade students in a year-long chemistry course. They are required to have taken or be concurrently enrolled in algebra II. The hybrid weekly schedule includes three 45 minute class periods (Monday, Tuesday, and Friday) and one 85 minute class period (Wednesday or Thursday). Typically, lab instruction takes place during the 85 minute class period.

Theoretical Framework

The framework developed during this project was modeled after the SWH and a sequence of cognitive activities proposed by Neber and Anton (2008). This is a method of scaffolding student thinking throughout an inquiry experiment (Keys et. al, 1999). The process includes a template for teacher-designed activities and a template for student questions, with 8 and 7 steps, respectively (Appendix A). While the heuristic provides guidance for the entire inquiry process, this project focuses on the first two steps that prepare the student for inquiry. The first step, exploration of pre-instruction understanding, which is framed by the student question, “What are my questions?” is meant to initiate student thinking (Keys et. al, 1999, p 1068). This project designed a process for the use of a demonstration as the specific method of pre-assessing student understanding and initiating the inquiry process. The second step, pre-laboratory activities, which is framed by the student question, “What do I do?” represents the process of students designing laboratory experiments (Keys et. al, 1999, p 1068). This was addressed by the guiding questions portion of the project described in this capstone. The sequence proposed by Neber and Anton (2008) also layers well on top of these first two steps of the SWH, providing more detail to the process. Their sequence has five steps. The first two are addressed during the demonstration portion of the sequence: observation/phenomena and access prior knowledge. The second two are addressed during the guiding questions portion: epistemic questions, anticipated answers, and planning for evidence. The work by Neber and Anton (2008) is more specific and relevant than the SWH because it addresses chemistry laboratories specifically. In contrast, the SWH is designed for and has been used in a broad array of science classrooms.

Project Description

This project presents an instructional sequence that could be used by other instructors to adapt labs into a format that prepares students to develop their own experimental tests. This will include templates that outline an instructional process. This learning process includes two parts.

First, there is a teacher-led demonstration of a laboratory experiment. Second, students work through a series of guided analysis questions that facilitate making meaning of the demonstration and developing their experimental design. The materials include four documents, a teacher template (Appendix B), a generic demonstration outline (Appendix C), a guided analysis template (Appendix D), and a student notes template (Appendix E). The teacher template which, similar to a guided notes template, prompts the teacher to think about the outcomes and components of the experiment. The demonstration outline provides guidance on what content should be included in the direct instruction provided during the demonstration. The guided analysis template provides the sequence and genre of question to use to lead students through meaning making and developing their own experimental test. The students notes template provides space to make notes of each topic covered during the demonstration. In addition to the templates, the project fully developed 3 experiments appropriate for introductory high school chemistry that include a filled-out teacher template and an adapted question set (Appendices F-H).

The instructional process starts with a phenomenon presented as a laboratory demonstration conducted by the instructor. Following the demonstration, students work through a guided question set where they make sense of the demonstration and develop an experimental test for a secondary experimental question. When conducting the demonstration, the instructor will explain the aim of the demonstration, walk students through the technical procedures, and focus their attention on key observations. The students will take notes throughout. Their notes should include proper use of laboratory equipment, safety procedures, and quantitative and qualitative observations. As appropriate, this may involve the instructor modeling mathematical analysis of the data. The demonstration serves to stimulate students' prior knowledge, provide a basis for further investigation, demonstrate key laboratory techniques and pieces of equipment, and outline a sample procedure that students could replicate or modify.

Once the demonstration is complete the students will be broken into small groups. These groups will work through the guided analysis. This analysis will begin by helping students formulate explanations for the events observed in the demonstration. Then, they will be presented with a new scenario and experimental question. The guided analysis then helps them model the new scenario, develop anticipated results of their new scenario, and propose an experimental procedure to answer the experimental question. This process is modified from a sequence proposed by Neber and Anton (2008). Students may be supported by question stems, a specific list of available lab equipment, and specified appropriate range of quantities for chemical reagents.

Assessment

Project effectiveness will be evaluated during the 2020-2021 school year. There are two goals established by the research question. First, students design their own experiment procedure. Second, students learn chemistry content from the lab process. When implemented, if students are able to successfully design and carry out an experimental test, this will be a mark of initial success. Each experiment comes with its own challenges and the guided analysis will need fine tuning to reduce the amount of teacher intervention needed. The aim is to reduce teacher intervention to the point where a teacher will either approve or point out gaps and students have the tools to fill in gaps once they see them. Assessing the effect of this framework on content learning will be a more complex task. Two approaches will be used to accomplish this. First, students will complete a short multiple choice test on the content before the lab and after the lab. This will assess vocabulary, chemical concepts, and basic calculations where applicable. Second, students' final responses to the experimental question will be assessed. This will be assessed on a correct explanation of the concept being studied, as well as the clarity with which the student is able to utilize their observations to support that explanation. Additional marks of success will be student performance on unit tests and lasting understanding reflected on the semester final exam, although these benchmarks are also affected by the other instruction that takes place during the course.

Timeline

The templates and three example experiments were developed over the course of June 2020. This began with a general outline of the notes template and teacher template. Then several labs were adapted for the process and three were selected as useful exemplars. The templates were edited to reflect lessons learned from adapting those labs. The template and experiments were reviewed by a professor of chemistry and biochemistry in July of 2020. Next steps will require developing the student post-lab write-up and a rubric for evaluating student work. Pre and post-quizzes will need to be created in order to evaluate effects on content learning. Implementation of the experiments is anticipated during the 2020-2021 school year, as appropriate given the current COVID-19 pandemic. Once these experiments have been classroom tested and effects have been evaluated, this work will be shared informally with coworkers and members of a chemistry teacher group. Final steps may include sharing this work in a conference setting.

Summary

Chapter 3 discussed how research suggests that inquiry lab work improves student outcomes in science education, however, chemistry students rarely have sufficient prior knowledge to design their own experiment without substantial scaffolding. Using the SWH and a pre-experimental instructional sequence developed in previous literature as a foundation, this project designed a framework that can be used to appropriately scaffold inquiry activities in the chemistry classroom. This framework includes a demonstration phase where the teacher provides background knowledge and technical instruction and a guided analysis phase where students work through a set of guiding questions that help them make sense of the demonstration and design a safe, appropriate procedure for their own experiment. Chapter 4 presents a personal reflection on the project. This reflection evaluates the role the literature played in the final framework design, shares my personal learnings from the project, and discusses potential for further research.

CHAPTER FOUR : Conclusion

This chapter discusses my personal reflections on this master's capstone project. This project started with the needs of high school chemistry students who would benefit from more laboratory-based learning and more autonomy in that learning. The project was framed by the question: *How can a pre-laboratory instructional framework help high school chemistry students independently design experiment procedures in order to transform inquiry experiments into an effective tool for content learning?* This reflection begins with a short note on my personal growth as a result of the capstone process, followed by a retrospective on the research literature that had the biggest impact on the design of the instructional framework that emerged from my work. Next, my personal takeaways from the project are described before concluding with the limitations of the work, suggestions for further research, and benefits to the profession.

Professional Growth

The primary impact of this project on my professional practice has resulted from the deep dive into the research and research community that exists around chemistry education. While I was peripherally aware of educational research prior to this work, I am now soundly versed on the inner-workings of the research and am familiar with professional organizations that are working in areas that interest me and impact my teaching practice. I read work by several researchers whose research projects have spanned over a number of years. The literature review revealed how work develops over the course of years and how people from across the globe are collaborating to make that research happen. The body of work I have encountered is colossal, but it left me with the realization that current research in chemistry education is focused on undergraduate learning and there is a relative gap in research on high school classrooms. The process has given me the skills and knowledge that I needed to be able to engage with the research community. I hope that the work I have done on my capstone project will be a springboard that launches me into professional work that reaches beyond my immediate school or district.

Literature Revisited

The literature review supported this project by providing both a theoretical framework for my thinking and practical instructional tools to include in the templates. The theoretical perspective provided by the research placed the method of inquiry-based teaching in historical context, established student negotiation of meaning as an essential element of inquiry, and accounted for the multifaceted nature of inquiry in a laboratory setting specifically. In the discussion of the historical origins of the modern inquiry method, it is revealed that the original attempt at student inquiry died out because teachers shifted away from direct instruction (Rayner-Canham & Rayner-Canham, 2015). This focused my attention on the ways teacher-led instruction supports student-led inquiry as I attempted to avoid this historical weakness of the inquiry approach. An effective and engaging classroom must balance these two instructional styles.

The discussion of the science writing heuristic (SWH) established the positive impact of inquiry on student learning outcomes (Keys et al., 1999). The structure of the SWH emphasizes how each step of the inquiry process requires students to process their understanding. This may be in the form of peer discussion, consulting outside texts, or conferencing with the teacher. These structures are the vehicle for students to draw understanding from self-directed inquiry

(Kingir et al., 2013). In the pre-lab section of the review, the discussion of student cognitive load brought to light the complexity of laboratory-based learning (Winberg & Berg, 2007). Students in a chemistry lab are negotiating the demands of the physical tasks of conducting a lab procedure, as well as attempting to make theoretical sense of the powders and liquids before them. Dissecting the cognitive load created by the laboratory setting established the areas in which this framework needed to support students during an experiment. These aspects of the literature impacted my general approach and my understanding of what learning needed to happen for students to be prepared to plan an experiment.

The five step process proposed by Neber and Anton (2008), outlined in Chapter 3, provided a foundation for the sequence of the tasks in the framework proposed in this capstone. With this sequence in mind, specific strategies proven effective by the research were then embedded in the instructional sequence. Step one proposed by Neber and Anton (2008), observation of a phenomenon, is achieved through a teacher-led demonstration. The demonstration template (Appendix C) was built to support active discussion between the teacher and students. It intentionally leaves out an explanation of the phenomena and students are asked to draw their own conclusions. This is in line with the evidence that active meaning making on the part of the students results in stronger mastery during demonstration-based instruction (Roadruck, 1993; Majerich & Schmuckler, 2007).

The framework includes teacher feedback throughout the process. Feedback happens during the verbal discussion during the demonstration, after students analyze the demonstration, and before they conduct their experiment. Peer feedback, while not formally described, would be naturally part of the guided analysis which is designed to be conducted using cooperative grouping structures. Both peer and teacher feedback were discussed extensively in the writing to learn literature as a key strategy to help students adjust their understanding of the concept at hand (Klein & Rose, 2010; Kovac & Sherwood, 1999). While the writing tasks included in the templates are not as formal as the tasks studied in the literature, the evidence of the influence of feedback on student understanding persuaded me to include it throughout the framework.

Finally, a small but influential phrase, "develop anticipated answers", shaped the guided analysis process (Neber & Anton, 2008). This phrase is step four in the process and substantially changed the way I, personally, think about preparing students for inquiry. Having students predict what outcomes may look like allows them to anticipate what data they would need to collect in order to test their prediction. This step clarifies how to help students identify the evidence they will need to support their final claims.

Major Learnings

As I reflect on the major learnings I have taken from the process of designing this instructional framework, I have come away seeing that effective inquiry may look simpler and perhaps less rigorous on the surface but that intentional simplicity builds a bridge between the student and the content. What follows are not meant to be considered as research backed claims or conclusions, but rather are my personal take-aways from this process.

The process of designing a framework for inquiry in the introductory high school chemistry classroom has revealed how the demands of a particular educational setting shape the inquiry process. As discussed in chapter one, high school chemistry demands that a significant amount of content be conveyed in a limited period of time. Evaluating how to open up labs to student inquiry while focusing their attention on the desired content has resulted in choosing simpler experimental setup. This choice of simpler experiments initially seemed contrary to the academic rigor that is often associated with the inquiry process. While a less complex task may on the surface seem too simple for a high school classroom, and perhaps it would be if it were given as a fully directed activity, simplicity reduces distraction and creates a clearer relationship between variables. For instance, the concepts taught through the moles of metal lab (Appendix H) could also be taught through the dehydration of copper sulfate (a common procedure, though not detailed here). In that case, the copper sulfate releases water which is a compound rather than the elemental hydrogen released by the aluminum reaction. Using the aluminum lab eliminates the potential confusion around the molar mass of a compound versus an element. Choosing simpler chemical systems allows for an inquiry process that directs students' attention to the desired content objectives.

Simpler chemical systems also allow for greater student independence during the guided analysis process. When writing questions for guided analysis, it became evident that students would need to infer a certain amount of the process. To write questions that allowed students to infer relationships meant that students needed familiarity with the chemicals involved. For instance, the precipitation lab analysis asks students to break down just one reaction at the particle level (Appendix G). This focuses their attention on the role of the ion charges in the formation of a precipitate. Once they have looked at this single reaction in detail, they are then asked to infer how that pattern would apply to the other reactions they have observed. Simplicity allows for guided analysis questions that students can answer independently and drive at the cause of a particular chemical behavior. Focusing on simple chemical systems benefits the inquiry process by both focusing on the desired chemical behaviors and increasing the independence with which students can infer the causes of those behaviors.

Finally, this framework has brought to light how structured inquiry can naturally build application tasks into a unit. It highlights how instruction must scaffold tasks in order to fully prepare students for the demands of applying their knowledge. The laboratory setting reveals the complexity of applying knowledge in a new setting. In order for students to operate autonomously, they must be knowledgeable of the physical and conceptual components at play in an experiment. When students are asked to explore independently, they must be prepared for and supported throughout that exploration. The direct instruction during the demonstration and scaffolded analysis questions are not a relic of older teaching methods but an essential component of inquiry. This framework, hopefully, bridges that gap and lays the groundwork for students to apply their chemistry knowledge to inquiry experiments.

Limitations

The primary limitation of this project is the absence of empirical testing. The research question establishes improved content understanding as a desired outcome. While the templates and sample labs certainly reflect effective practices as established by previous literature, empirical evidence needs to be gathered to support the finding that this process improves learning outcomes.

Aside from the need for empirical testing, the proposed framework focuses on developing student understanding of the chemical concepts rather than experimental design. The demonstration structure provides instruction on specific laboratory techniques but would need modification to include discussion of types of data provided by those techniques. The guided analysis template provides enough experimental design support to implement inquiry labs appropriate for introductory labs that require minimal quantitative data. This works for an introductory course where student procedures deviate very little from the procedure of the teacher-led demonstration because students are still mastering the basic laboratory skills. However, these materials would need to include more structure for experimental design if used in more advanced chemistry courses. Lab experiments typical to AP chemistry require more detailed quantitative data and more complex lab procedures. In order to ensure quality outcomes and student safety, the experimental design or "plan" stage of the guided analysis would need to be amended.

Finally, this framework does not extend to the data analysis or conclusion of the inquiry lab experience. The research question focused the project on preparing students to design an experiment. In that way, the framework addresses the question. It does not, however, complete the inquiry process.

Further Research

To reiterate the limitations, the first aspect of further research would be verification of content learning through this form of laboratory-based learning. In addition to testing this framework in a classroom, future research is needed to expand the framework for use in more advanced courses, develop the framework to include the completion of the inquiry process, and consider how longitudinal plans could be used to build skills and increase student autonomy over the course of a semester or academic year. This framework focuses on the pre-lab portion of instruction. To fully embrace the inquiry process further research would be needed to create and evaluate materials that support analysis and conclusion of the student experiment. The major learnings section discussed how this process scaffolds students' skills within the experiment. Further research could examine how skills can be scaffolded across the semester or school year. This would allow for increasing autonomy as students progress through their chemistry course. The final suggestion for further research is in regards to the complexity of the material supported by this framework. Currently, the templates are designed to meet the needs of mostly non-quantitative experiments found in introductory high school chemistry. Implementing these tools in a more advanced course, like AP chemistry, or would need to include scaffolding around planning more complex experimental procedures.

Communication of Results and Benefit to the Profession

After I have demonstrated proof of concept in my own classroom, these tools will be shared electronically through several professional groups that I participate in. I also have an interest in presenting this material in a professional conference format, however, I plan to gather more evidence about the efficacy of this approach prior to presenting it. The primary goal of this work is to provide a framework that would increase the feasibility of inquiry-based learning in high school chemistry. By providing a framework, hopefully, teachers will be able to adapt their current labs to an inquiry format and students will benefit.

Summary

This concludes the capstone project researching the question: *How can a pre-laboratory instructional framework help high school chemistry students independently design experiment procedures in order to transform inquiry experiments into an effective tool for content learning?* The literature review brought to light the complex cognitive demands of laboratory-based learning. This research revealed a variety of challenges that the project needed to address, including: teaching practical skills, connecting practical observations with theoretical understanding, and developing experimental design skills. Fortunately, the research also revealed that strategies, such as, appropriately timed feedback, open-ended questioning during a demonstration, and predicting answers to an investigation positively impact content learning. Using the research as a foundation, the framework proposed a two part solution. First, a teacher-led demonstration engages prior knowledge and teaches practical laboratory skills. This reduces the cognitive load placed on students during their own experiment. Second, a set of guided analysis questions helps students connect observations with theory and supports the experimental design of a student-led experiment to follow. This process develops practical laboratory skills and supports connections between observations and theoretical knowledge, while opening up opportunities for student autonomy. Development of the example labs revealed that using simpler chemical systems allows the guided analysis to draw direct links between observations and theoretical conclusions. Next steps will include developing materials for concluding the inquiry process after students conduct their own experiments and gathering empirical data regarding the effectiveness of this instructional framework. Further research is needed to consider how this framework could be expanded for use in quantitative experiments for advanced courses. Overall, this capstone project has successfully facilitated the development of a practical tool that integrates laboratory experiments with classroom learning.

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Appendix A

Teacher Template: A template for teacher-designed activities to promote laboratory understanding.

1. Exploration of pre-instruction understanding through individual or group concept mapping.
2. Pre-laboratory activities, including informal writing, making observations, brainstorming, and posing questions.
3. Participation in laboratory activity.
4. Negotiation phase I - writing personal meanings for laboratory activity (For example, writing journals).
5. Negotiations phase II - sharing and comparing data interpretations in small groups (For example, making a group chart).
6. Negotiation phase III - comparing science ideas to textbooks or other printed resources (For example, writing group notes in response to focus questions).
7. Negotiation phase IV - individual reflection and writing (For example, creating a presentation such as a poster or report for a larger audience).
8. Exploration of post instruction understanding through concept mapping.

Student Template: A template for student thinking.

1. Beginning Ideas -- What are my questions?
2. Tests -- What did I do?
3. Observations -- What did I see?
4. Claims -- What can I claim?
5. Evidence -- How do I know? Why am I making these claims?
6. Reading -- How do my ideas compare with other ideas?
7. Reflection -- How have my ideas changed?

Appendix B

Teacher Template

- ❏ Focus Question :
- ❏ Experiment Prompt :
- ❏ Scientific Principles required to answer the question
    - ❏
- ❏ Reagents

Name	Formula	Concentration	Notes

- ❏ Equipment

Name	Purpose

- ❏ Key Techniques
    - ❏
- ❏ Safety Protocols
    - ❏
- ❏ Disposal / Clean Up Protocols
    - ❏
- ❏ Prior Knowledge
    - ❏
- ❏ Vocabulary
    - ❏
- ❏ Important Observations to draw attention to
    - ❏

Appendix C

Generic Demonstration Outline

Before the demonstration

I. Discussion of prior knowledge
   A. Questions provided on Notes Template
   B. Students may be asked to attempt questions prior to class discussion.
   C. Clear, correct answers should be provided to students during discussion.
   D. Some experiments have a "wait time" while the reaction takes place. It may be appropriate to move the discussion of prior knowledge to this point.

II. Safety Concerns

III. Equipment Identification and Purpose

IV. Chemical Reagent Identification and Background Information as needed

During the demonstration

I. Explain key techniques

II. Describe each step in the procedure and its purpose

III. Direct student attention to key observations

IV. Use key vocabulary

Appendix D

Guided Analysis Template

I. Model demonstration events
   A. Using observations from the demonstration, students should be asked to model the events. The primary goal is to attach their observations to specific chemicals in the process. This may require students to infer connections between their observations and their knowledge of the species at play.
   B. May include:
      1. Particle-level drawing
      2. Comparison of quantitative data to identify trend

II. Connect with chemical principles
   A. These questions connect the model they have made with the chemical principles established in the prior knowledge discussion. These questions should help students describe "why" an event occurred.
   B. These questions should directly mention the key vocabulary and scientific concepts that the lab aims to teach.
   C. May include:
      1. Specific references to prior knowledge questions
      2. A series of questions leading students through a casual chain
      3. Quantitative analysis broken into small manageable steps

III. Hypothesize
   A. Students will respond to focus question
   B. This is the point where students fully explain their understanding. They should be asked to identify what, how, and why the events in the demonstration occurred.

Teacher Check I - Each group should check in with their teacher at this time. For teachers, this is an opportunity to correct any misconceptions or mistakes. It can also serve as a time to assess work and reducing time spent grading later.

Prompt - Student Experiment - This should describe the task of the experiment, the chemical reagents involved, and the available materials.

IV. Model the experiment
   A. Students should create a model of the experiment. Students should *identify each reagent present*, what equipment it interacts with, and what other reagents it may come into contact with.
   B. They should also *describe key properties* of the chemical reagents involved. For instance, they may note the charge on ions or identify a chemical as an acid or a base.
   C. Students may be asked to *use chemical principles* involved in the demonstration *to infer* or predict the interactions in their experiment.
   D. This model may also be more general than the specific experiment to allow students to think more broadly about the chemical behavior they expect to see.
   E. This may include:
      1. Particle level drawing
      2. Balanced chemical equations
      3. Looking up properties of reagents involved

V. Hypothesize results
   A. Students should be asked to predict the outcome of the experiment. Leave room for students to make the wrong prediction. Confronting a wrong hypothesis can be as useful to students as confirming a correct hypothesis when it comes to fully understanding a concept.
   B. In order to make this an exercise based on logic rather than a guessing game, it may be helpful to provide hypothetical data or to ask students to make a hypothesis about general results or trends they expect to observe.

VI. Plan Experiment
   A. Walk students through the process of planning their experiment.
   B. This may include:
      1. Safety protocol
      2. Variables to be designated as constant, independent, or dependent.
      3. Determining the quantities of reagents needed.
      4. Writing a step-wise procedure.
      5. Creating a data table.

C. Adjust these steps to your students' abilities and the complexity of the experiment. It may be appropriate to try a scaffolded procedure where students fill in blank steps with their own choices.

Teacher Check II - At this point, you will check to see that your students will be prepared to begin their process. It may be helpful to have a list of essential elements to check for like: necessary data points in their data table, specific steps in the procedure, knowledge of safety, and clean-up procedures. Again, this can be a useful moment to check work off for grading so that time does not need to be spent reviewing these answers after the lab has been completed.

Appendix E

Demonstration Notes Template

Focus Question:

Prior Knowledge Questions

1.
2.

Equipment:	Safety:
Reagents:	Products:
Procedure:	Observations + Measurements

Appendix F

Gas Pressure - Teacher Template

- ❏ Focus Question
  - ❏ How does temperature affect pressure?
  - ❏ How does volume affect pressure?
- ❏ Scientific Principles required to answer the question
  - ❏ Temperature and Pressure have a direct relationship
  - ❏ Volume and Pressure have an indirect relationship
  - ❏ KMT / Particle speed and collisions can be used to describe changes in pressure, temperature, and volume.

- ❏ Reagents

Name	Formula	Concentration	Prior Knowledge
Air!	mixture	N/A	

- ❏ Equipment

Name	Purpose
Pressure Gauge & Tubing x 3	Measure Pressure
Plastic Syringe x 3	Hold Sample of Gas & Measure Volume
Beaker x 2	Holding water
Ice	Reducing temperature of water
Hot Plate	Increase temperature of water
Thermometer	Measure Temperature

- ❏ Key Techniques
  - ❏ Set up of the pressure sensor
- ❏ Safety Protocols
  - ❏ Don't touch the surface of the hot plate
- ❏ Disposal / Clean Up Protocols
  - ❏ Rinse beakers with distilled water and dry thoroughly

- ❏ Questions to draw out prior knowledge
    - ❏ Why do we need to keep some variables constant in an experiment?
    - ❏ What is a direct relationship?
    - ❏ What is an indirect relationship?
    - ❏ How do gas particles cause pressure?
- ❏ Vocabulary
    - ❏ To use during the demonstration
        - ❏ Temperature
        - ❏ Volume
        - ❏ Pressure
        - ❏ Control
        - ❏ Particle Collision
        - ❏ Direct & Indirect Relationship
- ❏ Important Observations to draw attention to
    - ❏ Measuring volume

Demonstration Description

1. Discuss prior knowledge questions with the class.
2. Show the syringe with markings for volume measurement and the pressure sensor. Discuss units of pressure and volume that will be used.
3. Fill 3 plastic syringes with equal volumes of gas.
4. Connect each syringe to a pressure gauge.
5. Place one in a cold water bath. Place the second in a hot water bath. Leave the third at room temperature.
6. While the gas samples reach the temperature of the water bath, lead the class in a discussion of
    a. What variables are we testing?
    b. What variables are we controlling?
    c. What is the purpose of the water baths?
    d. What influence does the temperature have on the particle behavior and predicting how will it affect the pressure?
    e. (The prior knowledge questions could also be discussed at this point instead of at the start.)
7. Adjust the plunger so the volume matches the original volume.
8. Instruct the students to record the pressure reading for each syringe.
9. Direct the students to begin working through the guided analysis in small groups.

Gas Pressure - Demonstration and Guided Analysis

Focus Question: How does temperature affect pressure?

Prior knowledge:

1. Why do we need to keep some variables constant in an experiment?
2. What is a direct relationship?
3. What is an indirect relationship?
4. How do gas particles cause pressure?

Equipment:	Safety:
Procedure:	Data:

Discussion Questions:

5. What variables are we testing? What variables are we controlling?
6. What is the purpose of the water baths?

Guided Analysis

Model

1. How did lowering the temperature affect the pressure?

2. How did raising the temperature affect the pressure?

Connect

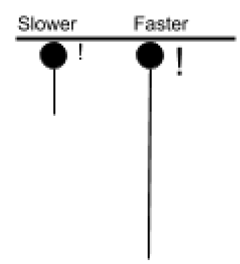
3. How does a particle's speed change when its temperature is increased? Decreased?

4. Based on the temperature, in which syringe were the particles moving the fastest?

5. Based on the temperature, in which syringe were the particles moving the slowest?

6. Based on the pressure, in which syringe were the particles hitting the walls of the container with the most force?

7. Based on the pressure, in which syringe were the particles hitting the walls of the container with the least force?



8. Draw a particle diagram for each of the syringes. Show the gas pressure with collisions of the particles against the wall. Use the length of the "tail" to show the speed of the particle. Use an exclamation point or other symbol to show the force of the particle collisions with the container. See example.

Syringe 1	Syringe 2	Syringe 3

Hypothesize

9. Based on your observations, are temperature and pressure directly or indirectly related?

10. Describe how raising the temperature causes the particles to create greater pressure. Use the words speed and collision in your answer.

Experiment Prompt: How does the volume affect pressure? You will be provided with a syringe and a pressure sensor. You must determine whether pressure and volume have a positive or negative relationship.

Model

11. Given the **same number** of particles in each syringe, draw a model of particle movement at two different volumes. Assume both samples are at the same temperature. Use the same symbols as you did above. Will the average speed of the particles be the same or different in each container? Will the number of collisions with the container be the same or different? Think about how this will affect the pressure the gas particles cause.

Smaller volume	Larger volume

Hypothesize

12. Do you predict the volume and pressure will have a direct or indirect relationship? Explain your thinking using the terms particles, collisions, and surface area.

Plan

13. What variables will need to be constant?
14. How will you hold them constant?
15. What variable will be your independent variable?
16. How will you alter that variable?
17. Write a procedure for conducting the experiment. (Consider how you will keep the number of particles constant.)
18. Create a data table. Include at least 5 volumes to test.

Appendix G

Predicting Precipitation - Teacher Template

- Focus Question -
  - What causes silver, calcium, and iron ions to precipitate?
  - How can we use precipitation to identify ions in a solution?

- Scientific Principles required to answer the question
  - Negative and positive ions form ionic compounds
  - Insoluble compounds form precipitates
  - Practice predicting the products of a double replacement reaction
- Reagents

Name	Formula	Concentration	Notes
Iron (III) Nitrate	$Fe(NO_3)_3$	0.1 M (apx.)	For Iron Ion
Calcium Nitrate	$Ca(NO_3)_2$	0.1 M (apx.)	For Calcium Ion
Silver Nitrate	$AgNO_3$	0.1 M (apx.)	For Silver Ion
Sodium Carbonate	Na_2CO_3	0.1 M (apx.)	For Carbonate Ion
Sodium Chloride	NaCl	0.1 M (apx.)	For Chloride Ion
Potassium Thiocyanate	KSCN	0.1 M (apx.)	For ThiocyanateIon
Ammonium Hydroxide	NH_4OH	0.1 M (apx.)	For Hydroxide Ion

- Equipment

Name	Purpose
Pipette or Dropper Bottle	Transfer Liquid - not measuring!
Well Plate	Sample Organization
Toothpick	Stirring

- Key Techniques
  - Precipitates are opaque, Use white paper to investigate
- Safety Protocols

    - ❏ Silver nitrate will create dark spots on your skin and clothing. Use caution. Wear gloves and apron.
- ❏ Disposal / Clean Up Protocols
    - ❏ Silver must be collected and disposed of separately in the fume hood.
- ❏ Questions to draw out prior knowledge
    - ❏ What do soluble and insoluble mean?
    - ❏ What two types of ions form an ionic compound?
    - ❏ How do ionic compounds behave once dissolved?
    - ❏ If students are not familiar with writing products for a double replacement reaction, the teacher should guide them through this process.
- ❏ Vocabulary
    - ❏ Soluble
    - ❏ Insoluble
    - ❏ Ion
    - ❏ Compound
    - ❏ Precipitate
- ❏ Important Observations to draw attention to
    - ❏ Opaque solids

Demonstration Description

1. Walk the class through the prior knowledge questions.
2. Share with students the "always" soluble compounds/ions. ($NaNO_3$ NH_4NO_3 & KNO_3)
3. Introduce the arrangement of the well plate.
4. Introduce solutions. Remind students that these are soluble compounds.
5. Provide students with the names and have them determine the formulas or vice versa in their notes.
6. Discuss safety concerns with silver nitrate.
7. Mix the solutions systematically in a well plate shown via a document camera.
8. When a precipitate forms draw student attention to the change in opacity. Poke with a toothpick. Place over paper with words or images to demonstrate opacity.
9. Discuss the terms precipitate and insoluble.
10. Encourage students to note color in their observations.
11. Once all the solutions have been mixed and results are recorded, the students should begin working through the guided analysis in small groups.

Predicting Precipitation - Demonstration and Guided Analysis

Focus Question: What causes silver, calcium, and iron ions to precipitate?

Prior Knowledge:

1. When ions are dissolved in solution, what do they look like?
2. What do soluble and insoluble mean?
3. What two types of ions form an ionic compound?
4. Compounds we know are soluble:

Equipment:	Safety:
Reagents- Write names & ions with charges	Products- Write the formulas for new solids

Observations:

	Fe^{+3} ($Fe(NO_3)_3$)	Ca^{+2} ($Ca(NO_3)_2$)	Ag^{+} ($AgNO_3$)
Na_2CO_3			
NaCl			
KSCN			
NH_4OH			

Guided Analysis

Model

1. Draw out the ions in the $AgNO_3$ and NaCl solutions before mixing. Label their charges!

$AgNO_3$	NaCl

Connect

2. We know that negative and positive ions attract to form ionic compounds. What are the two possible *new* compounds produced when $AgNO_3$ & NaCl were mixed?

   a. b.

3. Which of these is an “always” soluble compound?

Hypothesize

4. What is the chemical formula and name of the precipitate?

5. What ion could be added to a solution to make dissolved Ag^{+} ions form a precipitate?

Experiment Prompt: You will be assigned an unknown solution that may have one or more of the cations, Fe^{+3}, Ca^{+2}, Ag^{+}. You must design a testing scheme to determine what cations are in your solution. Your objective is to use as few tests as possible to determine the identity of your unknown.

Model

6. Identify the solid in each reaction observed in the demonstration
   a. write the balanced chemical equation
   b. label the "always" soluble compound as "(aq)"
   c. label the other product as "(s)" - this is the precipitate that you observed
   d. write the formula for the precipitate in the "products" box in your notes.

Hypothesize

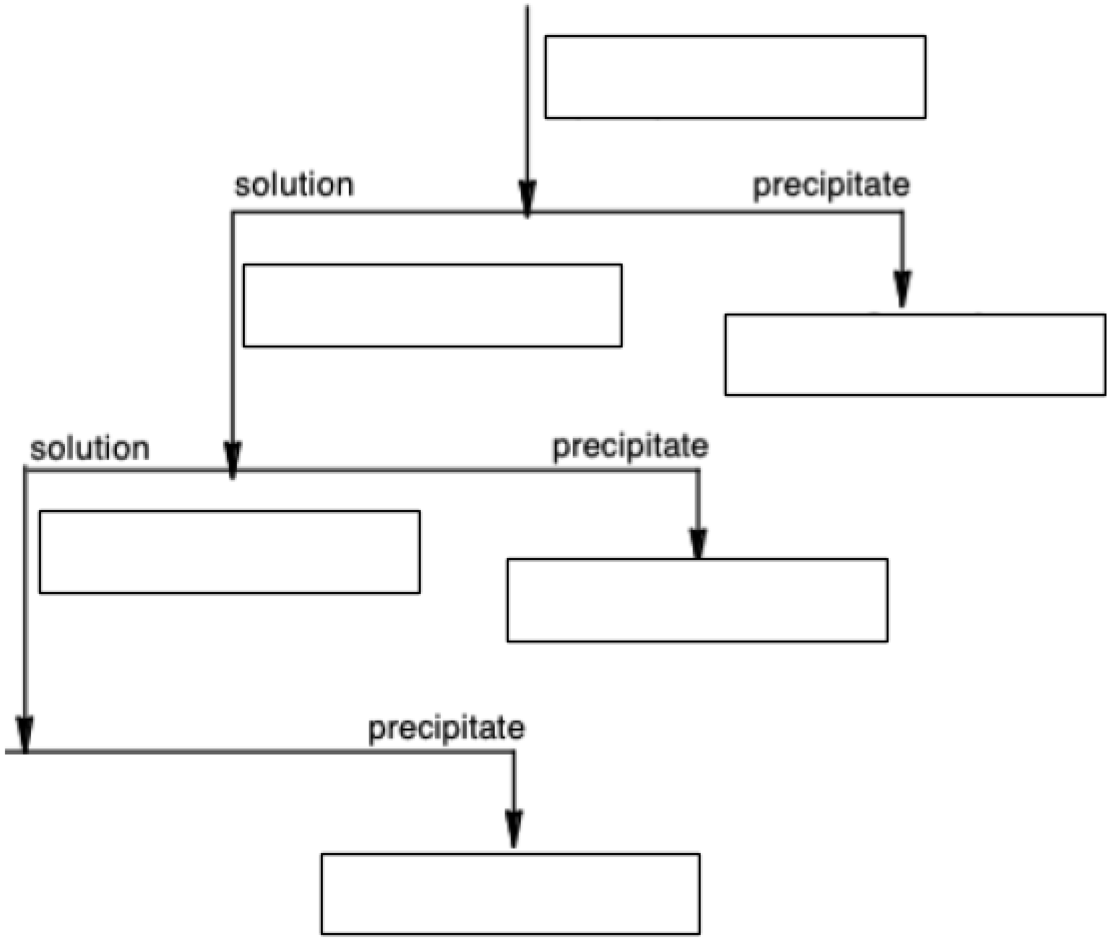
7. Make a hypothesis about which solutions will create a precipitate. List all possible solutions.
   a. If a solution has Ca^{+2} ions in it then, ______ will cause a precipitate to form.

   b. If a solution has Fe^{+3} ions in it then, ______ will cause a precipitate to form.

   c. If a solution has Ag^{+} ions in it then, ______ will cause a precipitate to form.

Plan

8. Fill in this flow chart with the steps you will take to test your solution.



Appendix H

Moles of Metal - Teacher Template

- ❏ Focus Question -
    - ❏ Is matter conserved in this reaction?
    - ❏ How can we experimentally verify a balanced chemical equation?

- ❏ Scientific Principles required to answer the question
    - ❏ Mole Concept
    - ❏ Mole Ratios in Chemical Equations
    - ❏ Mole to Mass Conversion

- ❏ Reagents

Name	Formula	Concentration	Prior Knowledge
Aluminum	Al	Solid	Metal, Al^{3+} ion
Zinc	Zn	Solid	Metal, Zn^{2+} ion
Magnesium	Mg	Solid	Metal, Mg^{2+} ion
Hydrochloric Acid	HCl	3M	Will complete a single replacement reaction

- ❏ Equipment

Name	Purpose
Volumetric Flask or Erlenmeyer Flask	Contain the reaction, reduce loss from evaporation
Scale	Measuring Mass

- ❏ Key Techniques
    - ❏ Zero scale before placing objects on the scale
    - ❏ Subtracting out mass of containers

- ❏ Safety Protocols
  - ❏ Acid - Corrosive to skin and garments. Handle with care. Wear glasses
- ❏ Disposal / Clean Up Protocols
  - ❏ Acid must be neutralized before pouring down the drain
- ❏ Prior Knowledge Questions
  - ❏ What is the molar mass of Mg?
  - ❏ What is the molar mass of H_2?
  - ❏ What is the ratio between magnesium and hydrogen in the chemical equation?

- ❏ Vocabulary
  - ❏ Mass
  - ❏ Mole
  - ❏ Mole Ratio
  - ❏ Coefficient
  - ❏ Single Replacement Reaction

- ❏ Important Observations to draw attention to
  - ❏ Bubbles!

- ❏ Questions to drive student curiosity
  - ❏ How can we use this to determine the mole ratio?

Demonstration Description

1. Discuss the prior knowledge questions with the group.
2. Explain how the design of the flask reduces water loss.
3. Discuss how to safely handle the hydrochloric acid.
4. Balance the reaction of magnesium with hydrochloric acid. This is an opportunity to remind them that this is a single replacement reaction and discuss the different physical states each reactant is in.
5. Mass the solution of HCl and the flask
6. Mass the Mg
7. Add the Mg to the flask
8. Discuss what gas is being released in the bubbles.
   a. If desired, this is a moment where you could test for H_2 gas using a glowing splint.
9. When the reactions have subsided, ask students if they think that matter has been conserved. (This is a red herring.)

10. Mass the flask with the new solution.
11. Discuss the change in mass. If the mass changed, how can matter be conserved?
12. Does that change match the mass of the Mg? Why?
13. Discuss how students might calculate the mass of the hydrogen gas that is released.
14. Does the mass stay the same? Why not?
15. This discussion can be left open-ended because students will address these questions again in the guided analysis.
16. Direct students to begin working on the guided analysis in small groups.

Moles of Metal - Demonstration and Guided Analysis

Focus Question: Does a balanced chemical equation represent the number or the mass of the particles?

Prior Knowledge:

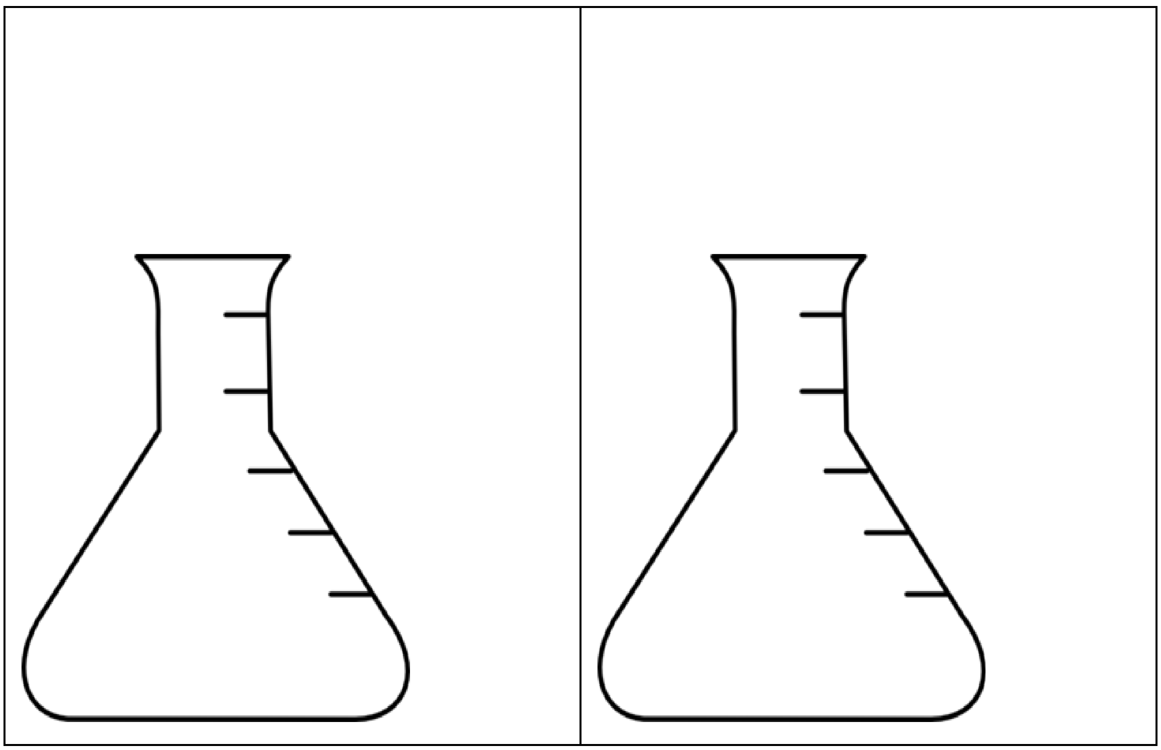
1. What is the molar mass of Mg?
2. What is the molar mass of H_2?
3. What is the ratio between magnesium and hydrogen in the chemical equation?

Equipment:	Safety:
Reagents:	Products:
Balanced Chemical Equation:	
Procedure:	Observations + Measurements

Model

4. After the reaction takes place, where does the chlorine end up? What is its physical state?

5. Using your chemical equation, draw a particle diagram of the reaction before and after. Represent each element, Mg, H, and Cl, with its own shape. Start with 5 particles of Mg and 5 particles of HCl. Label ions with charges!



Connect

6. Compare the mass of the solution before (without the Mg) and the mass of the solution after the reaction. Did the mass of the solution change?

7. Look at your model above. For every Mg atom that is added, how many H_2 molecules escape?

8. If the number of escaped molecules of H_2 are the same as the number of atoms of Mg that are now in the solution, why did the solution change mass? What is different about the atoms of Mg and the molecules of H_2?

Hypothesize

9. Does the chemical equation represent the mass or the moles of particles? Use your observations to support your answer.

10. Using the mass of the magnesium ribbon, calculate the number of moles of Mg that reacted

11. How many moles of hydrogen were released?

Experiment Prompt: You will be given a metal sample that is either Zinc or Aluminum. You must determine the identity of the sample using your understanding of mass and mole ratios.

Model

12. What is the charge of the zinc ion?

13. What is the charge of the aluminum ion?

14. Write out a balanced equation for the reaction of aluminum and zinc with hydrochloric acid.

    a. Al ( ) + HCl ( ) →

    b. Zn ( ) + HCl ( ) →

15. Compare the two equations. If two samples with identical **moles** of metal were added, which sample would produce more hydrogen gas?

16. If two samples with identical **masses** of metal were added, what additional factor would you have to think about to decide which metal produces more hydrogen gas?

Hypothesize

17. Consider this: you are given aluminum and the group next to you is given zinc. Both samples have the same mass. Which group will produce more hydrogen gas? Why? Show calculations.

Plan

18. Write out the mathematical steps that you would take to calculate the mass of hydrogen gas produced from the mass of the metal. (There will be three conversations/steps.)

19. Consider the data collected in the demonstration. What additional data point will you need to determine the identity of your metal?

20. Write a procedure, using the demonstration as a model, to measure how much hydrogen gas is produced from the reaction.

21. Construct a data table.