A CRITICAL LOOK AT SAFETY INSTRUCTION IN THE GENERAL CHEMISTRY LABORATORY

by

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(Under the Direction of Norbert J. Pienta)

ABSTRACT

Over the past two decades, general and organic chemistry classrooms have incorporated active learning techniques to replace the long-held tradition of “sage on the stage” lectures.[1] These active learning strategies have included, but are not limited to, classroom response systems (“clickers”), think-pair-share, discovery-based activities, and peer teaching.[2-3] When implemented correctly, these strategies enforce meaningful learning, which is the integration of newly learned material with previously learned concepts.[4] After students integrate these concepts, they can then be used to solve unfamiliar problems.[5] The active learning methods instructors employ in chemistry classrooms are not yet used in safety instruction in the laboratory. The purpose of this work is to understand how teaching safety in a passive manner is affecting the ability of general chemistry students to minimize risk in unfamiliar safety situations. The study began with observations to not only note current missteps students are making in response to risky situations but also to observe how the TAs choose to present safety material in pre-laboratory lectures. The next step was to interview general chemistry students and TAs to acquire their technical knowledge of safety guidelines as well as the steps they would take to minimize risk in specific situations. The underlying themes in the observations and interviews built the assessment, the results of which give valuable information about students' ability to minimize risk after two semesters of passive safety instruction in general chemistry laboratory.

INDEX WORDS: Laboratory Safety, General Chemistry, Critical Theory

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DEDICATION

To my family who always believed in my ability to succeed and who supported me through this entire process. To my boyfriend, Hunter, who supported my crazy ideas and listened to my frustrations with care and attention. To my best friend, Elizabeth, my constant cheerleader and resident expert in all things grammatical. Lastly, to my fur child, Aldous Snow Broussard, the one who made me smile even on my most stressful days.

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CHAPTER 1

CRITICAL THEORY

Theoretical Frameworks

Before discussing the research of this work, it is essential first to review the topic of theoretical frameworks. When performing social sciences research, there are as many views to take as there are types of people. The researcher could believe there is a power imbalance between males and females, a system contains minority groups struggling to find upward mobility, or there are classroom dynamics that favor certain types of students, to name a few.[6] Focusing on all of these views would be an insurmountable task, but focusing on one requires the use of a belief about the research based on prior evidence. A *theoretical framework* is a set of guiding principles from established research that allows the researcher to focus on a particular worldview.[7] Once the researcher establishes their worldview, then the researcher can tailor all experiments and analysis to reflect this worldview.[8]

The development of a theoretical framework that fits the research project comes in one of two ways. The first way begins with the researcher reviewing all previous, relevant literature on the topic and determining the point of view that no prior work has considered.[9] The researcher then looks into all possible theoretical frameworks, finds the one that closely fits the research, and uses the framework to make an experiment and analysis plan.[10] For example, say an early childhood education researcher was interested in the technology used in elementary school classrooms and students' reactions to it.

After performing a literature review on the topic, the researcher finds that there have been no studies which look at the technological use habits of introverted versus extroverted elementary school children. In their search for the appropriate framework, the researcher finds that *trait theory* describes the measurement of personality traits that are stable across time (such as introversion or extroversion) and how the traits affect behavior.[11] Keeping trait theory in mind, the researcher then sets up a series of experiments with elementary school students taking introversion and extroversion tests and then interacting with technology in the classroom while the researcher records data. The researcher then analyzes the data and focuses on trends that occur between introverted and extroverted students.

The other way a researcher can develop a theoretical framework is by reading the relevant literature and then taking an exploratory approach to see the trends that emerge naturally from the system.[6] Say a science education researcher wanted to study leadership qualities in teaching assistants across different scientific disciplines after a thorough review of leadership and teaching assistant research. Several leadership frameworks are possible. Teaching assistants could reward and punish the students to encourage compliance which puts the study in the *transactional theory of leadership framework*.[12] Perhaps teaching assistants work with the idea that the comfort and needs of their students should come first which falls under a *servant theory of leadership framework.*[13] The researcher cannot determine which of these frameworks is most appropriate because they have no prior literature in the leadership qualities of teaching assistants in STEM courses. After performing observations of teaching assistants across the science disciplines of interest, the researcher determines that there is no “best” leadership style for every science and that there is a dependence on discipline, placing the study in a *situational leadership framework*.[14] The researcher can then set up experiments and analysis that focus on the differences in teaching behaviors based on context.

The theoretical framework we describe in this work falls under the latter category. As we will discuss further in later chapters, the research concerned the safety knowledge and habits of students and teaching assistants in the general chemistry laboratory. The relevant research in chemistry laboratory safety is mainly concerned with ways to teach laboratory safety or assessing safety knowledge using fact-recall questions.[15-26] There is no current literature on student and TA safety adherance during experiments or students' ability to minimize risk in unfamiliar scenarios before and after taking general chemistry laboratory. After the researcher observed the general chemistry laboratories (discussed in Chapter 6), the remaining experiments and analysis fall into the tenants of the *critical theory framework.*

Critical Theory

Critical theory has its roots in understanding and improving political systems. When a political action provided unjust consequences to its citizens, the critical theory presented a way to change the tide of the current structure.[27] Critical theorists would first point out the action and its reasoning for those who made the decision. They would then relate the costs of the citizens it impacted the most.[28] Finally, they would offer ways that the system could improve with the caveat that those who were most affected should have a voice in the ultimate decision.[27] In this way, critical theory is not altering variables to observe the outcome but instead is a way to observe the consequences of our actions.

Since its inception in the 1930's, critical theory has expanded to the areas of history, literature, and, specific to our purposes, the social sciences. For example, Link and coworkers used critical theory in the study of elementary students at low-income institutions.[29] The study followed two students as they progressed from kindergarten through fourth grade and their attitude towards learning. In the beginning, the students had a very social view of learning and valued teamwork and community. After a significant focus on standardized test scores starting in the second grade (as part of the No Child Left Behind initiative[30]), students began to focus only on performing better than their classmates and had a very anti-social learning experience. Link and coworkers posit that the focus on standardized test scores is forcing students to conform to a particular type and those who do not fit receive an inferior education. The authors suggest that instructors focus on education rather than test scores to guide classroom learning.[29]

The decision to use critical theory in this work started with research into an entirely different project. At the start, the researcher intended to create an online general chemistry laboratory program using inquiry-based experiments (described in Chapter 5), which are difficult to implement in a hands-on setting. After surveying 2-year college professors to gain their opinions on online laboratory programs, the most common response was a rejection of online labs because students could not learn safety guidelines as efficiently as they do in a hands-on setting. However, previous research in laboratory safety did not include any studies on students' ability to minimize risk and identify hazards after completing a hands-on general chemistry lab.[15-26] The researcher wanted to know if there was any evidence that the students were learning safety solely because they were working around hazardous chemicals.

There are two reasons why the critical theory applies to the research described in this work. The first, and most important, is that the researcher did not have any control over safety instruction in the general chemistry laboratory curriculum beyond their classroom. The laboratory coordinator for the general chemistry laboratory is responsible for all TA and student training, as well as laboratory manual instructions. The other TAs have control of their classrooms, and the researcher did not have the authority to change their instructional method. Therefore, there was no opportunity for the researcher to adjust variables and compare results to a control group made up of students under the current safety instruction system. The second reason is that preliminary observations of TAs and students in the general chemistry laboratory indicated that the current method of safety instruction led to inconsistent instruction between classrooms and a general lack of awareness of hazards on the part of the TAs. In the observations, this led to students injuring themselves and requiring researcher intervention. The signs all pointed to a need for change, which required the compelling argument provided by critical theory.

There are four essential aspects of critical theory:

1. A detailed account of the current system and, if possible, the accurate reasoning for the decisions made thus far
2. Consequences of the current system (found through population statistics, interviews, and longitudinal studies, for example)
3. Possible ways to improve the current system based on previous evidence
4. Encouragement of input from those affected by the system and possible ways to acquire input[31]

The work described in the following chapters will follow the same format. To start, we will discuss the purpose of the study. Then we will discuss how students learn and ways to facilitate lasting memory of the material. We will then go into an in-depth description of the current system for teaching laboratory safety in general chemistry, including TA training and instructions students receive on a week-to-week basis. Then the experiments will describe the outcome of the present method of TA training and safety instruction. The experiments include observations of TAs and students in the laboratory, interviews with TAs and students to gauge safety knowledge, and a safety assessment to track safety knowledge from prior knowledge to the end of the second semester of general chemistry (GC2). After the researcher has presented all evidence indicating that changes to the present safety instructional method are necessary, suggestions will be made to help enable these changes. The work concludes with suggested ways to allow feedback from students and TAs to ensure that the system is made cooperatively instead of singly.

CHAPTER 2

FOSTERING SAFETY KNOWLEDGE AND ATTITUDES EARLY

Origins of Recent Focus on Safety

In 2011, the American Chemical Society (ACS) formed the ACS Safety Culture Task Force to develop a system of instruction and training in laboratory safety for undergraduate and research laboratories.[32] The formation of the task force was the result of a tragic academic research laboratory incident.[33] On December 29th, 2008 a UCLA chemistry research assistant named Sheharbano (Sheri) Sangji scaled up a previously performed reaction combining vinyl bromide and tert-butyllithium. Tert-butyllithium is an intensely pyrophoric reagent, meaning that it ignites in open atmosphere. While pulling back a syringe containing tert-butyllithium, the syringe plunger came out of the syringe, exposing the tert-butyllithium to air as Sangji also knocked over an open flask of hexane. As the tert-butyllithium ignited, it lit the hexane and Sangji's clothes on fire. Sangji died from burn injuries sustained from the incident eighteen days later.[34]

The reason that ACS believed it was their duty to educate academic laboratories in promoting a safety culture lies in the events leading up to the incident and the aftermath. While making notes for the reaction, Sangji did not include any risk minimization that comes with scaling up a reaction from 53.79 mL tert-butyllithium to 159.5 mL tert-butyllithium. Sangji also did not follow the Aldrich Technical Bulletin AL-134 on working with air sensitive reagents which indicated that the individual should use glass syringes and a one- to two-foot-long needle.[35] Sangji used a plastic syringe and a 1.5 inch needle.[34]

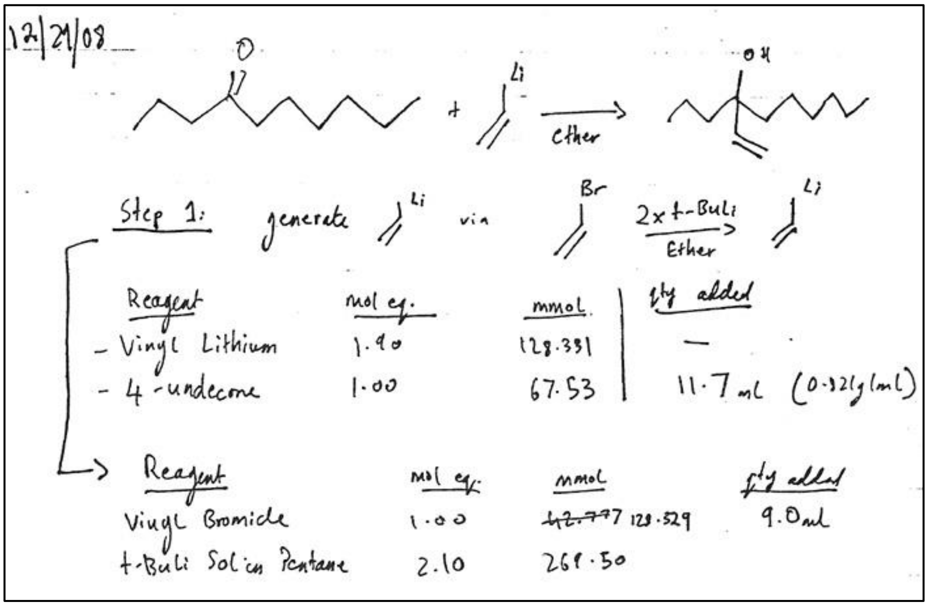


Figure 1 Sheri Sangji's Laboratory Notes (Credit: UCLA)

Sangji was also not wearing full personal protective equipment such as a flame-resistant lab coat and gloves, and it is unknown if she was wearing laboratory goggles.[36] When the reagents ignited and set Sangji on fire, neither Sangji nor a lab member in the same room thought to use the safety shower to put out the fire and rinse the reagents off Sangji.[34] Instead, the lab partner attempted to use a lab coat to smother the flames on Sangji, while a member of an adjoining lab called 9-1-1.[37] After putting out the fire, the lab member sat Sangji down under a sink and attempted to splash water on her.[34]

Two months before the incident, UCLA performed a laboratory safety inspection and found thirty safety violations in the research laboratory.[38] While the chemistry professor, Patrick Harran, fixed some of the issues (although it is not known which ones), Cal/OSHA investigators found many safety violations in the aftermath of the event.[34] The lab also lacked documentation of safety training and admitted that while Sangji had worked in industry before joining the lab, she had not undergone Emergency Health and Safety (EH&S) training when she started the UCLA position.[36]

The entire tragedy distills down to a series of decisions based on a single assumption: nothing terrible is going to happen. Moreover, if it were only one of these mistakes, perhaps Sangji would still be alive. However, the sheer number of violations and mistakes makes it necessary to step back and consider if our labs are making the same assumptions.

ACS Steps Towards Emphasizing Safety in Academic Laboratories

In 2012, a report released by the ACS presidential commission indicated that most chemistry graduates going into industry positions needed remedial safety training.[39] In other words, after an average of four years of undergraduate teaching laboratories and undergraduate research (required by most institutions), chemistry graduates still did not have adequate safety training. To combat the issue, the ACS Division of Health and Safety and the ACS Committee on Chemical Safety developed resources for research and teaching laboratories to promote an attitude of safety while working around chemicals.[40-42] In the resources, ACS promotes the use of R.A.M.P or **R**ecognize the Hazards, **A**ssess the Risks, **M**inimize the Risk, **P**revent Emergencies.[41] According to the ACS Committee on Chemical Safety, following this method is the most effective way to prevent unfortunate laboratory incidents.[33]

The ACS Committee on Chemical Safety also makes recommendations on how to present safety guidelines to different audiences. One suggestion was to emphasize safety attitudes, knowledge, and skills from high school with continuing development until professional research using the spiral method of learning. In the safety spiral method, students begin to learn to respect chemicals and identify hazard symbols in high school. As the student works in undergraduate research, the student starts to learn about risk assessments when making laboratory procedures. The student also builds on their knowledge of safety guidelines during this time. When the student starts graduate research, they begin to train others in safety and must hold others accountable for their actions. Finally, as a professional chemist, the student must not only hold others accountable but also is responsible for keeping the laboratory up to safe standards. Each level builds the student towards being responsible in their safety decisions.[43]

Another suggestion made by the committee contributes to this theme of teaching safety in steps rather than in one great lesson. The committee advises that the instructors of teaching laboratories give the safety instructions that are relevant to the student at their level. In other words, rather than teach the student the about laser safety in general chemistry (where students do not have the opportunity to work with lasers) cover the safety guidelines for working with strong acids and proper waste disposal, for example. Presenting the material in small, relevant doses gives the student the opportunity to engage with their current lesson.[44]

While the resources and suggestions from the ACS Committee on Chemical Safety are very useful to those who seek them out, there is still a lack of oversight in teaching laboratory safety practices and manual publication.[33] Again, it is important that we step back and assess the safety culture in our teaching laboratories where we can foster either a respect for chemicals or an assumption that nothing terrible will happen. In the following chapters, this research will prove that an unchecked system leads to inadequate training, an assumption of safety, and an environment filled with safety violations, all the same symptoms that led to the tragedy at UCLA.

CHAPTER 3

HOW STUDENTS LEARN

Learning Goals

When planning a curriculum, it is essential to establish learning goals, or objectives the instructor would like for the student to achieve by the end of the course.[45] Creating the outcomes before starting the curriculum allows the instructor to construct lessons and assessments focused on these goals.[4] For example, a class whose learning goal is that the students gain the ability to argue scientifically will have very different lessons and assessments from a class that would like students to solve problems using concepts. The former would likely have opportunities for the students to build arguments amongst themselves while tests would include essay-type questions. The latter would likely have a lesson in concepts followed by problems to solve while tests would include problems that are unfamiliar to the students. The instructor determines the specific learning outcomes by considering the discipline, teaching style, and tradition. The most general learning outcomes, however, are *retention* and *transfer*.

Retention is the ability to recall information in the context in which the student learned it.[46] For example, if a student learns about the ideal gas law during lecture, the student proves their retention by reciting the ideal gas law equation. While retention is a useful outcome for answering fact-recall questions, we would like students to be able to apply their learned information to new scenarios. Transfer is the application of previously learned concepts to unfamiliar problems.[5] Using our same example of the ideal gas law, the instructor may ask the student why helium balloons decrease in size after exposure to liquid nitrogen. If the student can transfer their lesson to the new question, they will be able to explain the phenomena using the ideal gas law. We should note that transfer only occurs after the student has retained the information.[47] In the previous example, the student could not accurately explain the phenomena until they have learned the ideal gas law equation.

Now consider the general chemistry laboratory safety instruction. If the student only reaches the level of retention, then the student may know that a reagent is corrosive from the TA's pre-laboratory lecture. However, without the ability to transfer, the student will not know what to do if the reagent spills on the floor or their clothes. We want students to transfer safety information so that they can handle any situation that occurs in the laboratory. To do this, we must understand the research-based methods that have increased retention and transfer of concepts.

Rote Versus Meaningful Learning

We have established that the broadest learning goals are retention and transfer. When we focus on these goals in creating lesson plans and assessments, one of three broad *learning outcomes* is possible. These outcomes are *no learning*, *rote learning*, and *meaningful learning*.[5] We test for these three types of learning using an assessment that contains both retention (fact-call) and transfer (application, or new problem) questions. When a student cannot answer retention or transfer questions, we consider the student in the no learning category.[4] A student in the rote learning category can answer retention questions but cannot answer transfer questions.[46] The only advantage of rote learning is that new material does not interfere with previously acquired misconceptions.[48] If a student can answer both the retention and transfer questions, then the student has achieved meaningful learning.[49] Meaningful learning requires the integration of newly learned material with previously learned concepts for long-term storage and easy retrieval in memory.[4]

Now that we have defined our possible learning outcomes, we can discuss the ways to enforce these learning outcomes. No learning often occurs when a student does not pay attention in class or while reading the material.[5] Rote learning occurs when the student passively reads the material and receives passive instruction in lecture.[50-51] A student passively reads the material by not taking notes to summarize the text, writing out definitions, solving problems in the book, or taking notes. While an instructor cannot force a student to read the material actively, the instructor does have control in classroom instructional techniques and assessments. If an instructor uses a passive technique to teach the material, the student will passively learn the material in most cases.[52] We tend to think of passive instruction as lecturing to the students, but it can also include demonstrations, worked-out examples, videos, or any strategy that does not have the students answer a question or discuss the issue.[53] The type of assessment questions can also contribute to the rote learning. If a student notices that assessments (including homework, quizzes, and exams) all have questions that test retention, the student will only study for retention.[54]

Meaningful learning occurs through a technique known as *active instruction*.[4] In active learning, students engage with the material by discussing the concepts and ideas with the instructor or other students or reading the necessary literature. In making a proactive attempt to solve the problem on their own, the student integrates the new material with previously learned concepts and has to confront alternative conceptions.[55]

The student must still choose to learn meaningfully, however, or no learning and rote learning can still occur.[56] Most of the research in active learning in chemistry over the past few decades focuses on finding active learning strategies that appeal to students so they engage in the process.[49, 57] In this work, we will discuss active learning techniques that have had success in chemistry and other disciplines and are relevant to safety instruction in the general chemistry laboratory.

Active Learning Techniques

The first method that we can use in a general chemistry laboratory setting is *discovery-based instruction*. We can think of discovery-based instruction as modeled on the way that scientists perform research. The scientist has a problem to solve, and so they look to the literature, discuss the problem with colleagues, or perform an experiment to "discover" the solution.[58] In the classroom, the instructor presents the student with a problem to solve (or they come up with one on their own), the students discuss the problem with their peers or instructor, perform an experiment, or consult the literature.[59] Through the process, the student uses previously-learned concepts and finds evidence to support their conclusions. A caveat to discovery-based learning is that it requires guidance from an expert to be successful.[60] If the student does not receive expert guidance, then they may come to incorrect conclusions or conceptions that can inhibit meaningful learning.[61]

At first glance, this may seem to be the worst method for students to learn safety guidelines in general chemistry. In our context, discovery-based learning would mean that students must spill chemicals and take risks just to learn what they should do to correct themselves. However, discovery-based instruction can also promote meaningful learning outside of the classroom in pre-laboratory or -lecture assignments. For example, one study by Akpan and colleagues (2010) showed that students learning frog dissections through an online, pre-laboratory discovery-based assignment were more prepared for lecture and assessments than those who did not do the discovery-based assignment.[62] Discovery-based instruction could include a simulation of laboratory safety situations where students have to choose the correct response procedure or merely a quiz asking students how to handle reagents to minimize risk. In each of these components, the student would need a feedback feature to correct themself a in case the student forms an incorrect conception of a safety issue. For instance, say a simulation has a scenario where clutter led to a spill on the bench top. When asked to identify the cause of the spill, the student responds that the program chose high-risk glassware. If the program does not correct the student, they may not understand the value of keeping the benchtop free of clutter.

An active learning strategy that TAs can use in pre-laboratory lecture is *asking higher-order questions*. During lecture and laboratory, it is easy for instructors to fall into the habit of lecturing to the students and never asking questions.[63] When the instructors remember to ask the students questions, they tend to be lower-order, fact-recall questions that do not require the students to think about the "how" and only about the "what."[64] In Figure 1 below, the lower order question types are remembering and understanding, while application, analysis, evaluation, and creation are higher-order questions.

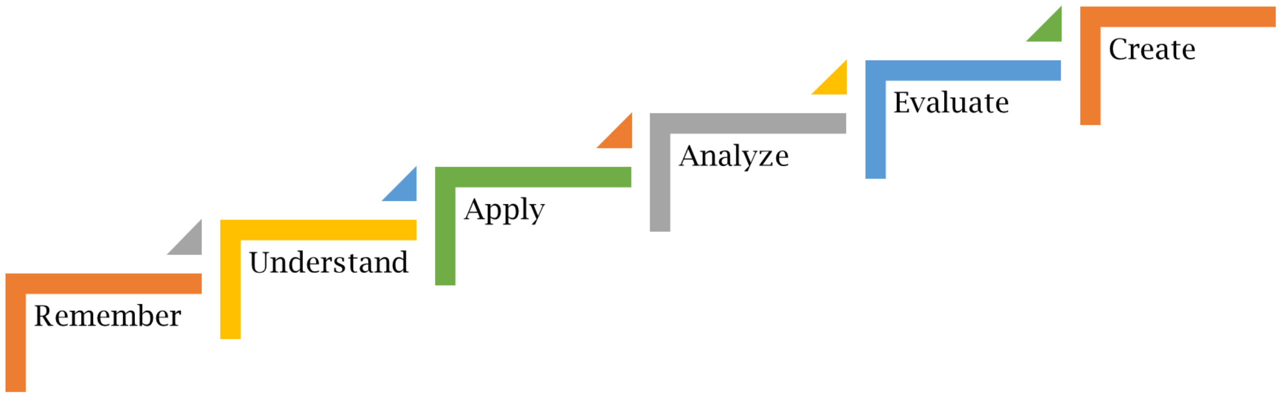


Figure 2: Bloom's Taxonomy of Educational Objectives[65]

The first type of higher order question is an *application* question. Application questions require the student to transfer the concepts they learned in class to new situations.[66] Asking the question in this format prepares the student for minimizing risk during an experiment. For example, if a TA were to use this type of question in laboratory safety instruction, they could ask the student, "We know that hydrochloric acid is corrosive, but what personal protective equipment could minimize the risk of getting burned?" Asking the question in this way forces the student to not only think about the necessary personal protective equipment but also why it is important.

An *analysis* question tests the students' ability to break down information into its constituent parts and understand how all of the parts work together.[65] This type of question is harder to apply to safety instruction because the ideas are well separated. However, a possible example could show the students a scenario with many high-risk decisions and ask the students to break down which aspects cause risk and why. They may also learn that many high risk decisions lead to large-scale laboratory incidents.

Evaluation questions require the student to make a judgment about a system or a result.[66] The student then must use previously learned concepts to justify the judgment.[65] Evaluation questions are simple to use in a safety context because the instructor can ask the student if a situation minimizes risks and why. For example, if an instructor would like to teach the students how to view reactions safely, they could hold a reaction beaker in unusual ways and each time ask the student if the way is safe and why or why not. The student is using their previously learned concepts of minimizing risk to evaluate the ways to view a reaction. Creation questions involve designing an experiment or scenario based on the students' previously learned concepts.[65] Having the students create safety scenarios falls under the last type of active learning we will discuss here: students acting as instructors.

When an instructor gives a student an assignment such as reading a chapter or solving a series of problems, the students' motivations are focused on themselves. They need to read the material to answer questions on an exam or in class. When the student reads, knowing that they have to present the material to their peers, however, causes their study to become *intrinsically motivated*.[67] Intrinsic motivation is the need to be self-sustaining so that the individual can help change the environment around them.[3] In other words, a student will try to learn the material meaningfully on their own so that they can accurately answer questions from their peers.

In a general chemistry laboratory setting, the method requires some retooling of the traditional format. Typically, students must prepare a pre-laboratory assignment which may include the experiment's algorithms, rewriting the procedure, or recording the purpose. In the "students as instructors" format, the student would have to do some pre-laboratory safety research on hazards of each of the materials using online safety data sheets (SDS). The students would also need a safety guidelines reference book for proper emergency response procedures and preparedness. If the student has access to those items, then the course can require the students to find all relevant safety information on the reagents and products for the day. When the student comes to the laboratory, the TA may randomly assign a student to teach the safety information for that day, with opportunities for other students and the TA to ask questions. The student must know the material well enough to field questions on any scenario their peers could give them.

We have discussed ways to promote meaningful learning and rote learning in this chapter. The rest of this paper will explore the instructional methods of general chemistry laboratory safety guidelines. The research we provide in this work will answer the following questions:

1. Is course-level instruction of safety guidelines in general chemistry active or passive?
2. What instructional techniques do TAs use to teach safety guidelines in general chemistry laboratory?
3. Are students able to transfer their knowledge of safety guidelines to unfamiliar safety situations?
4. Are TAs able to transfer their knowledge of safety guidelines into emergency response procedures they had not considered before?

CHAPTER 4

CURRENT STATE OF LABORATORY SAFETY INSTRUCTION

TA Training

This work concerns general chemistry laboratory safety instruction at the University of Georgia-Athens and, therefore, any results are reflective of the training, materials available, and curriculum of this setting. Interviews with new TAs provided the information on TA training, and we will discuss these interviews in further detail in Chapter 8.

The TA training course at the time of this research occurred for two days in the week before classes starting in the fall semester. On the first day, the laboratory coordinators for general and organic chemistry assigned TAs to their respective courses. The general chemistry laboratory coordinator then gave the new TAs administrative instructions. These instructions included grading consistency, make-up lab procedures, and the appropriate amount of information to give students when answering questions. The second day, the students performed two experiments from the general chemistry I (GC1) curriculum. The first experiment was Experiment 1 “Density: Determination of Sugar Content in Commercial Beverages”, an experiment that contains no chemicals with significant hazards or waste disposal.[68] The second experiment was Experiment 5 “Separation of a Mixture” which has mild chemical hazards and requires students to heat to evaporation or dryness using a hot plate.[68] On this day, the laboratory coordinator also introduced the new TAs to the laboratory and where the chemical shower, eye wash stations, and first-aid kit were located. The tour did not include instructions on how to use these items or when it was appropriate to use these items. However, this type of training is necessary because an ACS report on Advancing Graduate Education in Chemical Sciences (2012) found that chemistry graduates entering industry needed remedial safety training before starting lab work.[39]

New TAs had to attend weekly TA meetings which occurred one week before the experiment. In these meetings, the laboratory coordinator gave the TAs a set of instructions for teaching the lab, including important announcements and a few chemical hazards as well as the answer key for the experiment. The laboratory coordinator then walked the TAs through the technical aspects of the procedure and areas of confusion for students based on experience in previous semesters. TAs did not have TA meetings for every experiment in the semester and the lab coordinator sent an e-mail with the meeting contents to TAs on the weeks with no TA meeting. If there were any emergencies during a lab section, the lab coordinator told the TAs to text them or find the general chemistry laboratory manager for assistance.

Student Laboratory Safety Instruction

The laboratory coordinator sent an email to students taking GC1 one week before the laboratory started. This e-mail informed the students that they would need to watch a 35-minute safety video published in 1991 by the American Chemical Society (ACS) entitled “Starting with Safety.” After watching the video, the laboratory coordinator told the students to take a safety quiz about the contents of the video before the start of class (although this is not a requirement to take the class).[69] This video is no longer available through the ACS, but the laboratory coordinator gave the students a link to a copy on the video-sharing website Vimeo©™. The video covers the following topics:

1. Handling Chemicals Safely
2. Bunsen Burner and Glassware Safety
3. Thermometer Safety
4. Glass Tubing Safety
5. Centrifuge Safety
6. Dressing for Safety
7. Behavior in Lab
8. Emergency Equipment

The quiz is made up of fact-recall questions on the video topics and class policies. In the interest of preventing cheating, the topics of the quiz are not included in this work.

The lab manual safety hazards and the TAs pre-laboratory instruction for the rest of general chemistry I and the entirety of general chemistry II laboratory provide the content the students in laboratory safety. (All chemical hazards and lab manual warnings are in Appendix A and B) From this information, the researcher poses the following questions:

1. How are TAs teaching safety hazards and emergency response to their students in the laboratory?
2. What are the common safety violations in the general chemistry laboratory at this institution?
3. What do students know about the technical safety guidelines that they are expected to learn by the end of two semesters of general chemistry laboratory?
4. Are students able to transfer the technical guidelines to unfamiliar situations after two semesters of general chemistry?
5. Are the general chemistry TAs able to minimize risk when responding to a safety emergency in the laboratory?

Over the following chapters, we will answer these questions using in-lab observations, undergraduate and general chemistry TA interviews, and an online general chemistry laboratory safety assessment.

CHAPTER 5

SURVEY OF 2-YEAR COLLEGE LABORATORY COORDINATORS

Background

Verification or "cookbook" labs, wherein a student receives a step-by-step procedure and grades reflect a students' ability to reach an expected result, have been the traditional approach to teaching general chemistry labs in higher education.[70] From an organizational and fiscal standpoint, this method is near perfect. Laboratory coordinators budget chemicals, glassware, and equipment with very few unforeseen expenses.[71] The laboratory procedure can be adjusted such that students can complete experiments in the usual 3-hour time frame or may complete multiple trials in case of procedural missteps.[72-73] The lab reports are often streamlined into a worksheet format, allowing for efficient and equitable grading by instructors and teaching assistants.[74]

Unfortunately, the verification method also leads to a noticeable lack of learning gains, prompting instructors and researchers to question the necessity of general chemistry lab.[75-77] However, general chemistry lab has the power to allow students to develop essential problem-solving skills, so it is important to identify the aspects of verification method that are inhibiting effectiveness.

The first issue arises in simply considering the purpose of a cookbook. As in verification labs, the point of following a recipe is to generate the expected product as a result.[78] The drawback is that in reaching the anticipated results, there was no need to learn about the process of taking certain steps.[79-80] In that case, the only way to learn about the process is to obtain an obviously flawed result and to start investigating ways to improve it.[81] If the end product is not visibly unsatisfactory or students obtain the correct result, then the theory behind the process remains a mystery.[82-83]

For this reason, laboratory manuals often include extensive pre-laboratory background with chemical equations, worked examples, and real-world implications; in theory, this background should demonstrate the relevance of the procedure to the concept of study.[84-85] However, this has been shown to overload a student's working memory which is the area of short-term memory involved in the immediate translation of verbal or written instructions into actions.[86] Interpreting written instructions as well as unnecessary information in the manual utilizes an extensive amount of space in short-term memory, inhibiting beneficial information from being translated into long-term memory.[87] This focus on deciphering the written instructions, as well as the desire to leave the lab early, also leads to students ignoring or overlooking issues that arise while performing the procedure and causes blind spots in students' knowledge.[88-90] Instructors and TAs enforce this behavior because of blind spots from their undergraduate experience and are too embarrassed to work through problems with their students.[91]

Finally, since grading focuses on obtaining an expected result, the student is not forced to advance to the stages of higher order cognition set out by Bloom's Taxonomy (Figure 2 and Table 1) since there is no chance to analyze, synthesize, and evaluate their results.[92] Because of this, the student frequently remains only having knowledge of the topic, which is the lowest level of cognition.[93-95] In order to improve student learning gains in general chemistry lab, the instructional method needs to be modified so that students are taught to think like scientists instead of amateur chefs.

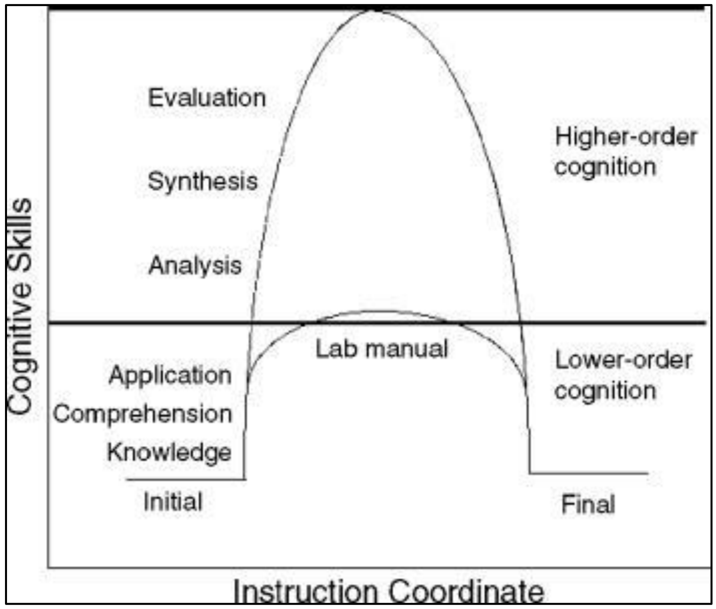


Figure 3 Lab manual levels of cognition: A visual representation of the level of cognitive ability students can hope to attain while using verification-type laboratories[93]

Table 1 Cognition Level Definitions: Technical definitions and examples of each of the levels of cognition

Cognitive Skill	**Description**	**Illustrative Phrase**
Knowledge	The remembering of previously learned material	Defines terms, identifies objects, states steps of a procedure
Comprehension	The ability to grasp the meaning of material	Explains a concept, interprets a graph, generalizes data
Application	The ability to use learned material in new and concrete situations	Solves problems, utilizes concept in novel situations, constructs graphs
Analysis	The ability to break down material into its component parts	Identifies pertinent data, identifies inconsistencies, establishes relationships between items
Synthesis	The ability to put parts together to form a new whole	Formulates a hypothesis, proposes a plan for an experiment, proposes alternatives
Evaluation	The ability to judge the value of material based on definite criteria	Judges the value of data, judges the value of experimental results, justifies conclusions

The inquiry-based method of laboratory instruction has seen marked improvement in students' problem-solving skills and understanding of chemistry.[96-97] Inquiry-based laboratories give students minimal information regarding the experiment: The lab manual includes a very succinct background, a problem to be solved, minimal to no procedure, and the lab report grading focuses on the student's ability to analyze the results they obtain rather than accuracy to an expected answer.[98] An example of this type of experiment is in Appendix C.

The types of inquiry-based labs used in higher education are *guided-inquiry* and *open-inquiry*. *Guided inquiry* typically has a short background with a problem to be solved and gives students procedural steps to complete which guide the student toward the analysis of a graph, table, or some other collection of their data.[99] Once the student has become familiar with lab techniques, the curriculum can transition into *open-inquiry* laboratories in which a student is given a problem to be solved or comes up with a problem on their own, and they must design experiments and evaluate the results.[100-101]

Despite results that prove that this pedagogical method leads to greater learning gains in chemistry and improved problem-solving skills, there are logistical disadvantages when incorporating inquiry-based experiments.[102-103] A survey of 203 laboratory coordinators for general chemistry (Figure 4) found that students learning concepts was the most important goal and learning facts was the least important goal in the general chemistry laboratory. However, when the survey asked how the laboratory coordinators structured their class and lab (Figure 5), the majority had a lecture teaching the concepts before the students performed the experiment, which we have established is not the way to learn concepts.[104]

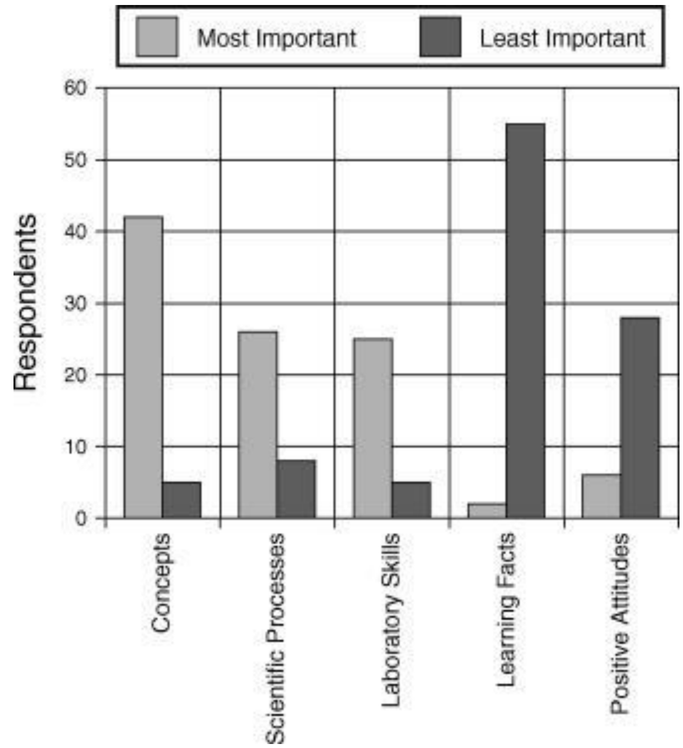


Figure 4 Lab Coordinator Goals

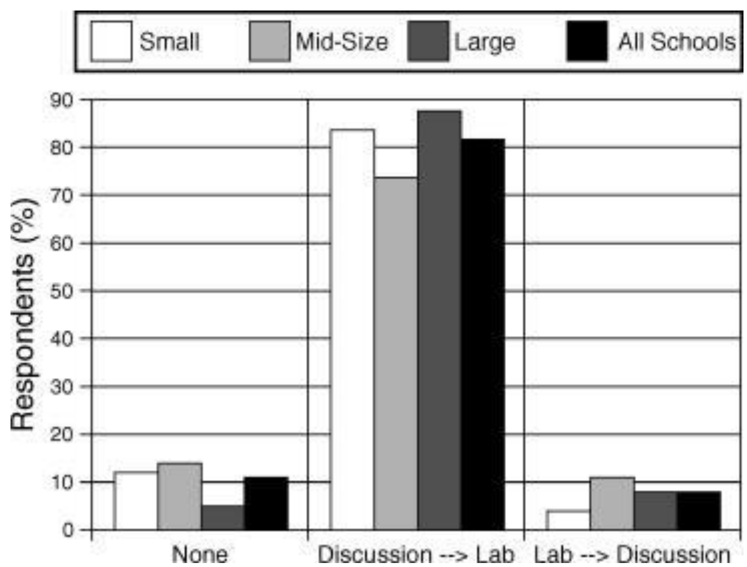


Figure 5 Lab Coordinators' Current Instructional Method

Because open-inquiry is dependent on students building their procedure, the cost of glassware, chemicals, and equipment fluctuates on a weekly basis, a situation which is not ideal for large class sizes.[105-106] Similarly, the time to complete the experiment may not fit into the allotted three-hour time frame when experiments must be adjusted and repeated if the results do not provide a solution to the problem.[107-109] It is also very difficult to train instructors and teaching assistants in the method, if their indifference or disdain towards the method leads to giving students a procedure or the answers to lab report questions.[110-113] A possible solution that would minimize or eliminate many of the issues with implementing inquiry-based methods into general chemistry curriculum is using an open-ended, virtual, inquiry-based laboratory program, heretofore referred to as OVIB.

OVIB programs have not been studied as extensively in chemistry as hands-on, inquiry-based labs. However, those who have tested OVIB programs against hands-on, inquiry-based labs have found a few advantages.[114-118] The first and most obvious is cost: Access fees for online lab programs are a one-time expense that is on the order of lab fees students typically have to pay in a hands-on setting.[114] There are also resources for pre-fabricated virtual labs which are free to students and instructors.[115] The second benefit is that students have freedom to design experiments that show reactions at the particulate level, allowing students to obtain a more in-depth understanding of certain phenomena.[62, 116] Moreover, the OVIB programs allow students to perform multiple trials or adjust experimental procedures in less time than a hands-on setting. Speeding up the reaction wait time allows students to perform all the experiments needed to obtain the clearest results.[117-118]

The original intention of this work was to construct an online laboratory program using the guiding principles of discovery-based learning (described in Chapter 2) which could be used in 2-year college institutions by those with a limited laboratory budget or who would need to accommodate students with less traditional schedules. To this end, we created a survey for 2-year college general chemistry laboratory coordinators from across the United States to gauge their opinions regarding online laboratories. The results of this survey gave the researcher a clear idea of what lab coordinators view as the goals of a hands-on laboratory.

Methods and Results

To check whether virtual lab programs have advantages over hands-on labs, it is important to understand the reservations that lab coordinators still have about implementing the technology at 2-year colleges, where there are minimal constraints to meeting ACS guidelines. There is also value in probing those who do carry out virtual labs in their curriculum to understand the aspects they find favorable as well as those features they would change if they had the opportunity.

Therefore, the Qualtrics© online survey program (available through the University of Georgia) was used to create a qualitative survey for general chemistry lab coordinators employed at 2-year institutions. The full survey appears in Appendix D. The lab coordinators were asked to choose the method used in their programs: hands-on, virtual, at-home chemistry kits, a mixture of at-home and virtual, or “other” where they were encouraged to explain what program they used. If the coordinators did not use virtual labs, then they were asked open-ended questions about what they liked/disliked about their current program and if they would consider using virtual labs with the opportunity to explain why or why not. If the coordinators were currently using virtual labs, then they were asked open-ended questions about what they liked/disliked about the program.

The University of Georgia Institutional Review Board (IRB) approved this study in March 2016 as acceptable human subjects research. The researcher e-mailed the survey link and instructions to 372 heads of division/department at two-year institutions across the country. The heads of division/department were invited to either complete the survey themselves or forward the e-mail to those responsible for deciding the curriculum in their general chemistry laboratories. The demographics breakdown is in Table 2, and the US region designation is in Figure 5.

Table 2 Survey Demographics: Demographics breakdown of 2-year college, general chemistry laboratory coordinator survey by region of the USA

US Region	**Count per Region**	**Use Virtual Labs in Curriculum**	**Would Consider Virtual Labs**	**Would Not Consider Virtual Labs**
South	27	16	1	10
Northeast	4	3	1	0
Midwest	19	7	4	8
West	16	4	2	10
Total	**66**	**30**	**8**	**28**

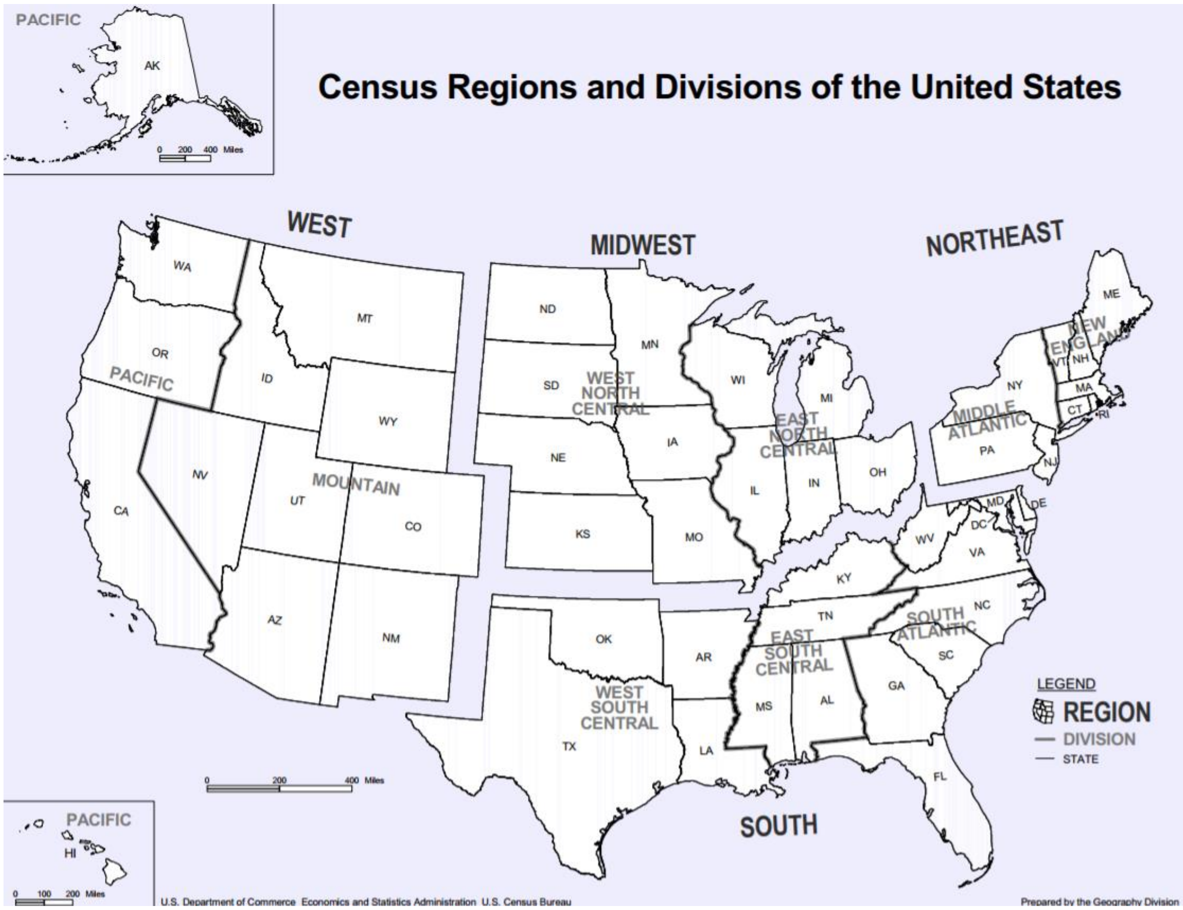


Figure 6 Census Designations: The US Census Regions and Divisions of the United States which was used to categorize the 2-year college, general chemistry laboratory coordinators in Table[119]

The responses to the open-ended questions were analyzed using inductive content analysis. In this method, there is no hypothesis based on previous research, only research questions. The researcher looks for common themes among open-response questions.[120] These themes can then be used to form hypotheses for further experiments. It is important to note that the researcher did not analyze the results quantitatively because of a lack of hypothesis before the study and a small sample size.

After analyzing the open response questions, the two themes that emerged most often came from those who vehemently oppose virtual labs for use in general chemistry. The first theme which emerged has been disproven with research in neurophysiology and chemistry education.[121-122] Lab coordinators' responses indicated that students needed the tactile experience of working with chemicals and glassware to learn chemistry effectively. This tactile feeling that they are referring to is an area of sensory memory called haptic memory which involves knowing how much force to use to pick up delicate objects or carry heavy materials.[123] This memory, however, is only transferable with repeated handling of the same objects. Unless a student is working with the same basic set of lab materials for the rest of their academic and professional careers, they will have to re-learn the skill for every new object.[121] Also, if the lab in question is a verification lab, research has shown that students do not think about concepts while they perform an experiment and put off thinking about theory at all until they calculate their results and answer post-lab questions.[122]

The second theme which emerged from the open-response questions was the idea that students will not learn laboratory safety or will not have a healthy respect for chemicals in a virtual laboratory setting. The response is logical: one of the most appealing aspects of virtual labs is there is minimal risk of injury or emergency. It also may be likely that students without that awareness could take foolish risks in the future hands-on lab. However, this is making the very large assumption that students currently enrolled in hands-on labs have sufficient knowledge of laboratory safety and that their knowledge is based on being around hazardous chemicals. Therefore, the remainder of this work is dedicated to understanding what students know about safety in both the intellectual and practical senses after two semesters in a hands-on, general chemistry laboratory.

CHAPTER 6

LABORATORY SAFETY OBSERVATIONS

The first step in understanding the preferred instructional method of safety guidelines and how the students respond to instruction is to observe how the students and TAs work in a laboratory environment. Descriptions of the experiment lend context to the observations of TAs and students.

GC1 Experiment 4 The Copper Cycle

In the course GC1, the students performed Experiment 4, "The Copper Cycle", an experiment where students learn about types of reactions and the conservation of mass through the purification of commercial-grade copper wire.[68] The reaction process is in Figure 7 below.

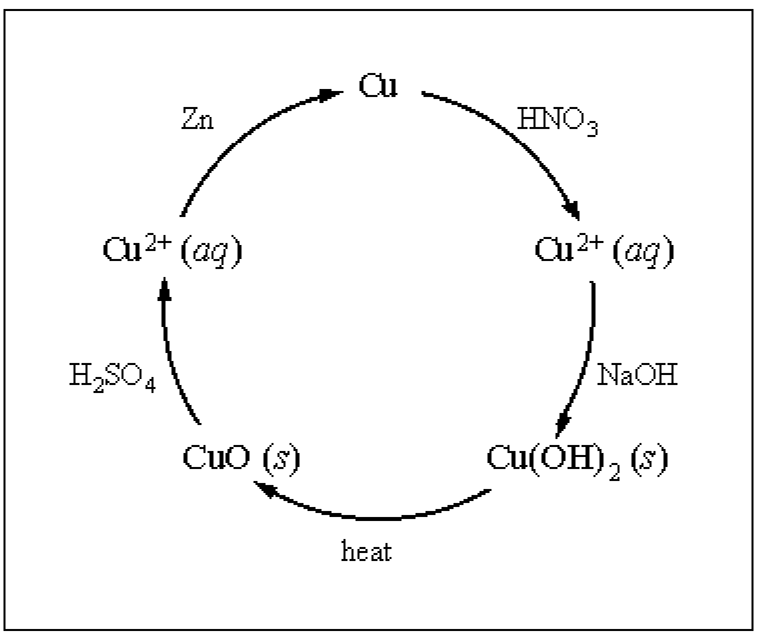


Figure 7: Copper Cycle Reaction Sequence[68]

This experiment requires that students work efficiently, as the initial dissolution of copper in HNO_3(aq) and the dehydration of $Cu(OH)_2$(s) by heating occur slowly and can prevent students from completing the lab in the three-hour period. Students are also required to work with strong acids and bases, the chemical hazards of which are in Table 3 below.

Table 3 Experimental, Chemical Hazards for "The Copper Cycle"

Chemical and Concentration	**Waste Disposal**	**Spill Response**	**Acute Effects**	**First-Aid**
Copper (solid)	Solid waste container	Sweep up and dispose of in the appropriate waste container	Hazardous in case of eye contact, **irritant**	Seek medical attention in case of eye contact, scrape solid off skin and rinse with water and mild soap
Nitric acid (98%)	Liquid waste container	Absorb with inert dry material and dispose of in the appropriate waste container	Very hazardous in case of skin and eye contact, skin contact produces burns, **irritant, corrosive, permeator**	Eyewash for 15 minutes, flush skin with water 15 minutes, seek medical attention
Sodium hydroxide (3 M)	Liquid waste container	Absorb with inert dry material and dispose of in the appropriate waste container	Very hazardous in case of skin and eye contact, skin contact produces burns, **irritant, corrosive**	Eyewash for 15 minutes, flush skin with water 15 minutes, seek medical attention
Sulfuric acid (6 M)	Liquid waste container	Absorb with inert dry material and dispose of in the appropriate waste container	Causes severe skin burns and eye damage, **corrosive**	Eyewash for 15 minutes, flush skin with water 15 minutes, seek medical attention

Zn (solid)	Solid waste container	Sweep up and dispose of in the appropriate waste container	Mild skin and eye irritant	Seek medical attention in case of eye contact, scrape solid off skin and rinse with water and mild soap
Hydrochloric acid (6 M)	Liquid waste container	Absorb with inert dry material and dispose of in the appropriate waste container	Very hazardous in case of inhalation, hazardous in case of skin and eye contact, skin contact produces burns, **irritant, corrosive, permeator**	Eyewash for 15 minutes, flush skin with water 15 minutes, seek medical attention

None of the chemical hazards described in Table 3 were in the lab manual procedure for this experiment. The TAs received pre-laboratory instructions from the laboratory coordinator. The instructions included a warning about working with strong acids (and did not mention the strong base) and washing any chemical splashes with "copious" amounts of water without mentioning how long the student needed to keep their skin or eyes under water. Neither the lab manual or the notes indicate that the first reaction of the procedure produces acutely toxic NO_2(g), the chemical hazards of which are in Table 4.

Table 4 NO_2 gas chemical hazards

Chemical and Concentration	**Waste Disposal**	**Spill Response**	**Acute Effects**	**First-Aid**
Nitrogen dioxide (gas)	Keep under fume hood always	N/A	Fatal if inhaled, causes serious eye damage and skin burns, **oxidizer, health hazard, corrosive**	In case of inhalation, seek medical attention immediately, eye wash 15 minutes, flush skin with water 15 minutes, seek medical attention

For the mass of copper suggested in the lab manual (0.5 grams), the reaction produces approximately 0.7 grams of nitrogen dioxide gas (calculated using the balanced equation below).

$$Cu\ (s) + 4\ HNO_3\ (aq) \rightarrow Cu(NO_3)_2\ (aq) + 2\ NO_2\ (g) + 2\ H_2O\ (l)$$

Keeping in mind that the reaction between the solid copper wire and concentrated nitric acid can last anywhere from 30 minutes to an hour, it is worthwhile to consider the short-term exposure limit (STEL) of nitrogen dioxide gas. This term is in units of mg/m^3 over a time limit of 15 minutes. If we assume that a reaction proceeds for 30 minutes and that half of the reaction occurs in 15 minutes while the student and their lab partner are standing over the reaction outside of the fume hood, then the students will be exposed to approximately 350 mg/m^3 of nitrogen dioxide gas in that time. However, the exposure limit of nitrogen dioxide gas is 9.4 mg/m^3 over a span of 15 minutes. Recognizing that this gas can cause burns to soft tissue such as that of the throat, eyes, and lining of the lungs, as well as the fact that there was lack of proper warning given to the TAs and the students, is vital to understanding the observation data.

According to the state of Georgia's "Public Employee Hazardous Chemical Protection and Right to Know Act of 1988", all chemical reagent bottles should have labels that adhere to the standards set by the Occupational Safety and Health Administration (OSHA).[124] According to the labeling standards, all hazardous chemical labels should include safety pictograms, a signal word, hazard and precautionary statements, the product identifier, and supplier information.[125] The only information provided on the labels in "The Copper Cycle" experiment were the product identifier and concentration, as seen in Figures 8-11.

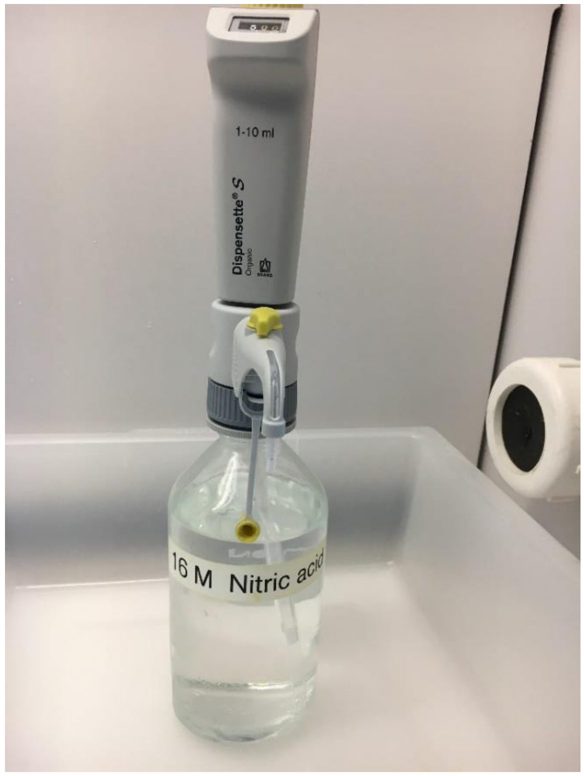


Figure 8 Nitric Acid Bottle Used in Copper Cycle Experiment

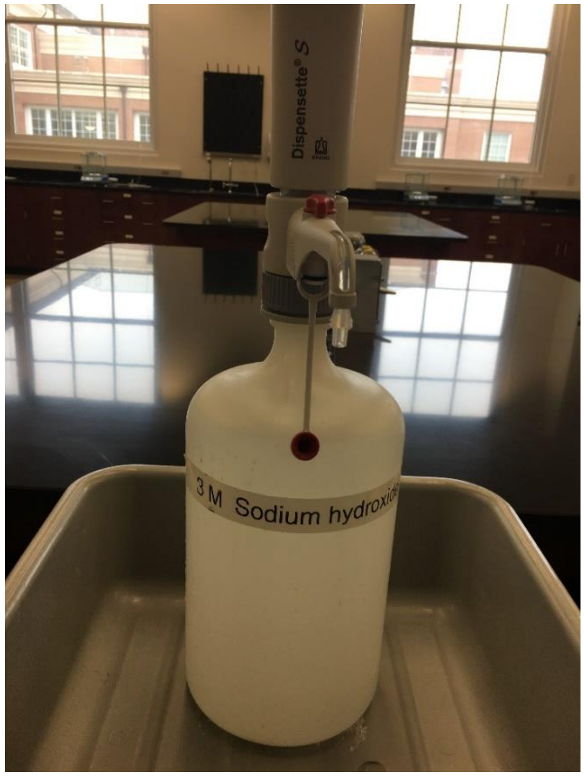


Figure 9 Sodium Hydroxide Bottle Used in Copper Cycle Experiment

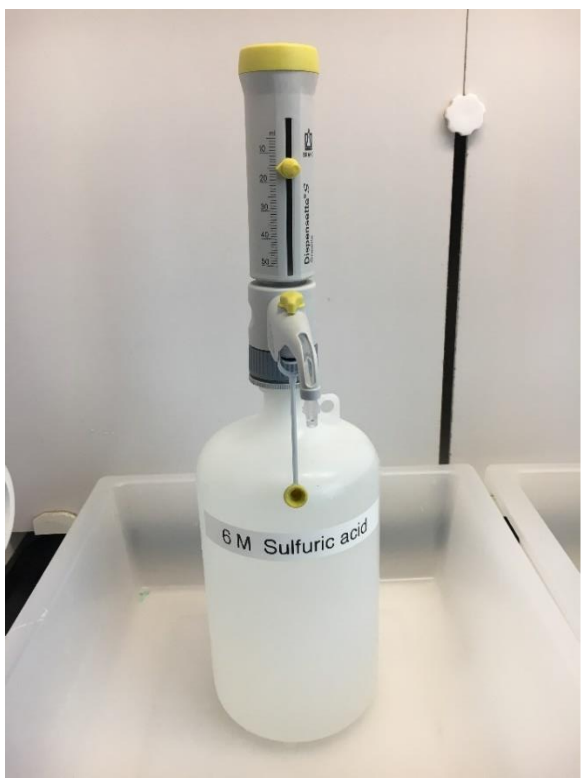


Figure 10 Sulfuric Acid Bottle Used in Copper Cycle Experiment

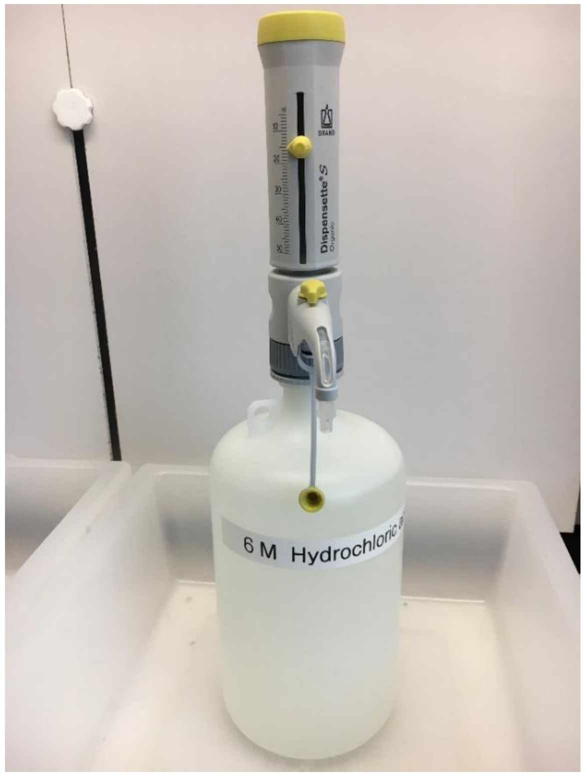


Figure 11 Hydrochloric Acid Bottle Used in Copper Cycle Experiment

The waste containers also contained limited information about the safety hazards, as well as contradicted the information in the laboratory manual by not including the copper solutions. Since the procedures for Experiment 3, “Zinc Iodide” and Experiment 4, “The Copper Cycle”, both left the student with residual zinc, the lab manager used the same zinc waste container for both experiments.

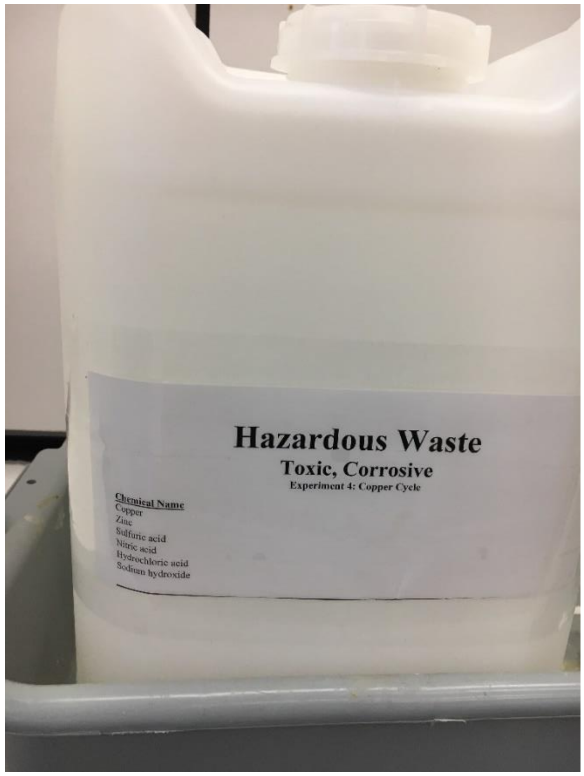


Figure 12 Hazardous Waste Container for Copper Cycle Experiment

Figure 13 Copper Waste Container for Copper Cycle Experiment

Figure 14 Zinc Waste Container for Copper Cycle Experiment

GC2 Experiment 5 The Complex Ion Equilibrium of Fe(III) and Thiocyanate Ions

The GC2 observations started with Experiment 5 or "The Complex Ion Equilibrium of Fe(III) and Thiocyanate Ions." The GC1 TAs have more extensive experience when compared to the GC2 TAs. The TAs responsible for teaching GC1 had taught GC1 in the previous semester(s) and so were not required to attend weekly TA meetings. The GC2 TAs, on the other hand, had never taught GC2 before and the laboratory coordinator required them to attend a TA meeting the Friday before the week of Experiment 5. The details of a typical TA meeting protocol are in Chapter 3.

In the Complex Ion Equilibrium experiment, the students determined the equilibrium constant for the reaction between iron (III) nitrate and potassium thiocyanate by titrating in increasing amounts of iron (III) nitrate and measuring the change in light absorbance of the solution using a spectrophotometer. The procedure required that the students use a burette to titrate the iron (III) nitrate into solution and, therefore, students had to minimize risk in pouring the solution into the burette by using a funnel. There were fewer reagents and lower concentrations included in Experiment 5 compared to 1211 Experiment 4, but there were still potential serious effects in case of skin or eye contact as seen in Table 5.

Table 5 Experimental, chemical hazards for the experiment "Complex Ion Equilibrium"

Chemical and Concentration	**Waste Disposal**	**Spill Response**	**Acute Effects**	**First-Aid**
Nitric acid (2.0M)	Liquid waste container	Absorb with inert dry material and dispose of in the appropriate waste container	Causes severe skin burns and eye damage, **corrosive, oxidizer**	Eyewash for 15 minutes, flush skin with water 15 minutes, seek medical attention
Potassium thiocyanate (0.008M)	Liquid waste container	Absorb with inert dry material and dispose of in the appropriate waste container	Hazardous in case of skin or eye contact, **irritant**	Eyewash for 15 minutes, wash skin with mild soap and water
Iron (III) nitrate (0.1M)	Liquid waste container	Absorb with inert dry material and dispose of in the appropriate waste container	Causes eye burning and skin rash, **oxidizer, irritant**	Eyewash for 15 minutes, flush skin with water 15 minutes, seek medical attention
Nitric acid (0.5M)	Liquid waste container	Absorb with inert dry material and dispose of in the appropriate waste container	Very hazardous in case of skin or eye contact, **irritant, corrosive**	Eyewash for 15 minutes, flush skin with water 15 minutes, seek medical attention

This experiment did have two safety warnings included in the laboratory manual. The first came before the procedural instructions and appears in italicized print:

> *The solutions included in this experiment contain nitric acid. Nitric acid is a corrosive material. Protect your eyes! If an acid solution comes in contact with your skin, rinse with copious amounts of water and notify your laboratory instructor immediately*.[126]

While this is certainly better than not including any safety hazard information, it is still an incomplete warning. Potassium thiocyanate and iron (III) nitrate are also materials that can cause damage to the skin and eyes and require first-aid treatment in cases of spills and splashes. Another issue is that while protecting eyes is a good strategy, the students in GC1 and GC2 do not have to wear the type of safety goggles that adhere to the face and can instead wear safety glasses which offer much less protection. Simply telling the student to protect their eyes does not give them instructions on what to do if something does get into their eyes. Moreover, there is an instruction again to rinse skin with copious amounts of water which a student or TA could easily interpret as a large volume of water in a few minutes rather than the 15 minutes that is recommended by the SDS.

The other safety warning included in the Experiment 5 procedure concerns waste disposal. The warning is at the end of the procedure before the data analysis instruction: "Place the reaction mixture and any left-over solutions in the waste container. The acid will be neutralized before disposal."[126] This instruction takes care to include all solutions so that students know that if they take too much of a reagent out of a bottle that they should dispose of it in the waste container. However, there are some issues with the wording in the acid neutralization instructions. One problem is that it does not instruct students how to neutralize the acid or what material they should use to neutralize the acid. The other issue is that the wording is unclear: do students need to neutralize their experimental solutions before disposing of in the waste container or does the experimental process neutralize the acid? The passive wording of this instruction can lead to missteps in properly disposing of chemicals.

As in the GC1 Experiment 4, GC2 Experiment 5 did not have the OSHA standard labeling required in Georgia federal institutions:

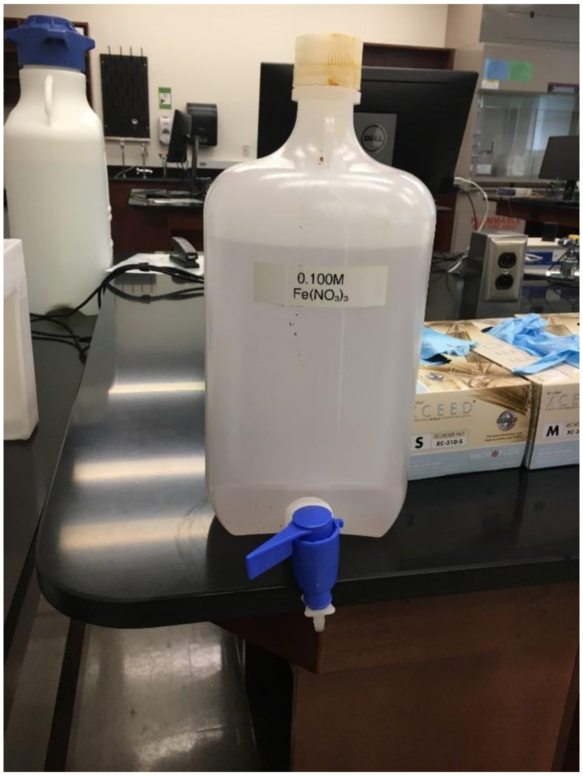


Figure 15 Iron (III) Nitrate Reagent Bottle Used in Complex Ion Equilibrium Experiment

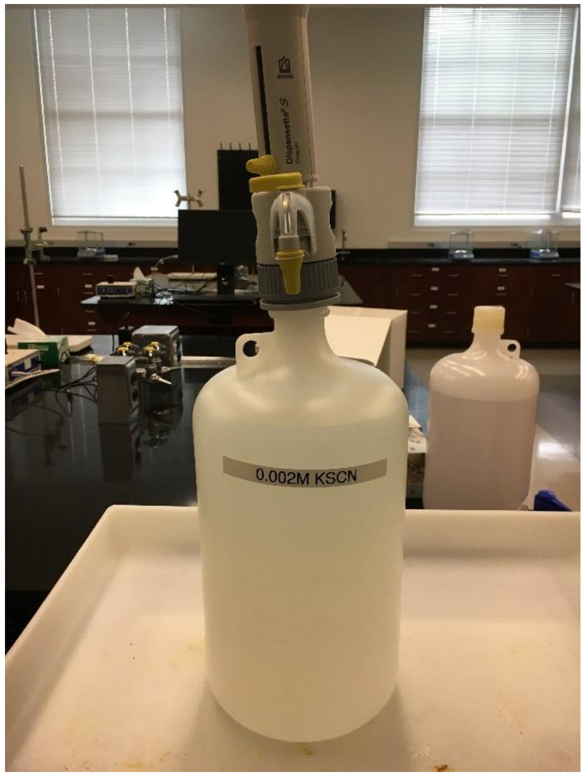


Figure 16 Potassium Thiocyanate Bottle Used in Complex Ion Equilibrium Experiment

Figure 17 Nitric Acid Bottle Used in Complex Ion Equilibrium Experiment

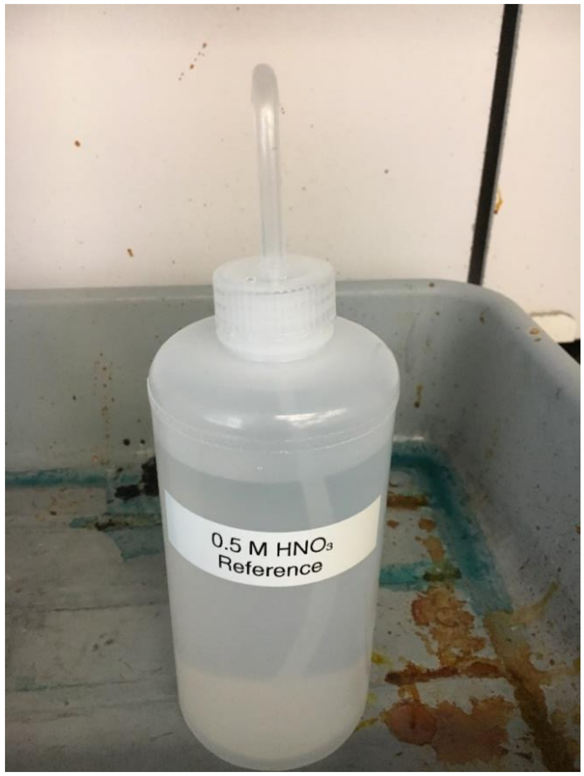


Figure 18 Nitric Acid Reference Used in Complex Ion Equilibrium Experiment

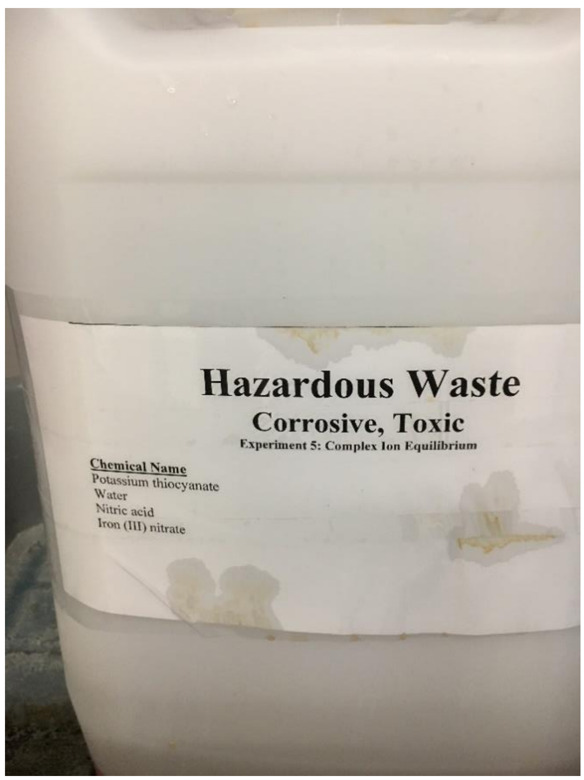


Figure 19 Hazardous Waste Container for Complex Ion Equilibrium Experiment

Since the researcher was not a TA for this course the semester of the observations, it is unknown what the lab coordinator told the TAs in TA meeting concerning safety and waste disposal. However, in the analysis portion of this project, we will discuss the common information included in pre-laboratory lectures for Experiment 5.

GC2 Experiment 6 pH Titration of Vinegar

Students performed Experiment 6 “pH Titration of Vinegar” in GC2 one week after UGA spring break and, thus, the TAs did not have a TA meeting one week before the performance of the lab. During the TA interviews discussed in Chapter 8, the TAs revealed that they also did not have a meeting before spring break regarding this experiment and only received a handout with the content they needed to include in the pre-laboratory lecture. A change in the structure of this kind gave the researcher the opportunity to compare the pre-laboratory lectures of TAs who had attended a TA meeting on the content versus those who had no TA meeting.

In the titration of vinegar, the procedure required the students to determine the concentration of acetic acid in vinegar by measuring the volume of strong base (sodium hydroxide) required to adjust the pH of the solution from acidic to basic. To that end, students had to pour approximately 50 mL of sodium hydroxide solution into burettes.This experiment had only two reagents, the hazards of which are in Table 6.

Table 6 Experimental, chemical hazards for the experiment "pH Titration of Vinegar"

Chemical and Concentration	**Waste Disposal**	**Spill Response**	**Acute Effects**	**First-Aid**
Sodium hydroxide (~1.0M, exact concentration unspecified in lab manual)	Liquid waste container	Absorb with inert dry material and dispose of in the appropriate waste container	Very hazardous in case of skin or eye contact, **irritant, corrosive, permeator**	Eyewash for 15 minutes, flush skin with water 15 minutes, seek medical attention

Acetic Acid (5%)	Down drain with plenty of water	Wipe with paper towel	Mild skin and eye irritant	Eyewash for 15 minutes, wash skin with mild soap and water

The experimental procedure in the lab manual included one italicized chemical hazard warning about sodium hydroxide:

> *Caution: The sodium hydroxide solution is caustic and may cause burns if not handled properly. If the solution comes in contact with your skin, rinse the affected area with cold water and contact your instructor*.[126]

Again, the manual includes some helpful information, but this does not include the whole story. The instructions tell the students to rinse the area with cold water but does not tell the students the amount of time that is appropriate for this type of spill. There were also no waste disposal instructions for any unused sodium hydroxide. Lastly, there were no instructions in the manual on how to minimize risk while pouring solutions into a burette.

The reagents for Experiment 5 also did not have the OSHA hazard labeling on the bottles. The laboratory manager did not provide a waste container for this experiment:

Figure 20 Sodium Hydroxide Bottle Used in pH Titration of Vinegar

Figure 21 Vinegar Bottle Used in pH Titration of Vinegar

As in Experiment 5, the researcher did not have access to the notes the lab coordinator gave the TAs before the performance of this lab. In the analysis, we will attempt to piece together the possible instructions given based on the TAs' pre-laboratory lectures.

Analysis

As there was no previous research into the practical understanding of safety in general chemistry labs, the researcher performed laboratory observations in March 2017 directly after obtaining UGA IRB and lab coordinator approval. The populations were sections of GC1 (N = 7) and GC2 (N = 13) selecting a different teaching assistant (TA) for each observation to minimize any bias in instructional technique. The researcher also noted the research field of each TA to account for any field-based predisposition to safety. The TA fields of study observed were analytical (N = 8), inorganic (N = 4), physical (N = 7), and science education (N = 1). At this institution, there is one TA per laboratory room, and the enrollment maximum are 24 students per class. Table 7 contains the experiment, TA field of study, and number of students in each observation session.

Table 7 Observation Demographics

Experiment	TA Field of Study	Number of Students
1211 Experiment 4 The Copper Cycle	Analytical	19
	Inorganic	21
	Inorganic	23
	Physical	16
	Physical	18
	Analytical	19
	Science Education	18
1212 Experiment 5 The Complex Ion Equilibrium of Fe (III)	Inorganic	19
	Physical	20
	Analytical	20
	Physical	19
	Physical	19
	Inorganic	19
	Analytical	20
1212 Experiment 6 pH Titration	Analytical	18
	Analytical	19
	Physical	19
	Analytical	15
	Physical	14
	Analytical	17

The researcher notified the TAs one day before observation without providing them information on the purpose of the observations. The assumption is that without the context of the study, the students and TAs behaved as they normally would. The researcher observed both students and TAs during lab sections while taking field notes. Each observation session began at the lab start time (in order in include pre-laboratory safety instructions) and ended when all students had completed the experimental portion of the day's experiment and cleaned up any waste or glassware. The researcher noted any time a safety-related event occurred, noting whether it was correct or incorrect. Recording all safety events allowed the researcher to note commonplace as well as unexpected events and compare these occurrences to the environment that fostered them. The notes were also time-stamped to allow the researcher to track the time lapse between safety violation and correction.

The researcher transcribed the field notes and analyzed them using inductive content analysis, described in Chapter 4, using the online qualitative analysis software, Dedoose©, to track themes that occurred across classes. Several themes emerged in the observations and are separated into *TA-centered* and *student-centered.*

TA-Centered Themes

Active learning strategies are an efficient way to promote meaningful learning during instruction. This work also provides a discussion of some active learning strategies that lend themselves to a laboratory lecture environment, such as higher-order questioning and students as instructors. The beginning of every observation session was the pre-laboratory lecture. None of the twenty TAs the researcher observed included active learning strategies in their safety instruction. In the GC1 "Copper Cycle" experiment, TAs informed the students of the safety hazards as a lengthy list of hazard warnings and instructions to wear gloves in most cases. None of the lectures included a hazard warning for nitrogen dioxide gas. There was also a hierarchy of acid and base hazards, at least in the opinions of the TAs. Some TAs did not tell the students to wear gloves at all, some said the students only needed gloves to use nitric acid, but the rest would not harm the skin, and some said the students only needed gloves when working with acids.

Pre-laboratory lectures in the GC2 experiments included very few safety instructions in general, but there were differences in the teaching of dilute acid hazards in the “Complex Ion Equilibrium” experiment. Three of the observed TAs mentioned nitric acid as hazardous and a spill on the skin as requiring copious amounts of water (as specified in the laboratory manual). The remaining TAs either did not mention nitric acid or downplayed the hazards, with one TA saying nitric acid was "not too scary." Two out of the six TAs teaching the “pH titration” lab mentioned that sodium hydroxide was corrosive.

If we compare the pre-laboratory lectures in the GC2 “Complex Ion Equilibrium” experiment to the “pH Titration experiment”, there was a marked difference in organization and content. TAs teaching the “Complex Ion Equilibrium” experiment had the benefit of a TA meeting the Friday before the experiments started, while the TAs could only work from a handout for the “pH Titration” experiment. As a result, all the “Complex Ion Equilibrium” pre-laboratory lectures included the same material presented in the same order. It started with a review of the day's reaction, followed by definitions of the equilibrium constant and Beer's Law, a derivation of the formulas, and an Excel tutorial before a variable safety instruction. The “pH Titration” pre-laboratory lectures, on the other hand, varied considerably on content and structure. Some TAs taught concepts, others focused on procedure. The observation that TAs listen to teaching instructions in TA meeting well enough to reproduce an entire pre-laboratory lecture has powerful implications for incorporating active learning into the laboratory.

The TAs in GC1 were challenged responding to student injuries from corrosive chemicals and broken glassware. In the "Copper Cycle" experiment, there were several instances of researcher intervention because of emergency response procedures. For example, during the first observation session, a TA handled a nitric acid burn by leaving the student's hand under water for 1-2 minutes and then putting Neosporin and a band-aid on the burn. The researcher had to put the students' hand back under water for an additional 15 minutes and told the student to go to the health center if they still felt pain. Another example came in the last observation of GC1, where the TA kept their back to the students grading papers while they worked on the procedure. A student at a lab bench near the researcher cut their hand on broken glass that was in their group glassware drawer. The researcher had to signal to the TA that the student hurt themselves as the student was attempting to treat the wound on their own. Once the TA was aware of the injury, they proceeded to get Neosporin and a band-aid until the researcher stopped them to suggest that the student put the cut under running water first. An appropriate intervention is to carefully and thoroughly wash a cut or wound that breaks the skin. Only one of the TAs in the observations reported injuries observed by the researcher to the laboratory coordinator. Keep in mind, all of these TAs teach two more sections of approximately twenty students each that the researcher did not observe, and there were seven additional TAs that the researcher did not have a chance to observe. It is not clear whether the observations extend to other sections but it seems prudent to suggest that they are common.

Another theme which occurred during the sessions were the apparent goals of the TAs, especially in GC1 observations. Because "The Copper Cycle" laboratory has many reactions to finish before the end of the class period, there is a chance that students may not have time to finish the experiment. As a result, five of the seven TAs that the researcher observed tended to overlook safety violations in favor of moving a student to perform the next task in the sequence. We will refer to these TAs as “laid-back.” As an example, one TA who was concerned with students speeding up reactions missed two students who kept their goggles on for a combined thirty minutes in a two hour and thirty-minute experiment. On the other hand, there were TAs whose main goal was that the students know the hazards and minimize risk. We will refer to these TAs as “strict.” For example, during “The Copper Cycle” experiment one of these TAs held a stack of watch glasses next to the fume hood containing the nitric acid reagent bottle. When a student added the nitric acid to the solid copper, the TA gave a watch glass to the student to cover their reaction as they walked to the other fume hood to complete the decomposition of copper.

Student-Centered Themes

The observed student-centered themes include a broad category of corrections to safety violations. The possible sources of safety procedure correction are from the TA, a student’s peer, or the student themselves. Based on the literature on students’ learning of laboratory skills, they would more likely correct their peers rather than correct themselves because they notice when someone else is making an error.[96] However, the researcher did not witness peer correction in any of the 20 laboratory sections in this study, and a combination of TA-correction and self-correction dominated the observations.

Student self-correction, or a student committing a violation and changing course to fit the safety guidelines, was related to how fastidious the TA was. For the students of "strict" TAs, it would take from three minutes to less than one minute to realize they were taking an unnecessary risk. An example of this short correction time occurred in the GC2 "Complex Ion Equilibrium" experiment: one student went to pour the iron nitrate solution out of his burette into the sink and as he was tipping the burette said, "Oh, I should put this in the waste container." Other examples of short correction times were when students would remove safety goggles and immediately replace them or start pouring a solution into a burette and stop to get a funnel.

On the other hand, students with "laid-back" TAs had much longer self-correction times. The highest risk examples of this trend are in the GC1 "Copper Cycle" Experiment. The longest time gap between the violation and student self-correction in this experiment was forty minutes. The violation was a student leaving their goggles on their forehead while stirring a solution under their chin and walking around the room. There was another situation which required intervention on the part of the researcher. During this experiment, the TA had not told the students the hazards of the nitrogen dioxide gas produced in the first reaction and did not tell the students to perform the reaction under the fume hood. A student started the reaction and realized that a brown gas was coming off the reaction. Assuming that the gas would soon dissipate, the student walked away from the reaction to get the next reagent. When the student came back and saw the gas was still coming off of the beaker, they signaled to their lab partner to get a watch glass to place over the beaker. In the meantime, the student put their hand over the beaker. As we saw in the hazard table for nitrogen dioxide, the gas is corrosive and requires immediate first-aid for skin exposure. Since the TA did not know this, the researcher had to pull the student aside to treat the chemical on the skin. As seen through this example, self-correction may have good intentions and outcomes but still is not the best way to minimize risk.

Another trend in self-correction was that students with “strict” TAs tended to have fewer safety violations than those with “laid-back” TAs. There could be two explanations for this trend. The first explanation is that the students feared the consequences that would be applied by strict TAs for violating safety instructions. For instance, one of the strict TAs in the GC1 Copper Cycle Experiment told students if they did not keep their goggles on then they would have points taken off their lab report. However, the explanation does not cover students correcting safety violations that the TA did not cover in pre-laboratory lecture. The second explanation offers possible reasoning: students who are consistently corrected become more mindful of minimizing risk than those who are rarely corrected. Regardless of the reasoning, the the trend is that strict TAs foster an environment of risk minimization.

From the data, we can formulate the research questions:

1. Do students in GC1 and GC2 know the technical guidelines set out by the American Chemical Society Committee on Chemical Safety for students in general chemistry laboratory?[41]
2. If students know the technical guidelines, are they able to apply the guidelines to real-life safety scenarios?
3. Are students influenced by the safety environment fostered by their TA?
4. Are there any differences between GC1 and GC2 students regarding technical safety knowledge and application?
5. Is there any difference among different populations (like between science majors versus non-science majors) regarding safety knowledge and application?

CHAPTER 7

UNDERGRADUATE SAFETY INTERVIEWS

Background and Methods

From the observations, students at this institution did have the ability to correct themselves when they violated a safety guideline. The challenge arose when students had a TA who did not focus on correcting safety violations quickly. The result was that the student would take longer to correct their mistake than students with “strict” TAs. Is the effect of “strict” or “laid-back” TAs carrying over into students' knowledge of technical safety guidelines or how to minimize risk? Deciding if there was a connection between these topics required interviews with the GC1 and GC2 students.

The University of Georgia Institutional Review Board (IRB) approved this study as acceptable human subject research in February 2017. The researcher invited the students to participate in the interviews via an announcement on the CHEM GC1 and GC2 page on eLearning Commons (eLC), the online learning management system for the University of Georgia. The participants received compensation in the form of an entry into a drawing for a $75 Wal-Mart gift card. Those who did not want to participate in the interview were able to sign up for the drawing by e-mailing the researcher.

The interviews consisted of three sections: current laboratory environment, knowledge of technical guidelines, and real-life scenarios. The first part established whether the student had a strict or laid-back TA. As we saw in the laboratory observations, TAs fell on a spectrum of strictly enforcing laboratory safety to openly committing safety violations in front of their students. The questions included those that established not only the student's opinion of their TA's safety enforcement but also the guidelines their TA chose to enforce regularly. This would enable the researcher to compare the information in this section to the remaining responses and to understand if environment and strictness play a role in students' ability to transfer safety knowledge to new situations.

The second section of the interview consisted of questions containing topics that the American Chemical Society Committee on Chemical Safety considered necessary for students to know before they start organic chemistry laboratory.[127] The items included a mixture of hazard symbols, emergency response procedures, terms, phrases, and safety equipment. There were follow-up questions to each fact-recall question that asked the students about situations in the lab concerning the topic. For example, when the participants responded to a question about the hazard symbol for corrosive chemicals, they then had to answer how they would protect themselves if they saw the same logo on a reagent bottle. Questions of this type served the purpose of preparing the students for the kind of transfer questions the researcher would ask in the third section. The fact-recall items also serve as a scaffold to assist participants in preparing answers to the follow-up transfer questions.

The concluding section of the interview included only transfer questions with no safety guideline context clues. The researcher presented the participant with situations that could occur in the laboratory, and the student responded what they would do in that scenario. For example, one question asked the participant how they would react to a chemical on their skin if the laboratory procedure did not require them to wear gloves.

The researcher based the question directly from the observations data because the GC2 Experiments 5 and 6 did not offer students gloves, even though the chemicals in those procedures have acute skin effects. Gauging what students would do (as opposed to what they should do) allows the researcher to note the impact of environmental cues as well as other common issues in the observations.

Analysis

The researcher interviewed a total of twenty students: fifteen GC1 and five GC2 students. Majors included genetics (N = 3), biochemistry and molecular biology (N = 1), biological sciences (N = 5), nutritional sciences (N = 1), exercise and sport science (N = 5), health promotion (N = 1), chemistry (N = 1), biochemical engineering (N = 2), and biomedical engineering (N = 1). The lack of a significant difference in the response themes from major to major precluded the analysis of response differences among majors in this work.

The researcher analyzed the interviews using inductive content analysis to find themes which occurred within the data set. Using this method, the interviewer reviewed the data during the study and edited and added questions to the protocol to draw out themes from previous interviews. When the interviews no longer produced new themes, the researcher stopped taking interview data.[128]

The first theme that the researcher noted was that the students gave their TAs very high scores for enforcing laboratory safety at the beginning of the interview. All the students except one gave their TA an A, A-, or A+; the one exception gave their TA a C for not enforcing goggles and other personal protective equipment (PPE) during class. While these scores were high at the beginning of the interview, the student realized their

TAs' faults as the researcher kept asking questions. For example, one student gave their TA an A but realized during the remainder of the interview that when the researcher asked about proper PPE that their TA did not tell the students with long hair to tie their hair back during experiments. Another student who gave their TA an A- realized in final questions that their TA did not tell students to stay off their phones during laboratory, an activity that they believed would lead to distraction while handling chemicals. The students thought their TAs were doing the best they could until they started considering everything that could happen in the laboratory.

The ACS video that the students must watch at the beginning of the semester says that cuts from glassware are the most common laboratory incident in general chemistry laboratory. While the researcher's observations did not support this assertion, the researcher did want to know if the TAs had told them what to do in case of a cut on glassware or if the student could figure out what to do themselves. Only one student remembered their TA telling them how to clean a cut from glassware, and the TA included all necessary steps (rinsing, antiseptic, bandage, and possibly health center). The remaining students attempted to answer the question but missed that they needed to rinse the cut with water first.

The researcher asked the students to identify the source of their knowledge that a chemical with which they are working is hazardous. The responses mainly included the TA's pre-laboratory lecture, and if the TA did not mention the reagents, then the student assumed they were not hazardous. We observed that many times TAs did not mention the reagents that they did not know were hazardous or qualified the warning with, "The reagent is not too hazardous." The students also took context clues from their environment. The students assumed that a reagent was hazardous if the lab manager stored it in the fume hood. The issue with the response is that many labs (including GC1 Experiment 4 "The Copper Cycle" that the researcher observed) store chemicals that have acute hazards at the front of the room. The students also considered reagents to be hazardous if the lab manager provided gloves. In a question during the final segment, the researcher asked the students what they would do if a reagent spilled onto their skin in an experiment that did not require gloves. The students unanimously responded that if they did not need gloves then the chemicals must not be hazardous.

In the second portion of the interview, the students had to answer questions that were mainly fact-recall questions about specific safety guidelines. The first section included questions about hazard symbols that the general chemistry students should be aware of according to the ACS guidelines.[127] The researcher chose the hazard symbols (Figure 23) for corrosives, acute toxicity, environmental damage, and irritant since these were the most relevant to the general chemistry laboratory curriculum at this institution.

Figure 22 Hazard Symbols Used in Interview (Top row: Corrosive hazard, acute toxicity; Bottom row: Environmental Hazard, irritation hazard)

As we discussed in the previous chapter, reagents in general chemistry do not have these hazard symbols. As a result, the researcher turned this series of questions into application questions. Thus, the researcher followed up each hazard symbol question with a question about what the student would do to prevent injury if they saw this symbol on the label of a reagent bottle. Most participants could identify the corrosive and environmental hazard symbols and could tell the researcher how they would minimize risk. The responses to the acute toxicity hazard symbol were mainly that the chemical causes death, a response which errs on the side of caution. Protecting themselves from harm for this symbol meant wearing proper PPE and keeping the reagent in the fume hood. The irritant hazard symbol had a variety of responses including electrical hazard, flammable reagent, general caution, and sharp objects. When the researcher asked what they would do to minimize risk for the symbols, students matched their response to their definition of the symbol. For instance, for the student who responded that the symbol meant sharp objects said that they would let the TA handle the material, possibly by using a broom to clean it up.

The next set of questions contained various areas that the ACS guidelines specified for general chemistry students taking the general chemistry laboratory course. Students performed well on most of the topics or could come up with logical answers if they were not familiar with the subject. For instance, the researcher asked the students what the term, “The dose makes the poison” means and how it applies to the work the students do in general chemistry. Most students had never heard the phrase before but related the definition back to a topic they were familiar with, taking medicine. They reasoned that taking one pain pill would not cause harm but taking a whole bottle could kill a person. Applying this logic to general chemistry laboratory, the students said that the experiments that minimize volume (sometimes mentioning concentration) reduce the risk of significant spills and chemicals on the skin.

Within this set of questions, students created a heirarchy of the chemicals they believed to be harmful. In most interviews, the students cited corrosive chemicals, specifically concentrated acids, as being the most hazardous chemicals in the laboratory. When asked about solid chemicals or strong bases on the skin, the students minimized the risk of injury. The students believed they should brush solid chemicals off their skin and into the trash, but did not mention rinsing the skin. The students’ responses also indicated that strong bases did not affect the skin. The logic agrees with the observation data where most TAs did not mention the strong base in the GC1 Copper Cycle Experiment as a hazard requiring gloves.

Standard answers and alternative conceptions appear throughout all the interview data. For example, students struggled with predicting how long to stay in the safety shower or over the eyewash. Answers varied from one minute, five minutes, or until pain or burning ceases. The results agree with the instructions in the laboratory manual and TA instructions, where time is never specified, only an amount of water (i.e., copious). However, most safety data sheets and the ACS guidelines state that most reagents require flushing with water for fifteen minutes, with the exception that the student should rinse bases for thirty minutes. Since the students work with strong, concentrated acids and bases in several experiments, it is essential that the students understand the importance of rinsing for the right amount of time. The distinction is especially important since we observed that several students tried to treat chemical burns themselves without telling the TA.

The second alternative conception was that students believed there was fire equipment in various places in the laboratory. The TA asked the student what they should do if a fire broke out during an experiment. Typically, the student responded that they would inform the TA and the TA would either evacuate the class or use a fire extinguisher. The researcher then asked the students where the TA would locate a fire extinguisher. Only three students responded that the fire extinguisher is in the hallway (the correct answer). The remaining students answered that the fire extinguisher was at the front of the room, next to the fume hood, or under the computers with the first-aid kit. The students also believed there were fire blankets in the laboratory. In a question on how to properly use a safety shower, the students responded with the correct procedure but said that the TA would conceal them from view using a fire blanket. When the researcher asked the student the location of the fire blanket, the students said that it was under the computer with the first-aid equipment. The current laboratory rooms do not contain fire blankets, and there are none in the hallway. The response agrees with the laboratory safety video, however, because the video stated that a fire blanket should be in the laboratory for clothing fires and modesty in the safety shower.

The third standard response appeared in every interview: When a student could not answer a question, they said that they would ask their TA. There is nothing wrong with the response; it is what TAs told their students to do in most of the observations and is encouraged in the ACS safety video and guidelines.[69, 127, 129] However, many TAs in the observations also did not know what to do when students injured themselves or spilled chemicals.

In the third portion of the interview, the students had to tell the researcher how they would respond to specific safety situations. The situations included the student's eye itching during laboratory, spilling chemicals on their shirt, and working around cell phones and laptops, among others. In a majority of the interviews, the answers to these questions were entirely different from the responses in the technical guideline portion of the interview. Students separated what they should do and what they would do. For instance, in the second portion, the TA asked the students to name the standard guidelines that apply to any experiment in general chemistry. Most students responded that the lab bench should be free of clutter to prevent spills. However, when the researcher asked the students in the third portion how they would work safely with a laptop, the students responded that they would just try not to spill anything on the laptop. The students had a hard time connecting that the laptop takes up a significant amount of space on the benchtop.

The most significant example of the difference came in the safety shower questions. In the second portion of the interview, the students told the researcher that they should use a safety shower when they spill a hazardous chemical or a large volume of any chemical on themselves. During the third portion of the interview, nineteen students responded that they would just change their shirt if they spilled a beaker full of chemicals on it. One student mentioned the safety shower, but said they would avoid using it if they could.

The results of the interviews suggest that passive safety instruction has a limited impact on general chemistry students. However, we did learn that students are separating what they would do from what they should do; this may be dangerous in a laboratory safety context. We also saw that students had a dependence on their TAs to resolve all the safety situations the student could not. However, we do not yet know if the TAs know how to handle these situations. Therefore, the next step in the research is to interview the TAs to determine what they know about safety and their general attitude toward safety instruction.

CHAPTER 8

TA AND LABORATORY MANAGER SAFETY INTERVIEWS

TA Interview Background and Methods

The undergraduate safety interviews revealed that GC1 and GC2 laboratory students had several blind spots in their intellectual and practical knowledge of safety. Often, the response to these types of questions included some variation on asking the TA for assistance. We found the same trend in the laboratory observations: TAs informed their students during the pre-laboratory lecture that they should ask for assistance if they spilled a chemical on their skin. However, the observations also revealed that TAs often did not know how to handle common laboratory accidents when they occurred. Since the TAs are the first responders when a laboratory accident occurs, it is important to know how they would handle everything from mundane to rare emergency situations.

The University of Georgia Institutional Review Board (IRB) approved this study for acceptable human subject research in February 2017. The researcher contacted all general chemistry TAs assigned to teach Fall 2017 as well as the TAs from the laboratory observations performed Spring 2017. The TAs received an e-mail inviting them to participate in a study on their experiences teaching general chemistry laboratory. The researcher did not inform the TAs before, during, or after the interview that they were participating in a safety interview. Results on how TAs would react in emergency situations required that TAs did not study for the interviews beforehand. All participants were compensated with a $15 Wal-Mart gift card after the interview.

The researcher divided the interview into three sections: background and teaching preferences, emergency response procedures, and opinions on laboratory instruction. (Full questions appear in Appendix E). During the background and teaching preferences portion of the interview, the researcher asked the participants their background in chemistry to find if this had any effect on the TAs attitude on safety. For example, do TAs who work with hazardous chemicals regularly take the hazards more or less seriously than those who never have to work with hazardous chemicals?

Another portion of the participant background was a series of questions about TA training and TA meeting format. The questions included in this section were the easiest for those who had received training and attended TA meetings in Fall 2017. However, asking veteran TAs these questions provides valuable information about the consequences of training once and assuming complete and lasting knowledge. The final background and teaching preferences questions sought information about how the participants ordered their pre-laboratory lecture, frequent questions they receive from students, and their opinions on students' ability to complete experiments without their assistance. Asking these questions forces the TA to give their opinion on their teaching without asking them directly because direct questions are often hindered by trying to appear humble.

The second section of the interview was emergency response procedures that ranged from commonplace to rare. The following list is from the American Chemical Society Joint Board-Council Committee on Chemical Safety and University of Georgia Emergency Preparedness:[130-131]

1. Cut from broken glass
2. Solid chemical on skin
3. Corrosive reagent spill (on surface)
4. Concentrated base on skin
5. Student fainting
6. Fire in laboratory
7. Fire alarm
8. Tornado warning
9. Campus active shooter warning

Since the researcher only observed TAs handling two of these emergencies (cut from broken glass and concentrated base on the skin), these questions provided the best approximation of the TAs' approach to the remaining situations. For each question, the researcher asked the participant if they had learned the proper response in training or a TA meeting. The purpose of understanding the origins of the knowledge is to investigate once again if the safety knowledge attained in training lasts for the duration of teaching experience.

The concluding section of the interview contained questions about the participant's opinions on general chemistry laboratory and teaching. The questions started with the participant's attitude towards teaching before and after teaching general chemistry laboratory. The responses can be related to the previous section: If a TA has always held negative beliefs about teaching and teaching reaffirmed these beliefs, the TA may have reflected that attitude in how seriously they respond to emergencies. The researcher also asked the participants what they believed should be the goals of general chemistry laboratory (a long-debated topic in chemistry education research) and if their students were achieving these goals.[74, 85, 104] The answers elucidate the motivations of the TA: if they teach to build concepts, reinforce topics from lecture, or build laboratory skills, as examples. The final question was the same one presented to the undergraduates in their interview: If you oversaw the laboratory, what would you change? The perspective now shifts to a group that has experience working behind the scenes and has observed the growth of sixty to seventy students per semester under the current system.

TA Interview Analysis

The researcher transcribed the interviews and performed analysis using the inductive content method we described in Chapters 4 and 6. To add context to the analysis, the researcher also compared the themes emerging from the TA interviews with the themes found in the observations and the undergraduate interviews. The discussion includes responses from the participants to illustrate the themes found in the interviews. No names are included in the analysis.

A total of eight TAs participated in the interviews, and covered every major discipline offered in the department: Physical (N = 2), analytical (N = 2), organic (N = 1), inorganic (N = 2), and science education (N = 1). Three of the TAs participating in the interview had also participated in the laboratory observations (one inorganic, one analytical, and organic). Three participants started teaching the semester that the interviews took place (one analytical and two physical). The two remaining participants were veteran TAs who did not teach in Spring 2017. The experience level ranged from three months to 8 years of laboratory instruction.

As discussed previously, the first section of the interview contained questions about the TA's training. For the new TAs, the responses in this section contained a high level of detail. All three of the new TAs described the same basic experience, outlined in Chapter 3. As the years of experience increased, the details in the story decreased until the TA with eight years of experience could not remember their training at all. The following response is from a TA with multiple years of teaching experience:

> Um, so from what I remember…Wow, that was, like, 4 years ago. Um, I know we had, um, we had to do some of the experiments before, beforehand, um, not all of them but only some of them. And, um, that's about it actually from what I remember. I just remember [the laboratory coordinator], and [the laboratory coordinator] went through all of the dos and don'ts of, like, teaching in terms of, like, um, what's appropriate and what's not, um, you know, and in terms of, like, grading and all that. But, yeah, that's all I can think of to be honest. Other than that, I think, in terms of the department, I think that was about it from what I can remember.

This TA had actually only taught for three years since training but still could not remember anything beyond the broad strokes.

The TAs who had only started teaching Fall 2017 were the only participants who answered questions regarding TA meetings. According to the new TAs, TA meetings consist of the laboratory coordinator handing out papers with the pre-laboratory notes and the answer key for that week's laboratory. The laboratory coordinator then gives a brief lecture about frequent problems students have while experimenting. If the laboratory coordinator does not believe the TAs are familiar with a laboratory technique used in the experiment, they will perform a demonstration of that technique. One participant described their frustrations with the current TA meetings:

> Um, I should qualify my remark first. For whatever reason, we have not had as many TA meetings as I would have expected. There have been at least three TA meetings that were canceled for whatever reason, and it ended with [the lab coordinator] sending us a letter instead. The letter would often summarize the meeting and would detail the specific things [the lab coordinator] wanted us to cover in our pre-lab lecture. Any-usually anything regarding disposing of materials would be in there as would demonstrating any new apparatus. The thing I remember most about the TA meetings was something that did not happen which was asking for feedback. Out of all the TA meetings, there were only two times where [the lab coordinator] asked for feedback, and in both cases, [the lab coordinator] already had a specific question [the lab coordinator] wanted feedback about and did not seem interested when the TAs expressed other concerns.

The other new TAs also mentioned the lack of opportunity for feedback during TA meetings in their interviews.

All TAs then answered a few questions about their pre-laboratory lecture preferences and preparation. Out of eight TAs, there was only one TA who discussed safety at the start of the pre-laboratory lecture. The TA in question also participated in the laboratory observations, and the field notes confirm this response. The remaining TAs did not speak about covering safety information at all but, instead, talked about teaching concepts, going over procedure changes, demonstrating the proper use of equipment, and discussing equations. First and foremost, the concern the TAs had was for students to know why they were doing the procedure. Five out of seven TAs expressed concern that the lab manual did not provide the proper connection between procedure and concepts. However, all of the TAs indicated that their primary sources for pre-laboratory lecture were the lab manual and the pre-laboratory handout from the laboratory coordinator. On one hand, the TAs recognize that there is missing information in the laboratory manual, but, on the other hand, they also do not look further than the lab manual and the person who wrote the lab manual for their preparation.

The TAs further indicated the inadequacies of the laboratory manual when asked if their students could finish an experiment without TA assistance. Five of the eight TAs said that their students would not be able to finish an experiment without assistance, as the procedure was unclear and the post-laboratory questions were unnecessarily complicated. The remaining three TAs did not specify that the lab manual had complete information, but, instead, said either that only highly motivated students could do it or all students could complete a few of the experiments without help. The TAs recognize that the students cannot make it through an experiment without help, but from the observations, the TAs were also not filling all the gaps left by the laboratory manual.

Based on the observations alone, TAs struggled with knowing what to do in emergency situations. However, the only situations the researcher could observe were students burning their skin on corrosive chemicals and cuts from glassware. The second portion of the interview, emergency response, gave some insight into the TAs' possible procedures. The first trend in the responses was that veteran and new TAs had distinct differences in answering common emergency response questions. For example, here is the response a new TA gave to a question regarding a student cutting their hand on glassware:

> I would check for a first aid kit and then I'd go tell [the lab manager], usually [the lab manager is] closest to my lab, sometimes [the lab manager is] not in there. And then I would go to [the lab coordinator's] lab or [their] office. [They're] not guaranteed to be there, especially in the morning or late at night. I haven't ever had a problem to go get [them]. Um, if it's a really serious cut then I would call [them] because [they] did give us [their] phone number to call [them] and [the lab manager's]. Um, and I really don't know otherwise.

In the response, the TA never actually answers the question, just states where they would find out what to do. For the scenario laid out to the TA, the student is bleeding from a cut on glassware that could have a hazardous material on or in it. Now, compare the response to the same question posed to a veteran TA:

> Um, well the first thing is to make sure you wash it real well, especially wash the cut real well to make sure there's no, like, chemicals going in there. Um, depends on the cut, so if it's a smaller cut like something could be handled by just me or something that could be handled by just putting Neosporin on it and a Band-Aid then I could be able to do it. If it's something that I think like, on the spot, I think it would need some more serious helpthen I would send them to the health center, either with me or with somebody else.

The veteran TA not only knew what to do if a student cut their hand but also knew how to handle various degrees of emergency without asking for help. The trend continued through all commonplace emergency scenario questions: new TAs would ask for help (primarily from the laboratory manager), and veteran TAs would resolve the issue on their own.

All veteran TAs shifted to asking for help when responding to questions about rare emergencies, such as tornado and active shooter warnings, and students fainting during lab. Changing from self-sufficiency to helplessness gives insight into the response difference in the usual emergency questions. New TAs may have never come across any of these scenarios since their teaching started a matter of months before the interview. From the beginning of the interview, we also know that new TAs did not receive safety instructions in training and rarely during TA meetings. Veteran TAs indicated that they had not come across the rare emergencies before, saying that they would ask the lab manager for help. In summary, all TAs have a hard time transferring laboratory safety guidelines to unfamiliar situations. It is only when the TA experiences the situation that they know how to handle it without assistance.

The TAs also had similar responses to the fire situation that we found in the 1211 and 1212L student interviews. Seven out of the eight TAs indicated that the fire extinguisher was somewhere in the laboratory, most commonly at the front of the room, under the computer with the first-aid kit, or next to the fume hoods. The initial explanation for the confusion during the undergraduate laboratory interviews was that students remembered the placement of the fire extinguisher in, say, a biology lab and attributed it to the chemistry lab. The TAs making the same mistake may indicate that, logically, the students and TAs expect there to be a fire extinguisher in the lab and come up with their own most logical placement. The issue is that if a fire does break out in the lab, the TA is looking for an item that is not there.

In the third portion of the interview, the TAs gave opinions on the goals of a general chemistry laboratory. The responses typically connected to the answers in the background section regarding pre-laboratory lecture structure. Six out of eight TAs indicated that the goal of general chemistry lab is to connect concepts from lecture to experiments on the same topic:

> Um, I think it's to introduce students to what it's like to work in a lab and what we practically do. Because you know, like, general chemistry you teach them the basics of chemistry and they have to, you know, certain things they have taken for granted and stuff like that. But I think the lab part actually helps them put all of that to practice more or less and see that it's not just a class that we learn just because. It actually has a practical application and a lot of the experiments actually show that. That it's like, "Oh, this is how people actually do it in real life" and all of that.

As the response suggests, students need to see what chemists do to learn chemistry appropriately. Based on the previous responses, TAs put concepts first in pre-laboratory lectures and their responses align with the goals of this question. Of the remaining TAs, one recounted the goals in the laboratory manual and reported if they agreed or disagreed with them, and the other indicated that general chemistry lab was a "weed-out class," or a class that prevents students from staying pre-medicine majors.

As we discussed previously, the final question of the interview was the same question posed to the undergraduates in their interview; The responses to this question were similar in that every TA said that they would get rid of Experiment 6, "Analysis of Vitamin C in Orange Juice." From the TA's standpoint, the experiment is problematic to teach because the students had never done standard acid-base titrations and now had to do back titrations. The TAs also responded that, again, they wanted to give feedback on procedures that were not working or topics that caused problems for students. They believed that, with TA experience in mind, the laboratory manual would improve enough that they would not have to cover a list procedure corrections during their pre-laboratory lecture. Lastly, the new TAs specified that they were disappointed that the emergency response procedures in the second part of the interview were not in their training. It is clear that training is an area that needs reform and that the TAs are aware of this.

Laboratory Manager Interview Background and Methods

In the previous section, we found that TAs had a dependence on the laboratory manager to resolve emergency situations and that the laboratory coordinator had encouraged this response during training. Therefore, the research must include the laboratory manager's emergency response procedures to get an idea of what would happen if any of these situations occurred. The UGA IRB approved this study as acceptable human subjects research in February 2017. The researcher contacted the laboratory manager via e-mail in January 2017, inviting them to participate in an interview about their job responsibilities. Again, the participant did not know that they would be answering questions about laboratory safety to prevent queuing or prior preparation. At the end of the interview, the participant received a $15 Wal-Mart gift card.

The interview had two sections: background and job responsibilities, and emergency response procedures. The background portion contained questions about the laboratory manager's experience in chemistry such as research, previous laboratory work, and educational achievements. The answers provide the manager's experience with hazardous chemicals and waste disposal. The next set of questions in the background portion were about job responsibilities: what is the manager expected to do to prepare the laboratory? Answers provide insight into the manager's opinion of their duty to respond to emergencies. The last portion of the background section asked about training specific to the position of laboratory manager.

The second section of the interview contained a similar set of emergency response procedures that the TAs were required to answer with a few exclusions. The researcher removed any questions that the TAs did not invoke the name of the laboratory manager. These items included spilling a corrosive chemical, and fires in the laboratory or the building. The manager also did not receive the question on campus active shooter warnings as it is the hope that TAs would stay in their labs and not make phone calls to the manager. The interview concluded with the same question asked of the undergraduates and TAs: if the lab manager was in charge of the labs, what would they change?

Lab Manager Interview Analysis

The lab manager of the general chemistry laboratories had a threefold background in chemistry: an undergraduate degree in general chemistry from the University of Georgia, undergraduate research in a biomedical and nanoparticle synthesis laboratory, and undergraduate work experience in the general chemistry labs as a prep attendant. The lab manager earned their bachelor's degree in chemistry from the University of Georgia in May 2017. The University of Georgia does not allow undergraduates to dilute concentrated acids and bases, even at the senior level. Undergraduate prep crew members, therefore, can only set out reagents and clean the labs and glassware.

The initial requirements for becoming the general chemistry laboratory manager were only a bachelors in a science major (not necessarily chemistry). The job description, according to the current lab manager, was also vague regarding the details of what a lab manager does. The lab manager described the gap between job ad requirements and their current duties:

> Um, I remember reading, like, the requirements on the website. It was like, “You will prep the labs.” And it was, like, a really, just like short description of what you’d be doing. And I guess the words, like, “Prep these labs” is actually, like, just everything. Um, it’s, I guess, any demand that keeps the labs functional and up to EPA standards. Um, so that includes, like, ordering reagents, preparing the reagents, um, making sure all the labs are within EPA standards. So, like, cleaning is a big part of it, hazardous waste, prepping glassware, maintaining the balances. Um, yeah, I don’t really know how to-it’s just a lot of small things for every lab.

The first impression of the lab manager is that they did not know what they were getting into when they took this position. However, if they went through proper training, there should not be a problem.

The lab manager then pointed out that there was no training. There was a one-week window where both the new and old lab managers were working at the same time, during which formal training was supposed to take place. The lab manager explained that they had a family emergency come up that week and could not attend the training. Since the university did not want to pay two people for the same position, the new lab manager had to learn everything from the previous lab manager’s notes. The laboratory coordinator did not make any attempts to train the new lab manager. As we learned previously, the lab manager was not allowed to make solutions as an undergraduate and would now oversee making large-scale solutions from concentrated reagents. The lab manager also did not attend the new TA training in Fall 2017 where the lab coordinator told the new TAs to call the lab manager if they had an emergency. The lab manager, for his part, did not realize the TAs were told to contact him in an emergency.

Of the five possible emergency situations covered in the interview, the lab manager only answered one correctly, responding to a burn from a concentrated base. In response to the question regarding a student spilling a solid on their skin, the lab manager replied that the TA should use the chemical spill kit in the laboratory cabinets. Not only are the spill kits in the laboratory not intended for solid spills but are also not to be used on skin. The lab manager had no response to a student fainting in the lab, which was a question that TAs commonly responded that they would ask the lab manager for help. If a student cut their hand on glassware, the lab manager skips straight to bandaging the wound instead of rinsing it off with water first to prevent chemicals getting into the bloodstream. For the question regarding tornado warnings, the lab manager did not know where the tornado shelter is in the building, and their best guess was the center hallway, which is lined on both sides by floor to ceiling windows.

The final question, again, regarded what the lab manager would change about the lab set up if they had the chance. Since the lab manager did not have to teach the labs, their response was a call for more support in running the labs. In the current system, the lab manager oversees all GC1 and GC2 laboratories, and in their opinion, they did not have the workforce to keep all the labs clean enough for EPA standards. While the lab manager did not think about the students, they are also at risk when the laboratory is dirty. For example, during one of the GC1 experiments, “The Synthesis and Decomposition of Zinc Iodide”, the students have to measure out solid iodine on a balance. The laboratory manual states that the iodine is corrosive to metals but does not mention that it is also corrosive to skin. Therefore, if a student spills the iodine on the benchtop, they could leave it because they think it is harmless. When the prep crew does not clean the lab, another student could put their hands on the bench and come away with chemical burns. A larger group of people on the prep crew benefits not only the lab manager but also the TA and students' safety. The lab manager also withheld detergent bottles from the laboratories in Fall 2017 and Spring 2018 and in the interview explained that this was because the EPA fines residue left by detergent on benchtops.

Taking the TA and lab manager interviews together, there is a greater need for proper training of the staff of the general chemistry laboratories. In the final chapter of this work, we will discuss possible routes of training reform and ways to ensure that TAs are enforcing safety guidelines during experiments.

CHAPTER 9

LABORATORY SAFETY ASSESSMENT

Background and Methods

The undergraduate safety interviews and laboratory observations gave a small-scale idea of students' ability to transfer safety guidelines into minimizing risk in a real-life scenario. To determine if the qualitative data from the experiments matched the abilities of a majority of the class, the researcher designed an assessment based on the safety situations where students struggled in both the observations and the interviews. With the assessment, we can track the progress of current safety instruction starting with prior knowledge and proceeding to the end of GC2.

The University of Georgia Institutional Review Board approved this study as acceptable human subject research in July 2017. The researcher contacted the GC1 students via eLearning Commons (available through the University of Georgia) at the beginning of the Fall 2017 semester before the students watched the laboratory safety video or took the laboratory safety quiz (discussed in Chapter 4). This set of results gave the students' prior knowledge of laboratory safety before starting general chemistry laboratory. At the end of the semester, the GC1 students completed the assessment again to determine the effect of GC1 on safety knowledge. The GC2 students also received the assessment at the end of the semester to determine the effect of GC2 on gains in safety knowledge.

The researcher chose the question topics and format based on several sources. The first source was the ACS guidelines for general chemistry safety instruction.[127, 129] The sources provided a basis for the issues that students should know after taking two semesters of a general chemistry lab. We could then rule out all of the topics that the lab manual and experiments do not include in any way. The researcher narrowed down this list by taking into account the common mistakes that students and TAs made during the observations and the interviews. For example, since the students had no trouble answering questions about how to minimize risk when weighing out a solid on a balance (an ACS recommended topic) we did not include the problem in the assessment. The process narrowed down the issues to the following list:

1. Spill response
2. Acute toxicity definition
3. Eyewash procedure
4. The dose makes the poison
5. Hazard definition
6. Cut on glassware
7. Chronic toxicity definition
8. Safety data sheet
9. Waste disposal
10. Acid strength vs. concentration
11. Risk definition
12. Inhalation and injection definition
13. Solid spill on skin
14. Personal protective equipment rules
15. Safety shower procedure

Since the scope of the research is to understand if students can transfer their knowledge of laboratory safety to new safety situations, the researcher did not ask fundamental fact-recall questions. Students knowing the definition of acute toxicity, for example, does not mean that they know what to do with a reagent with that hazard. Therefore, the questions had a transfer style which put the student in a laboratory situation and asked what they would do. The method also connects back to part three of the undergraduate interviews where students separated what they would do from what they should do. In this way, we will be able to see if a larger population of students show the same trend.

Question Difficulty and Discrimination

The first analysis we performed was on the individual questions. We determined *difficulty* and *discrimination* of each question using the 193 student responses who took both the prior knowledge and GC1 assessment. The researcher believed analyzing this group of participants would lead to more reliable results in question difficulty and discrimination because the results reflect the same participants' change over time. We determine question difficulty (p) by dividing the number of correct responses by the total number of participants. A difficulty value equal to or less than 0.25 indicates that 25% or fewer students could correctly answer the question and it is, therefore, difficult. On the other hand, a value equal or greater than 0.75 indicates that 75% or more students could answer correctly, meaning the question was easy. Objectively well-formed assessment questions fall between the two values. The researcher performed the difficulty calculations on the prior knowledge and GC1 separately to show how question difficulty changed after GC1. The results below are in the form of a heat map where difficult questions are in dark red, and easy questions are in dark green.

Table 8 Item Difficulty Heat Map

We arranged the items the heat map ordering on the Prior Difficulty column to show the range of difficulties as well as how that range changed after GC1. Eyewash Procedure, PPE Rules, and the Dose Makes the Poison were all easy questions for students before and after taking GC1. The result agrees with the interview data because most students could comfortably answer these questions without invoking the name of their TA. The most difficult questions, Acute Toxicity and SDS, were topics that TAs did not cover in the observations and students could not answer in the interviews. The difficult questions may lack the retention element that students need to answer transfer questions because the course never exposed them to the terms.

To determine if we need to remove or edit some questions in future iterations of the assessment, we need to look at the discrimination of each question. Highly discriminated questions mean that there is a clear separation in the number of correct answers between the top twenty-five and bottom twenty-five percent of scorers. Positive high discrimination indicates that the top twenty-five percent of scorers answered the question correctly more often than the bottom twenty-five percent of scorers. Questions with a low positive to negative discrimination specify that low scoring students are most likely guessing and choosing the right answer. We calculate discrimination by isolating the results of the top and bottom twenty-five percent of scorers on the assessment. We then calculate the number of correct answers in each group. To determine the discrimination, we subtract the number of low scorer correct answers from the number of high scorer correct answers and divide by the total number for each group. A discrimination value of equal to or less than 0.2 indicates that the question needs to be edited or removed from future assessments. The table below contains the low and high scorer correct answers, the difficulty heat map for reference, and the discrimination for the prior knowledge assessment.

Table 9 Difficulty and Discrimination Heat Map

Question	# Correct (75th Percentile)	# Correct (25th Percentile)	Difficulty	Discrimination (D)
Eyewash Procedure	49	28		0.4
PPE Rules	44	30		0.3
Dose Makes the Poison	40	26		0.3
Risk Definition	45	19		0.5
Spill Response	37	15		0.4
Cut on Glassware	40	18		0.4
Inhalation/Injection	38	11		0.5
Strength vs. Concentratio	25	8		0.3
Chronic Toxicity	22	9		0.3
Hazard Definition	31	6		0.5
Waste Disposal	22	8		0.3
Solid Spill on Skin	3	0		0.1
Acute Toxicity	15	6		0.2
Safety Shower Procedure	20	2		0.4
SDS	19	1		0.4

Although the difficulty calculations indicated that Eyewash Procedure, PPE Rules, and the Dose Makes the Poison were easy questions in the prior knowledge assessment and GC1, the results of the discrimination analysis designate that the questions are still discriminating between high and low scoring students. While SDS discriminates well, the acute toxicity discrimination is less than 0.2, meaning the researcher needs to edit or remove the question from future assessments. Another question with low discrimination was Solid Spill on Skin, indicating that the researcher needs to remove or edit this question. To confirm that the researcher should edit or remove these questions, we look to the GC1 discrimination table.

Table 10 Difficulty and Discrimination for GC1 Assessment

Question	# Correct (75th Percentile)	# Correct (25th Percentile)	Difficulty (p)	Discrimination (D)
Eyewash Procedure	51	39		0.2
Dose Makes the Poison	52	33		0.4
Risk Definition	51	30		0.4
PPE Rules	46	28		0.3
Cut on Glassware	48	23		0.5
rength vs. Concentratio	35	17		0.3
Spill Response	31	16		0.3
Chronic Toxicity	39	11		0.5
Safety Shower Procedur	35	9		0.5
Inhalation/Injection	36	12		0.4
Hazard Definition	28	12		0.3
Waste Disposal	28	9		0.4
Solid Spill on Skin	4	1		0.1
Acute Toxicity	13	6		0.1
SDS	23	8		0.3

According to the GC1 discrimination table, Eyewash Procedure should be edited or removed in future assessments because after GC1 the lowest scoring students are just as likely to answer the question correctly as the highest scoring students. Since we designed the assessment to measure the students' safety knowledge after taking general chemistry at this institution, we will use these results rather than the prior knowledge discrimination value. The calculations confirm the low discrimination of Solid Spill on Skin and Acute Toxicity, and so those questions will be edited or removed in future assessments.

Analysis of Raw Scores Between Prior, GC1, and GC2

The populations included in the total participants across the three timepoints are prior knowledge (N = 569), after GC1 (N = 351), and GC2 (N = 315). We performed an analysis of variance (ANOVA) on the students' scores between the three timepoints. We use an ANOVA to see if there is a significant difference among three or more groups. The ANOVA does not reveal which groups have differences, only that a significant change exists. We determine if there is a significant difference using the p-value. In this statistical test, the smaller the p-value, the less likely it is that the difference in results occurred by random chance. A p-value of less than 0.05 is significant in the following analysis at the 95% confidence level, while a p-value above 0.05 indicates that we cannot reject the null hypothesis, which states that the results are the same.

Since the ANOVA does not tell us which variables have significant differences, the researcher then performed paired t-tests to determine which points had statistically significant scores. In a paired t-test, the p-value determines significance, where a significant difference is confirmed when $p < 0.05$. The results of the analysis are in the tables:

Table 11 Average Scores for Each Test Group

Class	Average Score
Prior Knowledge	39.444
GC1	47.347
GC2	45.930

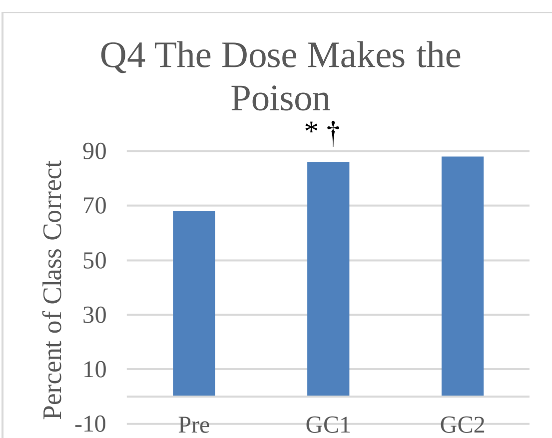
*Table 12 Results of Paired T-Tests of Average Scores: * p-value of <0.05, † p-value <0.0001*

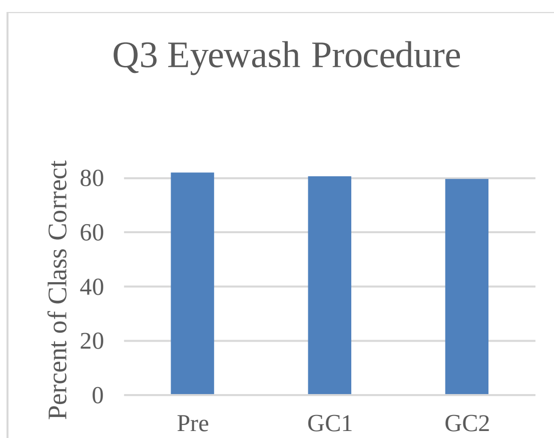
Class Comparison	Mean Difference In Score
Prior and GC1	7.903*†
GC1 and GC2	-1.417
Prior and GC2	6.486*†

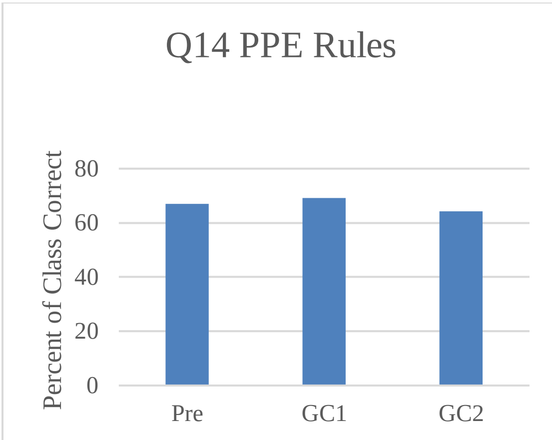
In the first table, we see the mean scores of prior knowledge, GC1, and GC2. There was no significant difference between GC1 and GC2. The results indicate that students did not understand safety more or less than when they ended GC1 but remained stagnant. To understand why the average score was so low even after two semesters of general chemistry laboratory, we need to look at the individual question scores to see the topics where students excelled and struggled.

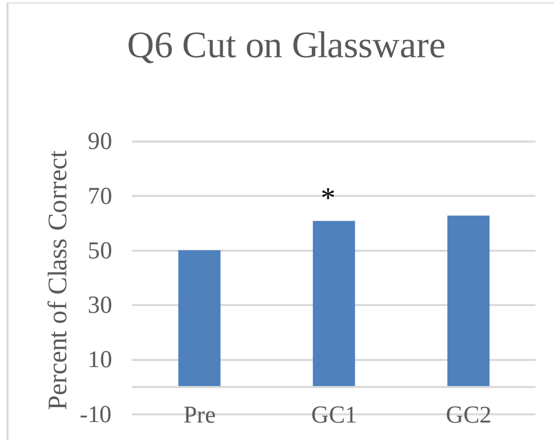
Analysis of Question Scores: Prior, GC1, and GC2

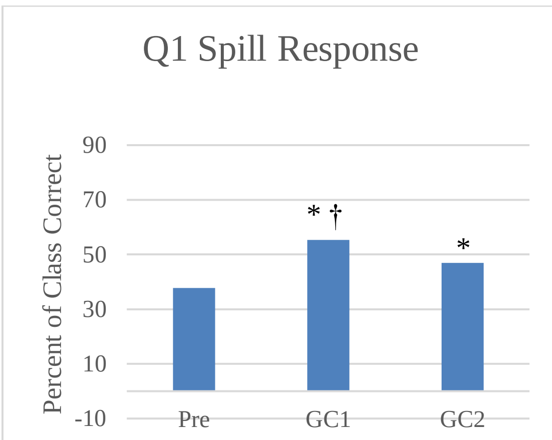
We performed an ANOVA on each of the questions, comparing prior knowledge, GC1, and GC2 as we did for the overall score averages. The researcher input the data as zero for incorrect answers and one for correct answers. Therefore, the percent of class correct is the average of zeros and ones for that time-point. After establishing the questions that had a significant difference between time-points, the researcher ran a paired t-test to determine which time-points were significantly different from each other. Significant differences ($p < 0.05$) have an asterisk above the bar, while highly significant differences ($p < 0.0001$) have an obelisk above them as well. In the plots below, the researcher indicates which results are significantly different from the time-point directly before it. Therefore, an asterisk above a GC2 bar would mean that there was a significant difference between GC2 and GC1 scores on that question. The data appear in a trellis display. A trellis display is a way to visualize the data so that we can easily see the questions where the students excelled and struggled. Essentially, the display arranges the data from the highest scoring question (i.e., the histograms at the top of the figure) to the lowest scoring question (at the bottom of the figure).

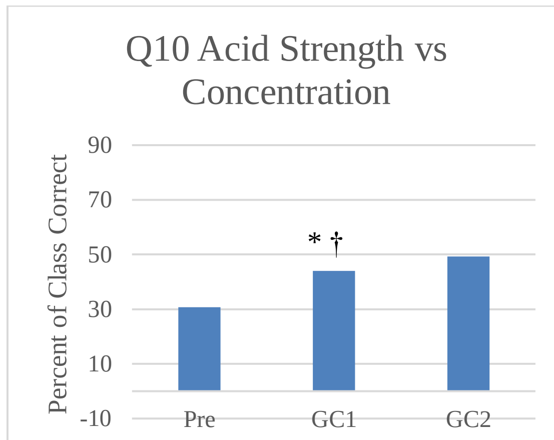


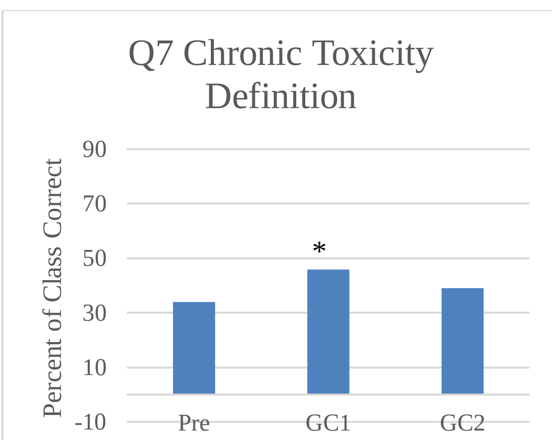


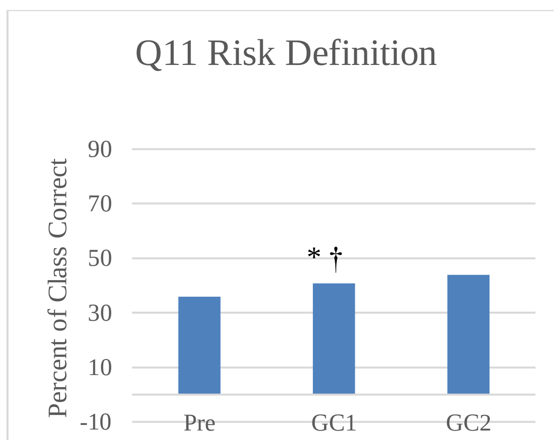

Q14 PPE Rules
Percent of Class Correct
0
20
40
60
80
Pre
GC1
GC2

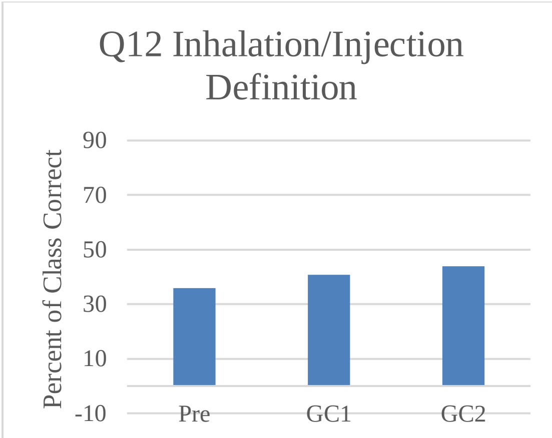

Q6 Cut on Glassware
Percent of Class Correct
-10
10
30
50
70
90
*
Pre
GC1
GC2

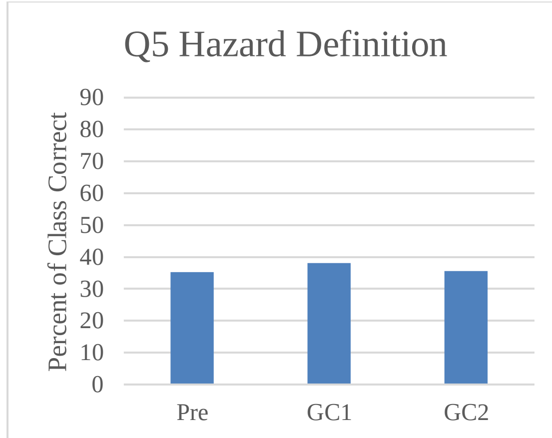

Q1 Spill Response
Percent of Class Correct
-10
10
30
50
70
90
* †
*
Pre
GC1
GC2

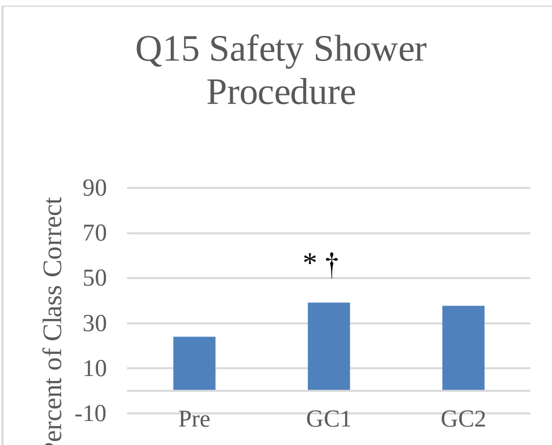

Q10 Acid Strength vs Concentration
Percent of Class Correct
-10
10
30
50
70
90
* †
Pre
GC1
GC2

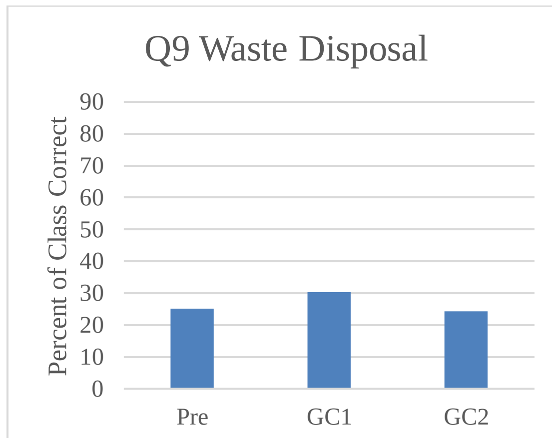

Q7 Chronic Toxicity Definition
Percent of Class Correct
-10
10
30
50
70
90
*
Pre
GC1
GC2

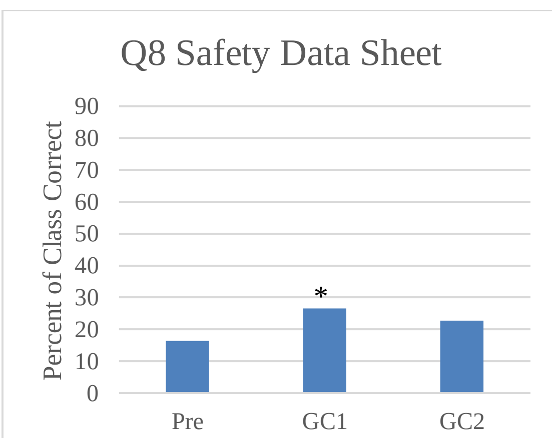

Q11 Risk Definition
Percent of Class Correct
-10
10
30
50
70
90
* †
Pre
GC1
GC2

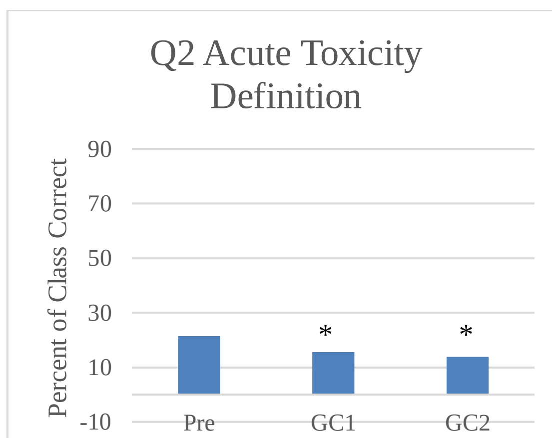

Q12 Inhalation/Injection Definition
Percent of Class Correct
90
70
50
30
10
-10
Pre
GC1
GC2


Q5 Hazard Definition
Percent of Class Correct
90
80
70
60
50
40
30
20
10
0
Pre
GC1
GC2


Q15 Safety Shower Procedure
Percent of Class Correct
90
70
50
30
10
-10
* †
Pre
GC1
GC2


Q9 Waste Disposal
Percent of Class Correct
90
80
70
60
50
40
30
20
10
0
Pre
GC1
GC2


Q8 Safety Data Sheet
Percent of Class Correct
90
80
70
60
50
40
30
20
10
0
*
Pre
GC1
GC2


Q2 Acute Toxicity Definition
Percent of Class Correct
90
70
50
30
10
-10
*
*
Pre
GC1
GC2

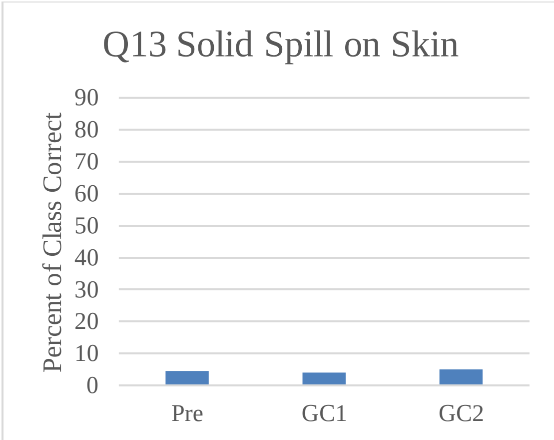


Figure 23 Trellis Display of Question Scores

There are questions that have significant differences between prior knowledge and GC1, but there are only two questions that had a significant difference between GC1 and GC2 (acute toxicity and spill response). The raw score and question ANOVAs confirm that students did not improve their ability to minimize risk in unfamiliar situations, but their knowledge also did not significantly decrease. If we isolate the students who took both the prior knowledge assessment and the GC1 assessment, we can understand how the students' answers are changing after a semester under the current system of instruction.

Analysis of Net Change in Question Scores Pre-Post

One hundred and ninety-three students responded to both the prior knowledge and post-GC1 assessments. If we limit the analysis to only these students, we can see how individual responses changed from previous experience to the end of GC1. The researcher scored the students according to the following rubric:

Table 13 Codes for Net Change Paired T-Tests

Condition	**Categorical Variable**
Correct → Incorrect	-1
No Change	0
Incorrect → Correct	+1

Averaging the change in score shows how the scores on individual questions improved or declined after taking GC1.

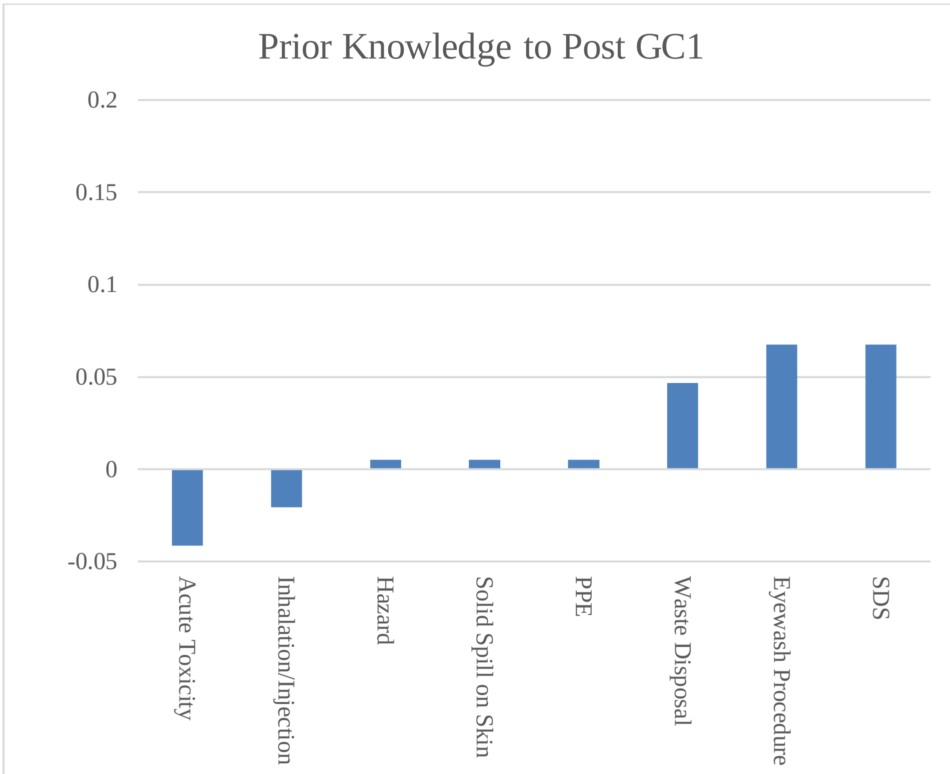


Figure 24 Net Change in Scores After GC1 (PPE is Personal Protective Equipment and SDS is Safety Data Sheets)

The first plot shows the questions that had the least amount of improvement after taking GC1. The trend with the acute toxicity question remains with the pre-post GC1 analysis. A net decrease also occurred in the inhalation and injection hazards question. The pattern breaks away from the ANOVA and student t-test among pre, GC1, and GC2, where there was no significant difference in the scores between prior knowledge and GC1. The students neither improved nor declined in their understanding of the hazard definition, solid spills on the skin, or proper PPE. We will discuss later whether they knew the answers initially or remained with the same incorrect answer. We then start to see a slight net advancement in the areas of waste disposal, eyewash procedure and knowing when it is appropriate to use an SDS.

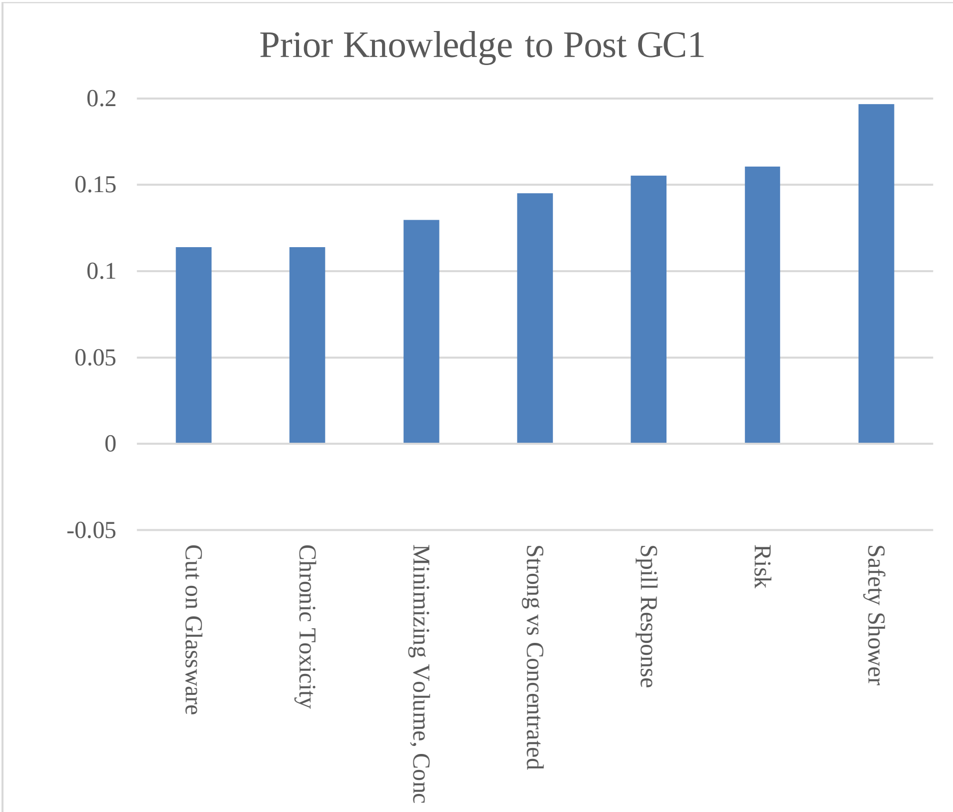


Figure 25 Net Change in Scores After GC1

The second half of the questions showed a net improvement of approximately ten percent to twenty percent. Several of the most improved categories are those that the lab manual encourages students to know or instructors reinforce in lecture. The lab manual includes safety instructions for cuts from glassware, spill response and using the safety shower. In the lecture, the students learn about acid and base strength and TAs in the observations reinforced that the students were working with strong acids. However, since these scores only represent the net change, they do not tell us how the students changed their answers or how many students did not change their answers at all. The plots only tell us the net effect of taking GC1 laboratory.

Analysis of Changing Responses Pre-Post GC1

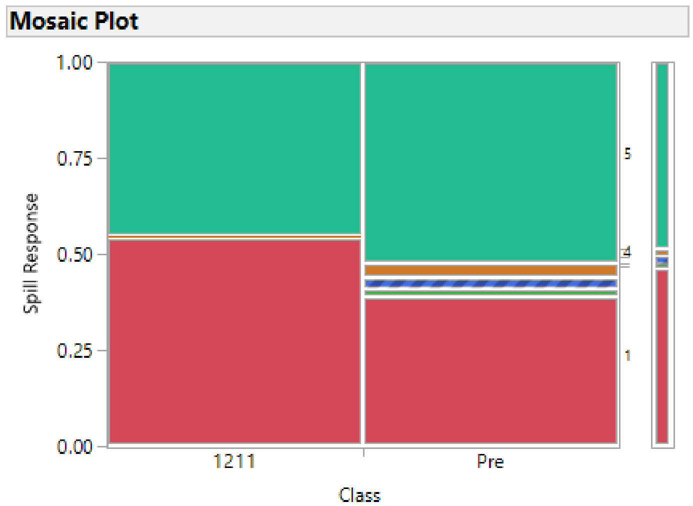
To understand the pre-post changes in scores, we must also look at the individual questions and how responses changed from prior knowledge to the end of GC1. Only the students who took both the prior knowledge and GC1 assessment are included in the analysis below to show how responses changed after taking one semester of GC1. In each of the examples below, the question from the assessment is listed first, followed by a Chi-Squared Analysis mosaic plot (generated with JMP), a Sankey diagram, and then the change in responses for individual students. We use Chi-Squared Analysis on categorical data (variables that fall into discrete categories) to measure how likely it is that an observed distribution is due to random chance.[132] In our case, the discrete categories are prior knowledge and post GC1 on the x-axis and the responses (1-5 equals A-E) on the y-axis. The area of the squares in the mosaic plot represent the proportion of students answering the response.

We use a Sankey diagram for categorical data to visualize how individuals in a group change through time or activities.[133] The left side of the plot represents the full population of students. The groups then break apart into their prior knowledge answer choices. The colors represent the option they chose on the prior knowledge assessment. The groups then break apart again to show how the answers changed after taking GC1. It is important to note that the categories will not line up on each y-axis because the plot shows the proportion of students who answered with that response. This method is an easy way to visualize the data and note the way the students change their answers between time points.

The change in response plot represents the number of students who started with a correct answer and switched to an incorrect answer, answered the correct or incorrect answer both times, or answered an incorrect answer and switched to a correct answer. Combining the Chi-Squared mosaic plot, the Sankey plot, and the change in responses allows us to see if general chemistry laboratory at this institution has any measurable effect on students' safety knowledge.

We will begin with the first question on the assessment: spill response with a strong base. ACS guidelines specify that if students spill a chemical, they should immediately move away from the spill and inform the TA. Instead of asking what to do if a chemical spills, the researcher framed the question as though the student was experiencing the event:

1. Amy spills a strong base onto the benchtop while trying to pour from a beaker into a 10-milliliter graduated cylinder. What should Amy do next?
    a. Move away from the spill and tell the TA*
    b. Wipe up the spill with paper towels
    c. Find the appropriate acid to neutralize the base
    d. Dilute the base with water before wiping with a towel
    e. Have a lab partner stand near the spill to prevent others from getting hurt while she informs the TA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Spill Response
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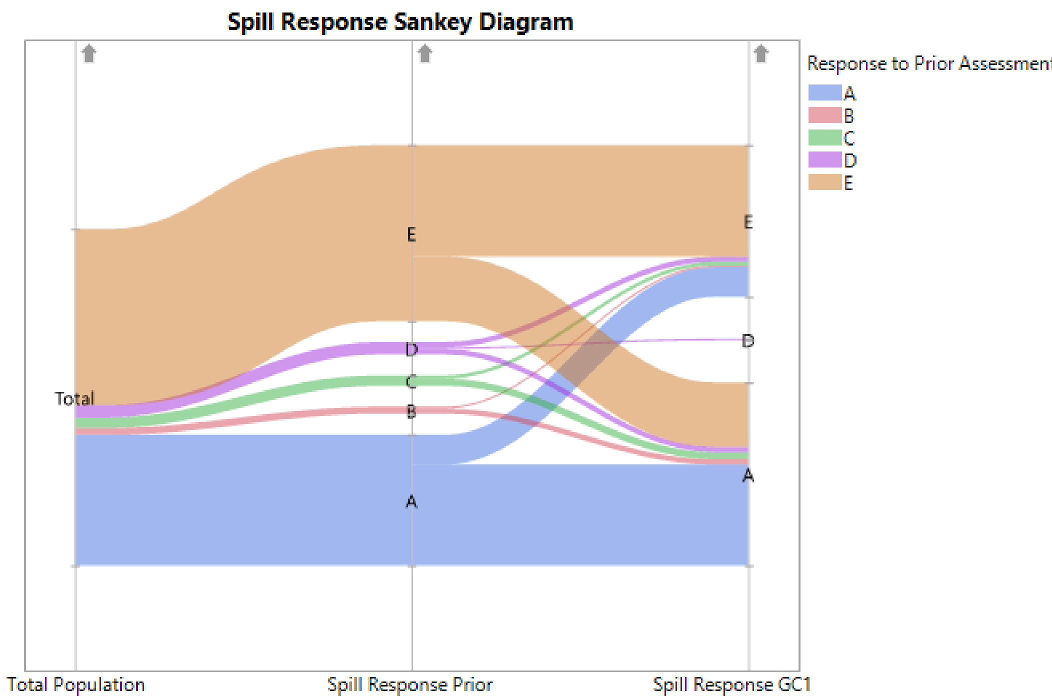
Spill Response Sankey Diagram
Response to Prior Assessment
A
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Total
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Total Population
Spill Response Prior
Spill Response GC1

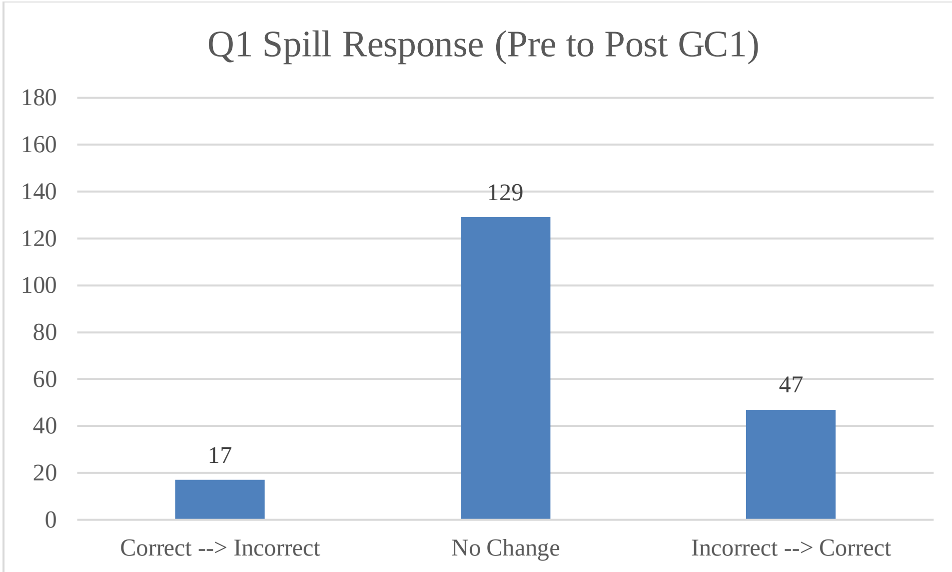


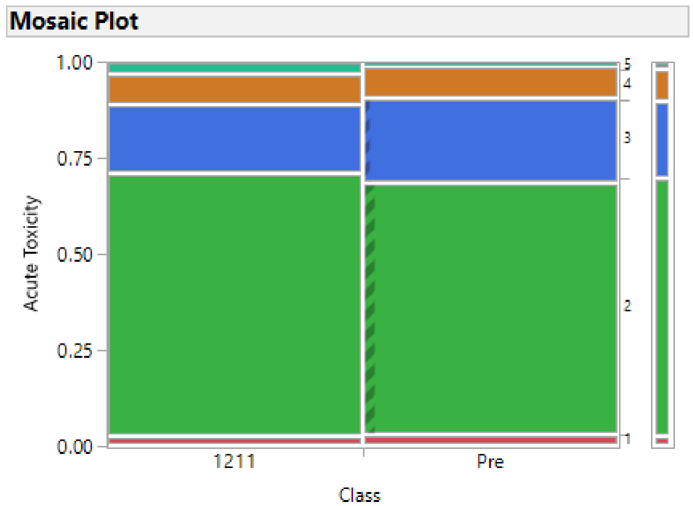
Figure 26 Q1 Spill Response Pre-Post Analysis

From the Chi-Squared mosaic plot, we see there is a near fifty-fifty split between A and E in both prior knowledge and the end of GC1. In prior knowledge, there is also a small group of students who responded with solutions where they (the students) were responsible for cleaning up the spills. These students changed their answers after taking GC1 to A or E where the TA is responsible for handling spills. The change in responses agrees with the observation data where the TAs told the students to inform them immediately if anything spilled during the "Copper Cycle" Experiment. It also agrees with the interview data where students depended on the TA to handle any spills that occurred in the lab and had a hard time saying what the TAs would do to handle acid or base spills.

A positive note on this question is that after completing GC1, the students are taking spills of strong bases seriously enough to warrant asking the TA for assistance. The result disagreed with the observation data when some of the TAs in GC1 did not mention the base as a chemical hazard or demonstrated how to use a dispensette pump on the base without wearing the proper PPE. There is also disagreement with the interview data where the majority of GC1 students did not believe that strong bases had any effect on the skin. The area where students struggle is realizing that putting another student near the spill puts that student at higher risk than if they stayed away from the spill. The TAs did not make the distinction during pre-laboratory lectures for the “Copper Cycle” Experiment.

The researcher took the second question directly out of the Copper Cycle Experiment. During the first reaction, brown NO_2 gas forms from the oxidation of metallic copper using concentrated nitric acid. The reaction takes approximately 40 minutes to dissolve a 0.5-gram copper wire (fully formed and not cut into small pieces). The evolves from the reaction, starting as soon as the acid hits the wire until complete dissolution. If a student keeps this reaction outside of the fume hood for the entire duration, the SDS advises that they should seek medical treatment immediately.

2. After standing over a reaction producing a significant amount of brown gas for approximately 40 minutes, you notice that your lab manual says the gas has **acute toxicity**. What is the correct response procedure?
    a. Step outside and get some fresh air
    b. Put the reaction under the fume hood to prevent further inhalation
    c. Go to the health center for treatment*
    d. Step away from the reaction and breathe deeply for 10-15 minutes
    e. Cough to clear the gas from your lungs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Acute Toxicity
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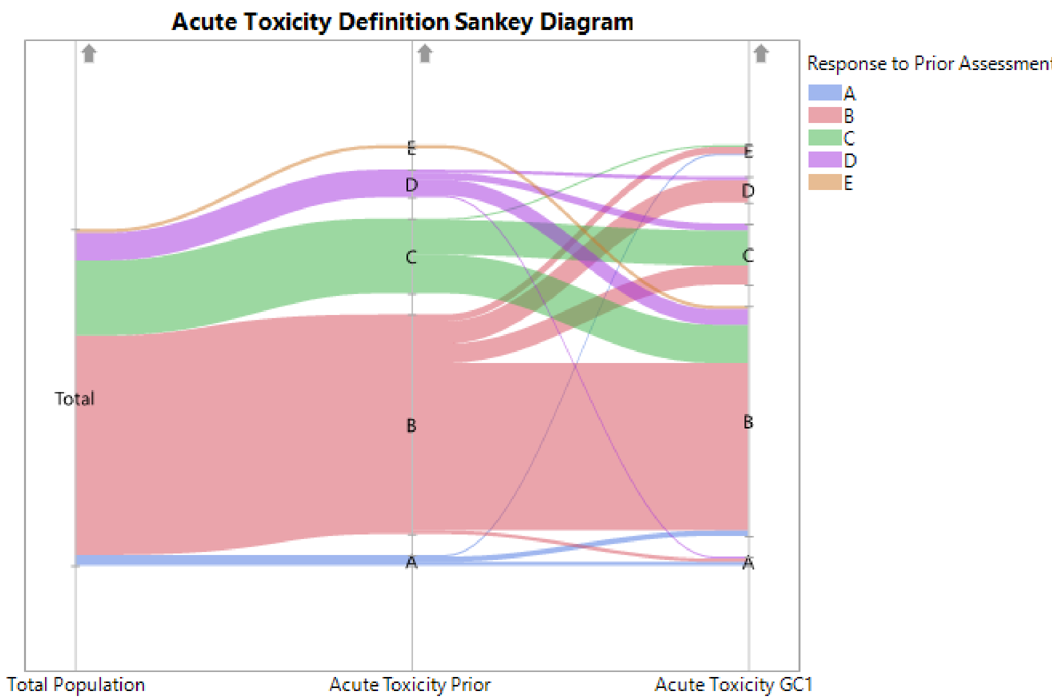
Acute Toxicity Definition Sankey Diagram
Response to Prior Assessment
A
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Total Population
Acute Toxicity Prior
Acute Toxicity GC1

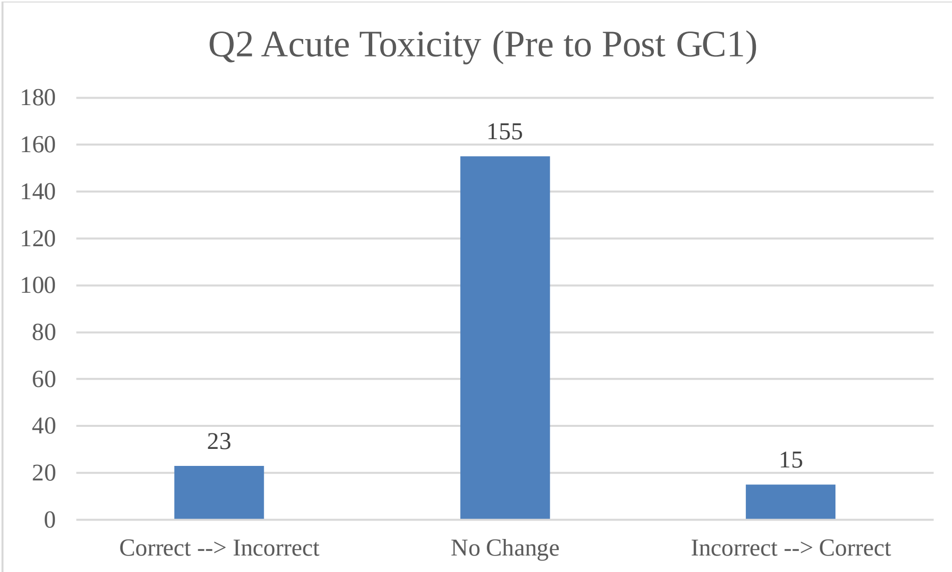

Figure 27 Q2 Acute Toxicity Pre-Post Analysis

The prior knowledge and post-GC1 Chi-Squared mosaic columns look very similar, a result which agrees with the pre-post change plot where the number of students changing their responses to the question was meager. The majority of students taking both assessments decided that the best course of action was to place the reaction under the fume hood to prevent further inhalation. There are a few possible explanations for the response. The first is that students are taking the next step to prevent other students from experiencing harm.. The other explanation is one that agrees with the interview data. In the interview, the students had a hard time defining acute toxicity because they related the term to an acute angle. Instructors taught the students that an acute angle is small and an obtuse angle is large, so they equated acute toxicity to small (harmless) toxicity.

In future adaptations of the assessment, the researcher may need to remove the fume hood response as an option or change the wording to clarify the meaning. A possible way to change the response would be to say, “Place the reaction under the fume hood until the gas no longer forms.” The researcher could also change the correct response to, “Place the reaction under the fume hood and seek medical attention.” to separate the students who do not know the true meaning of the term acute.

The third question in the assessment involves the student knowing what to do if their lab partner had splashed chemicals into their eyes. The researcher felt this was an area that students did not cover in response to the eyewash procedure question. Typically, students responded how they would handle themselves if they got chemicals in their eyes and did not mention needing help from another person. The students also felt they only needed a lab partner to assist in finishing lab reports or understanding the math. According to the ACS guidelines, lab partners are responsible for helping students when they splash chemicals in their eyes. They also stress the buddy system in the lab, to prevent an incident occurring that the student cannot inform the TA.

3. Your lab partner, Melody, has her goggles on her forehead and is leaning over your reaction beaker while it heats up on a hot plate. Suddenly, the solution boils and splashes into Melody’s eye. What should you do next to help Melody?
    a. Go immediately to the TA for help
    b. Check your procedure for warnings about the reagents
    c. Wipe the excess reagents off her eyes with a paper towel
    d. Get a cold compress from the first-aid kit
    e. Lead her to the eyewash station*


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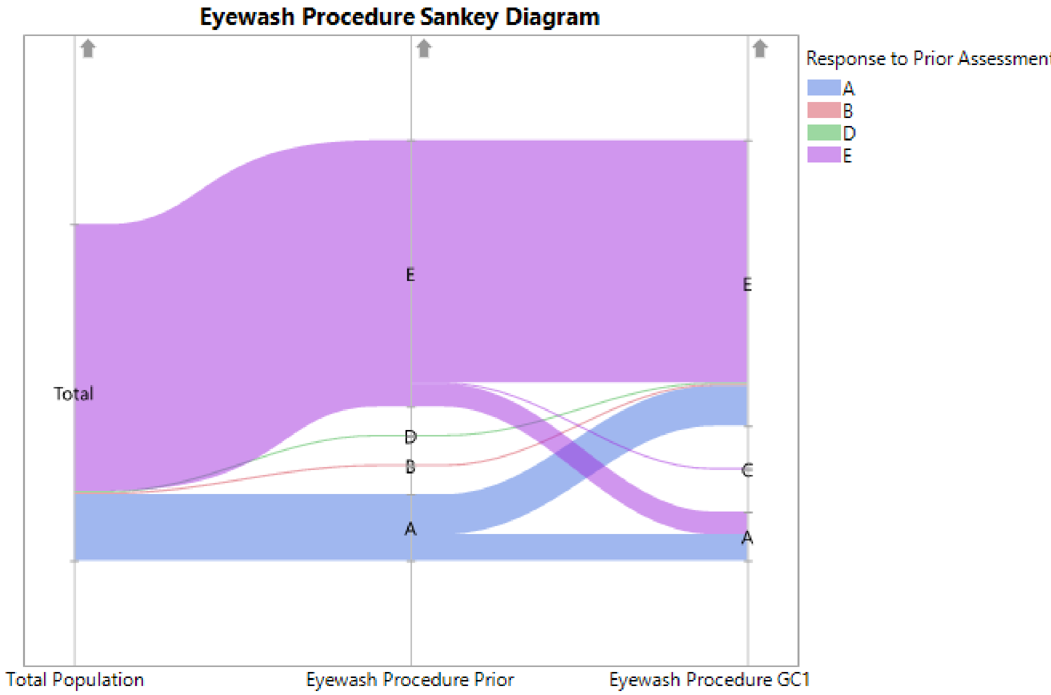
Eyewash Procedure Sankey Diagram
Response to Prior Assessment
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Eyewash Procedure Prior
Eyewash Procedure GC1

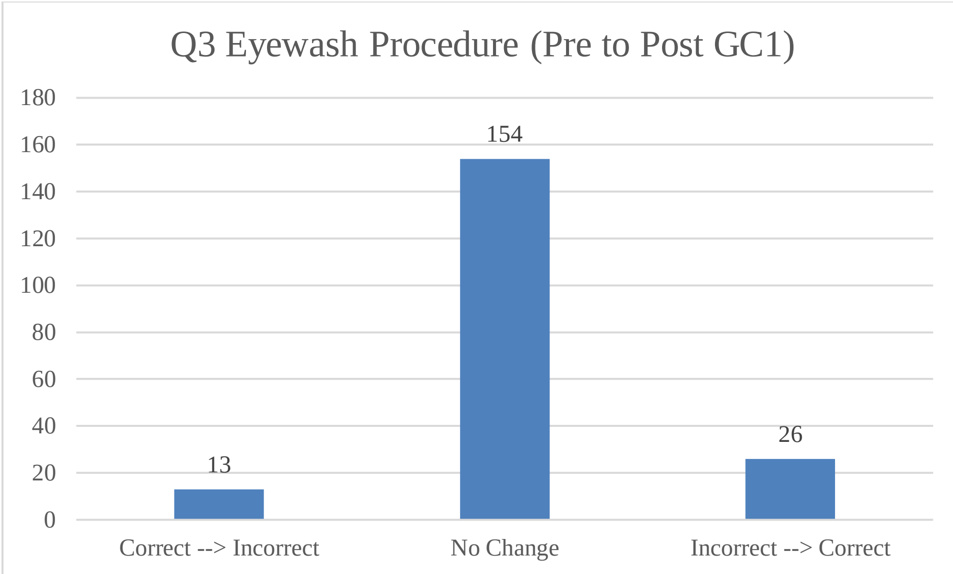


Figure 28 Q3 Eyewash Procedure Pre-Post Analysis

The responses to Question 3 split between answers A and E where E held the majority before and after GC1. Responding that the first step would be to tell the TA agrees with the interview data where the students believed the TA should be informed immediately of all issues. However, from the question about the eyewash station, the students also answered that they would immediately move to the eyewash station and then tell the TA. The overwhelming response from the assessment agrees with the latter explanation that the lab partner's eyes should come first. Taking GC1 lab did not have a significant effect on the emergency response.

The researcher based the fourth question on ACS guideline recommendation that students in general chemistry understand that lab coordinators design experiments to minimize the volume and concentration of hazardous chemicals. The practice, commonly described as, "The dose makes the poison," minimizes risks by preventing students from working with materials that could cause permanent damage. To answer the question correctly, the student needs to minimize both the concentration and the volume of sulfuric acid:

4. Dr. Smith is coming up with new experiments for the general chemistry lab. Below are his options for a reagent in a synthesis. Which option would be the safest for general chemistry students to use?

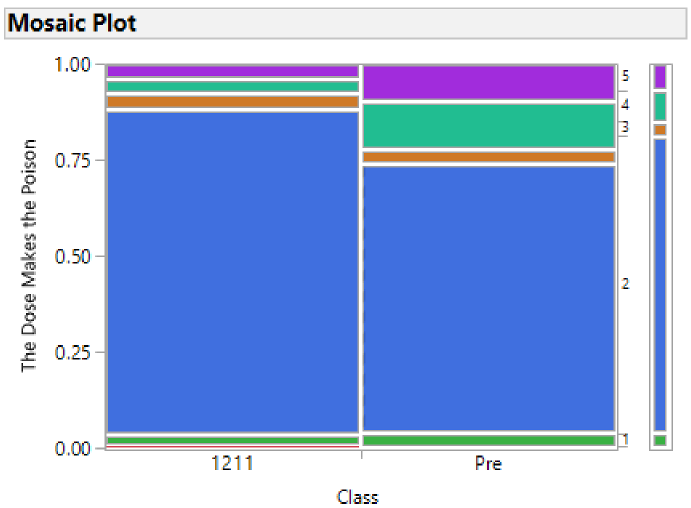
   a. 10 mL of 16 M H_2SO_4

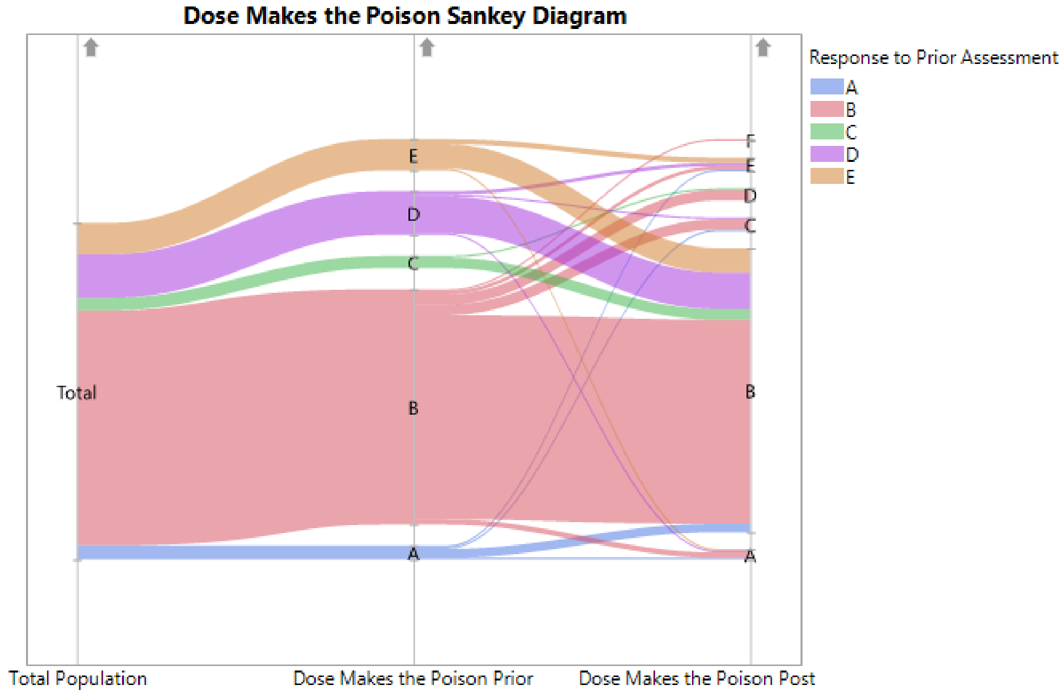
   b. 5 mL of 2 M H_2SO_4*

   c. 20 mL of 8 M H_2SO_4

   d. 3 mL of 10 M H_2SO_4

   e. 40 mL of 4 M H_2SO_4





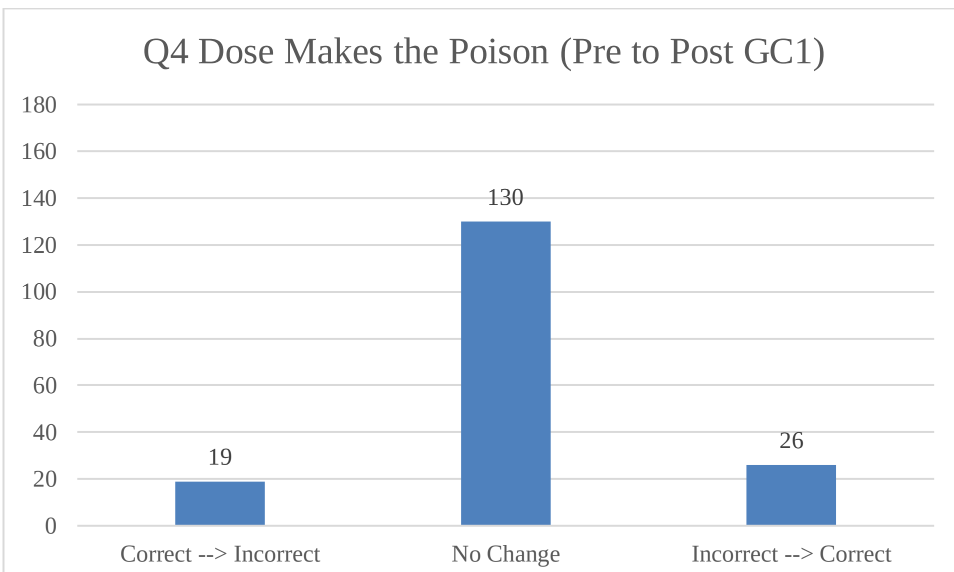
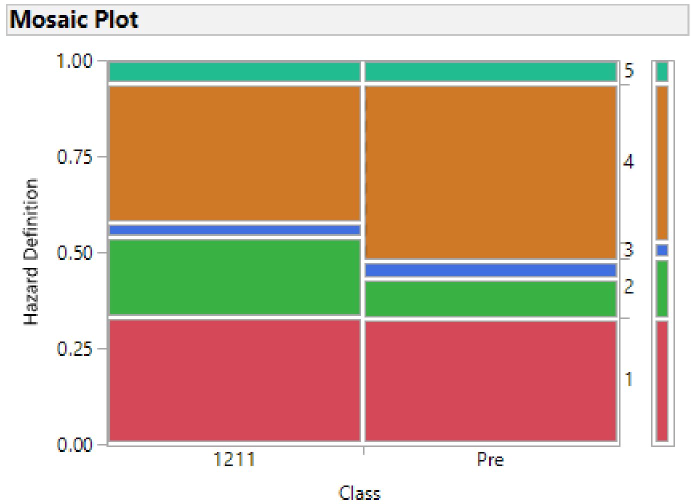


Figure 29 Q4 Dose Makes the Poison Pre-Post Analysis

A majority of students were able to minimize both the concentration and the volume of sulfuric acid before and after taking GC1 lab. The result disagrees with the interview data where students indicated that the meaning of, "The dose makes the poison" was that you needed to minimize the volume of hazardous chemicals. Not mentioning the concentration in the interview agrees with the procedures in GC1, which minimize volume but not concentration. However, when the researcher removed the phrase in the assessment the students could recognize even before taking GC1 that the laboratory coordinator needs to minimize both concentration and volume if at all possible.

ACS guidelines also specified that students should understand the difference between a hazard and a risk after finishing general chemistry laboratory. While the semantics may seem arbitrary to the casual observer, the idea is that students should be able to recognize when a situation is inherently dangerous and when they could make a situation safer. In this case, the question is asking about the former, or hazards, and the incorrect responses all represent risks.

5. Which of the following would be considered a **hazard**?
   a. A reagent that is labeled as corrosive*
   b. Picking up broken glass with your hands
   c. Pouring an acid from a large reagent bottle into a 10-mL graduated cylinder
   d. Leaning over a flame with long hair
   e. Pouring a solution while looking at your phone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Hazard Definition
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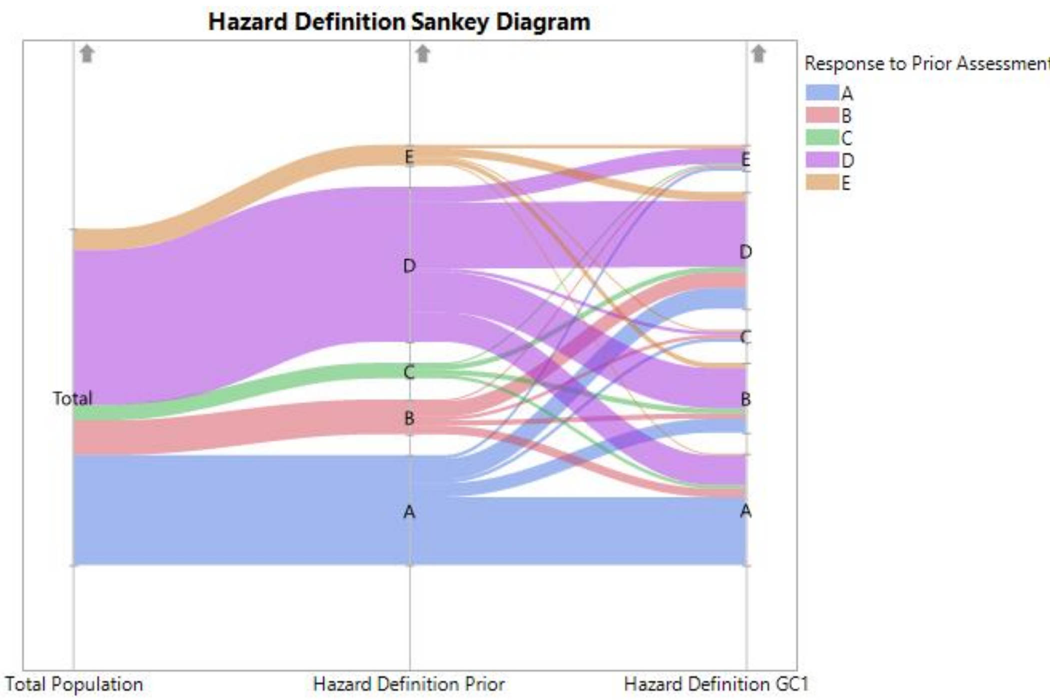
Hazard Definition Sankey Diagram
Response to Prior Assessment
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Total Population
Hazard Definition Prior
Hazard Definition GC1

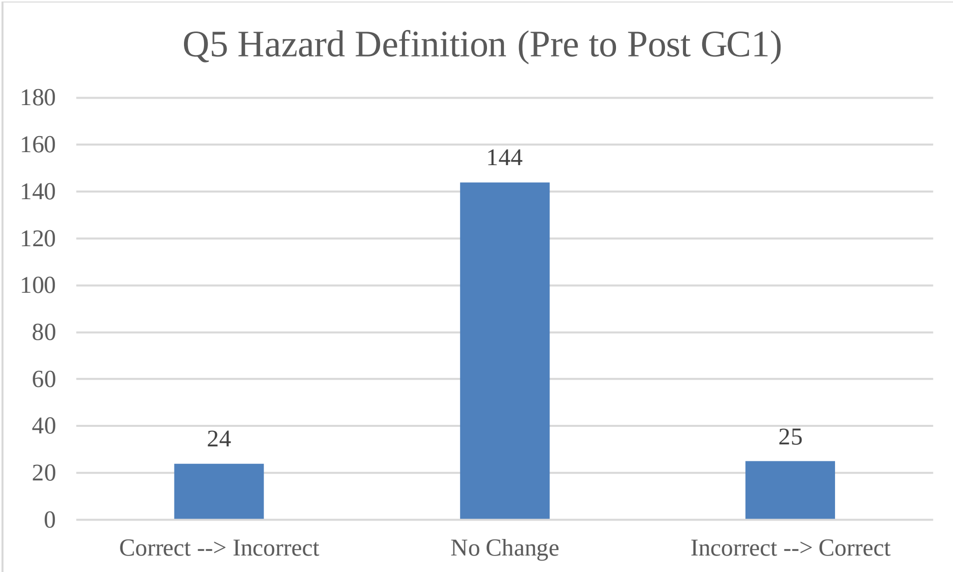
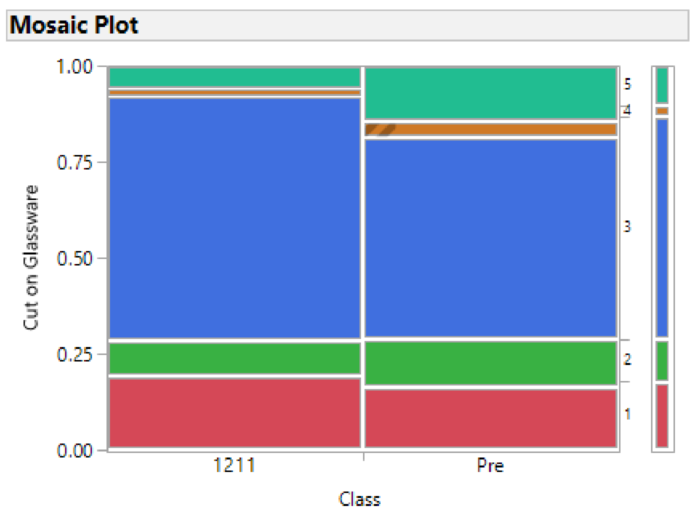


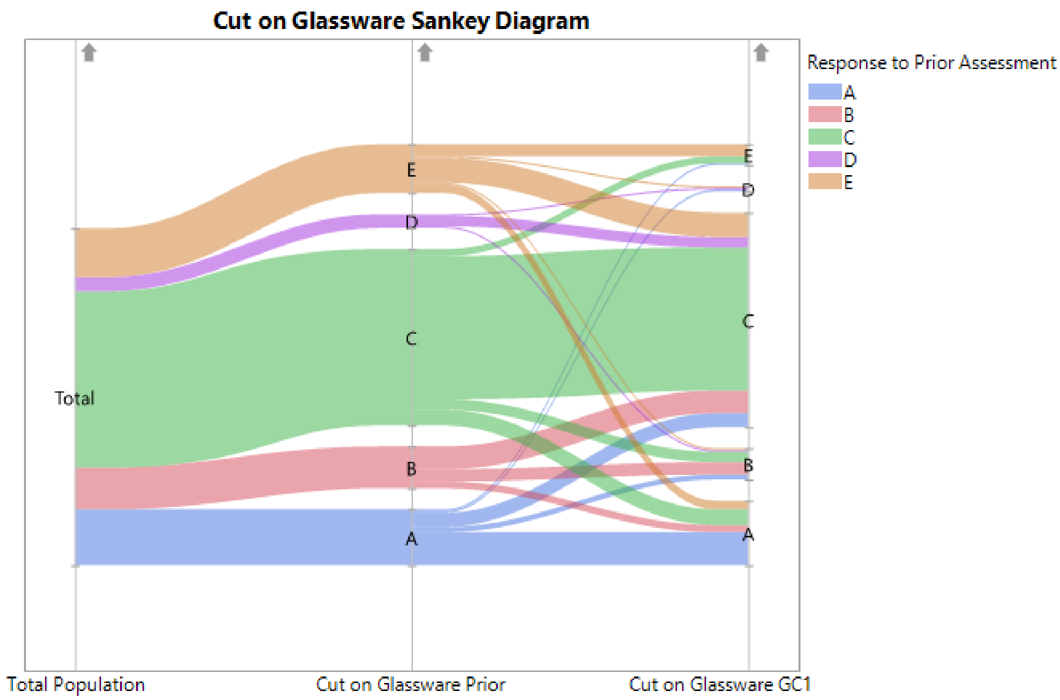
Figure 30 Q5 Hazard Definition Pre-Post Analysis

During the interviews, students struggled with separating examples of hazards and risks. When the researcher would ask the student for the differences between the terms, the students gave the standard response that risks were things a person could change and hazards were things they could not. However, when the researcher asked the student to name examples of hazards, the students named more risks instead. The results of the assessment agree with the interview responses. Students either understood what a hazard was before GC1 and sustained that knowledge or answered both assessments with an example of risk. The teaching assistants could mitigate the issue in the future by referring to chemicals by their hazards, such as corrosion hazard or inhalation hazard so that students recognize that they need to minimize risk around these materials.

In Question 6, the researcher eliminated the option for TA assistance that the participants had in question one. Since bleeding from a cut on glassware is a situation where they would not have time to find a TA, the researcher wanted to know what steps the students would take to tend to the wound. According to ACS guidelines, the student should first rinse the cut from glassware with water to prevent any chemicals from entering the bloodstream. They should then go to the first-kit and apply the appropriate disinfectant and bandage. If the wound is too severe, the student should seek medical attention.

6. You are swirling a solution containing a corrosive reagent when you accidentally hit the beaker on the benchtop and cut your hand on the broken glass. What should you do next?
    a. Go to the first-aid kit
    b. Grab a paper towel and begin to apply pressure
    c. Rinse the cut with water*
    d. Grab a paper towel and clean off the wound
    e. Go straight to the health center





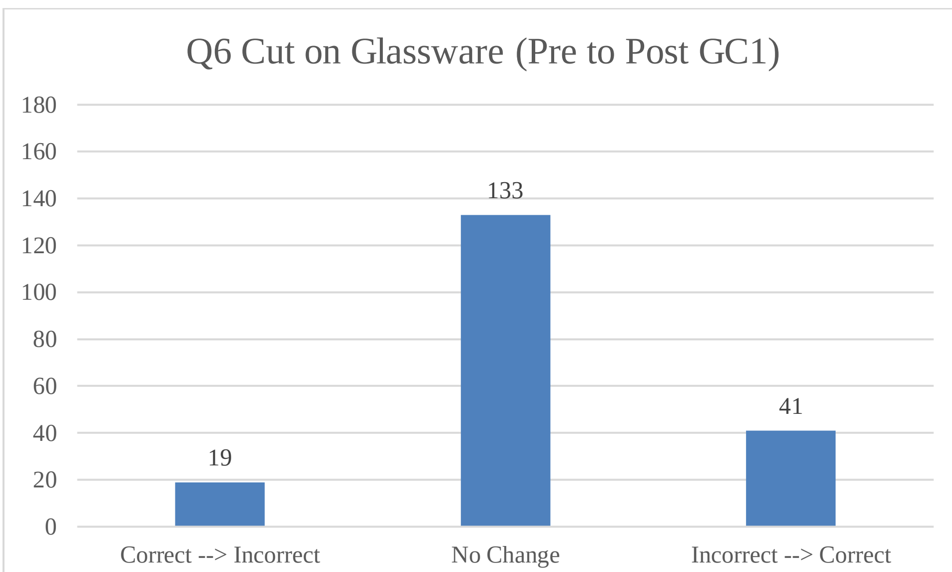


Figure 31 Q6 Cut on Glassware Pre-Post Analysis

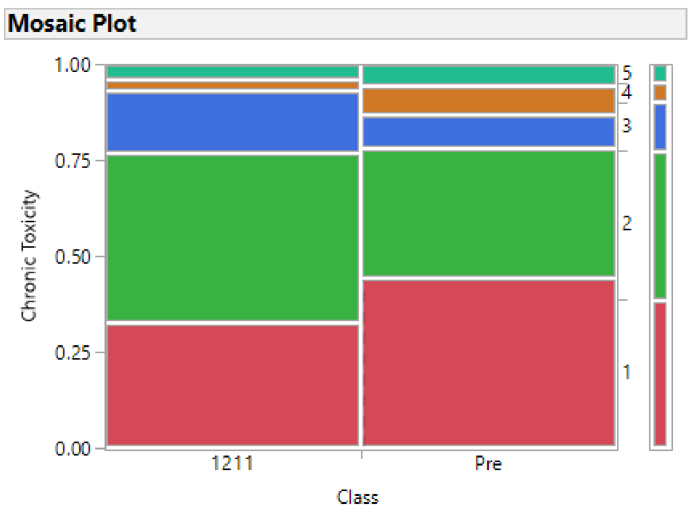
During the interviews, a majority of the students responded to "the cut on glassware" with a response that their TA had not told them what to do if they cut their hand on glassware. When the researcher asked the students what they would do, they said they would find the first-aid kit and apply antiseptic and a bandage. In the assessment, the researcher gave the students the option of rinsing the wound with water, and a majority chose this response before and after taking GC1. The problem is that in the TA interviews, a majority of TAs did not indicate that they would rinse a cut from glassware with water first. If they do not inform their students that rinsing is an option, it could prevent students from knowing to do that at the moment.

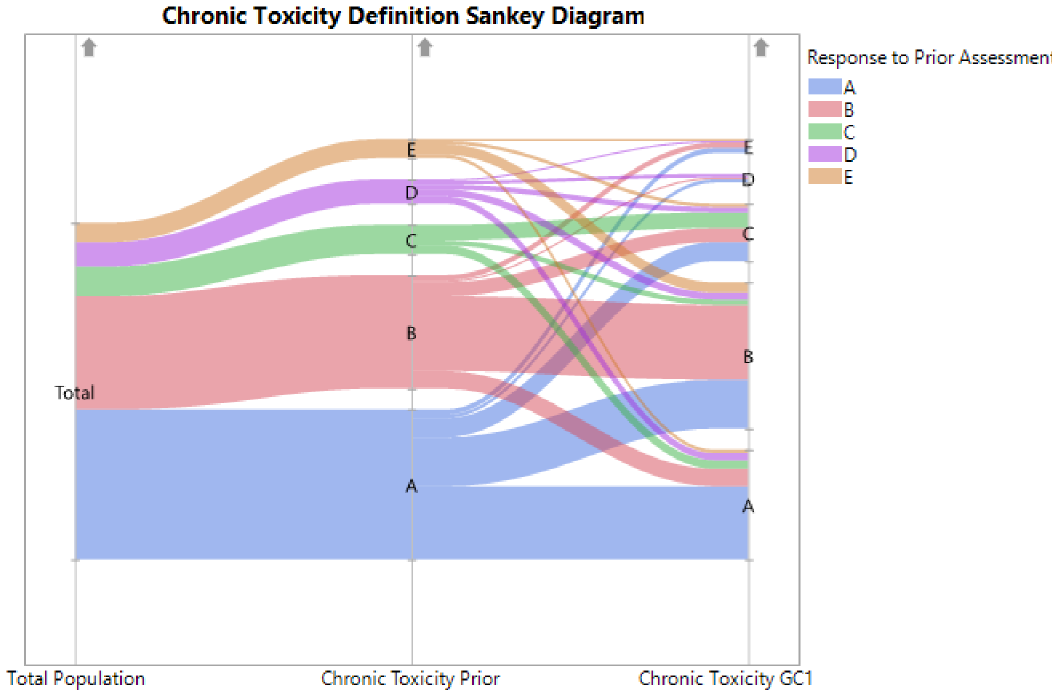
Question7 on the assessment was an internal validation question. The validation question allows the researcher to remove any participants who are clicking on the assessment without reading the questions or taking the process seriously. Essentially, the researcher informs the student that the question is validation and the reason for the question is to make sure they are paying attention. The researcher then tells the student which option to choose from an A-E list. If the student does not choose the response the researcher told them to choose then the researcher removes the student's responses from the analysis. While the next question says it is question seven, it was actually Question 8 in the assessment.

Chronic toxicity is not quite as crucial in a general chemistry laboratory as it would be in an industrial setting. Therefore, even in a lab that lists all the chemical hazards in the laboratory manual, the TAs and students may not emphasize the hazards of a chronically toxic material as seriously as an acutely toxic material. However, ACS guidelines require that students understand the distinction between the two types. Chronic toxicity implies that the individual has worked around the hazard for weeks or months at a time, causing long-term health effects. Students working with these types of materials would only experience the hazard one time in one week for a maximum of three hours.

The student, then, would only need to take steps to minimize exposure but would not require medical care for short-term exposure.

7. When leaning across the lab bench, you accidently inhale fumes from a solvent that has **chronic toxicity**. What should you do next?
   a. Go to the health center for treatment
   b. Put the solvent in the fume hood to prevent further inhalation*
   c. Step away from the reaction and breathe deeply for 10-15 minutes
   d. Cough to clear the fumes from your lungs
   e. Step outside and get some fresh air





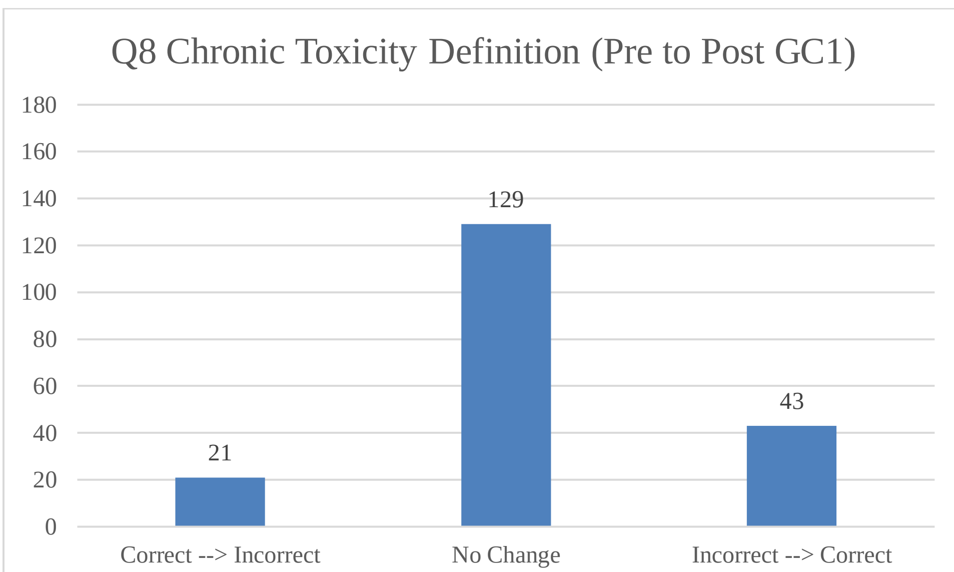


Figure 32 Chronic Toxicity Definition Pre-Post Analysis

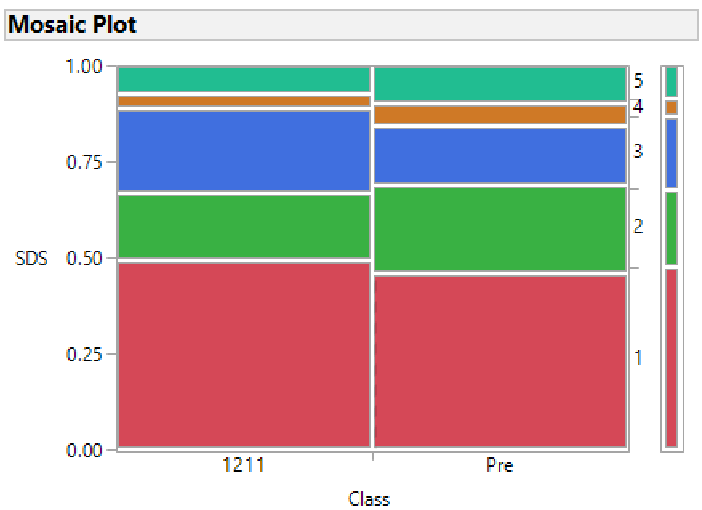
Like the acute toxicity question, students had difficulty understanding the meaning of the term because of its colloquial meaning. The interview data confirms the result. Students equated the word chronic with things like cancer, pain, and respiratory issues. Therefore, they likely assumed that the word chronic meant that a short-term exposure led to long-term health effects. Even after a semester of GC1, approximately 50% of students err on the side of caution and respond with procedures that address a health concern. Based on the laboratory manual, there are no hazard warnings about chronically toxic materials and the observations did not have any TAs mentioning chronic effects. Therefore, the most likely explanation is that students are using the colloquial definition of chronic as they did in the interview results.

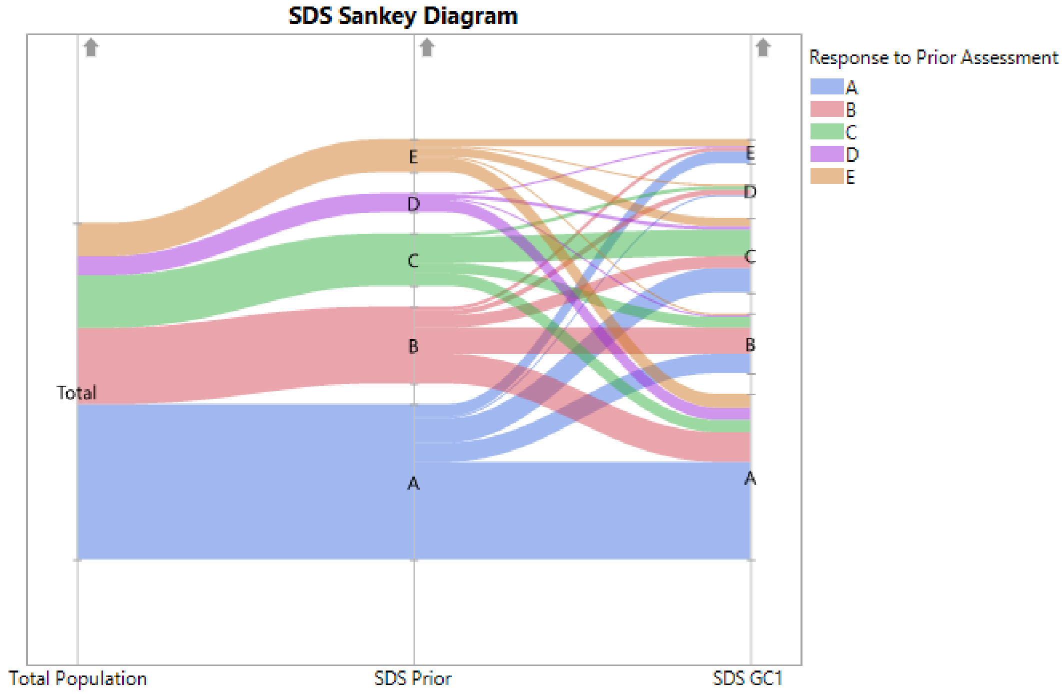
A safety data sheet has many uses in both the general chemistry laboratory and in research and industrial laboratories. In this work, we used safety data sheets to identify each of the chemical hazards in the observation experiments. Research laboratories receive a safety data sheet with every chemical that they order and it contains a standard list of information:

1. Chemical Product and Company Identification
2. Composition and Information on Ingredients
3. Hazards Identification
4. First-Aid Measures
5. Fire and Explosion Data
6. Accidental Release Measures
7. Handling and Storage
8. Exposure Controls/Personal Protection
9. Physical and Chemical Properties
10. Stability and Reactivity Data
11. Toxicological Information
12. Ecological Information
13. Disposal Considerations
14. Transport Information
15. Other Regulatory Information

A general chemistry student could use safety data sheets to look up the hazards of a reagent, what chemicals they should not mix with the reagent, and, if they get hurt, the safety data sheet tells the doctor how to treat the injury. It is no wonder that ACS guidelines recommend that students familiarize themselves with using safety data sheets during experiments. In the next question, the students must respond with the situation where a safety data sheet would be useful. To know how to answer the question the student must know what information a safety data sheet contains.

8. Listed below are several situations which may occur in the lab. Which situation would require the use of a **safety data sheet**?
    a. An accident needs to be reported to the university
    b. A student is about to set up a new piece of equipment
    c. A reagent spilled onto a student's clothes*
    d. Glassware was broken in the sink
    e. Several students were not wearing their safety goggles





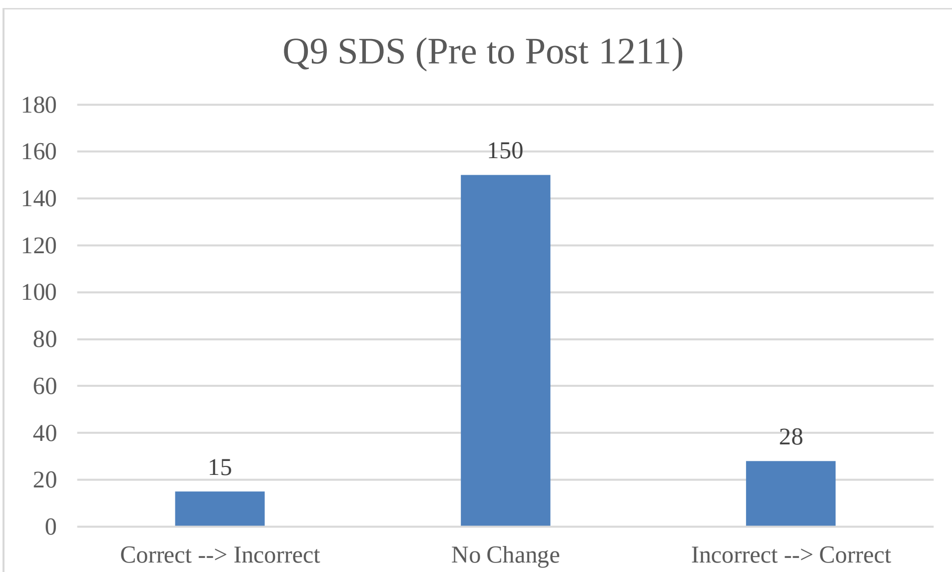


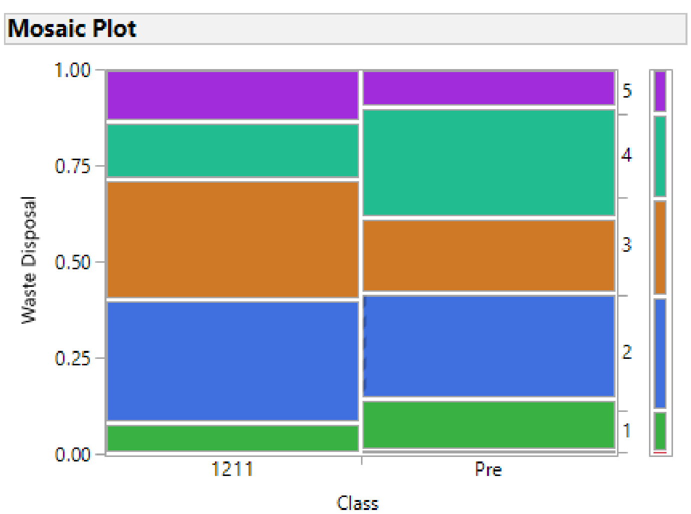
Figure 33 Q9 SDS Pre-Post Analysis

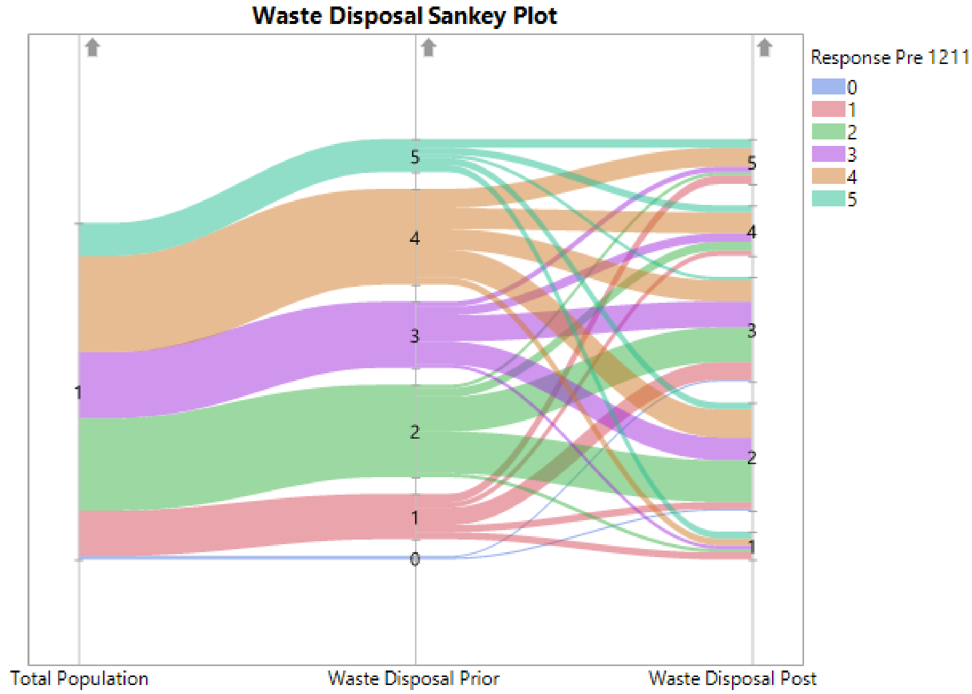
In the interview results, there were only two students who accurately knew what a safety data sheet is and what it contains. Of these two students, one stated that their TA used the binder of safety data sheets frequently to look up the hazards associated with the reagents and products. The rest of the students in the interview believed that labs used safety data sheets to track the number of lab accidents or to report laboratory accidents to the university. The students even went so far as to say that they were only answering that way because that is what the term sounds like it means. Again, the students had to answer using a colloquial definition when they did not know the real meaning.

The assessment results appear to agree with the interview results. Approximately half of the students answered that an individual would use a safety data sheet to report an accident to the university. The response that does not agree with the interview data is that an individual uses a safety data sheet when setting up new equipment, a choice selected by twenty-five percent of the students answering. The response also does not agree with the laboratory manual or the TA instruction. There is no reference to using a specific sheet to set up a new piece of equipment. The students may have just chosen the response because it sounded like a reasonable item to have in that scenario. Future iterations of the interview may ask the students what things they would need if they were to set up a new piece of equipment. Responses to the question may indicate that students require a sheet with a specific list of instructions.

The ACS guidelines state that the only items that should go down the drain in a general chemistry laboratory are food-based items or dilute solutions of salts. If students use a solid reagent or produce a solid product, the lab must provide a separate solid waste container. The guidelines and the safety video endorsed by this laboratory suggest that students should throw all gloves, weigh paper, filter paper, and other contaminated items into a hazardous waste bucket. Question 10 provides the researcher with information on how taking a general chemistry lab that does not follow these specifications in most experiments affects students' judgment on how to dispose of waste materials.

9. In the pre-lab lecture, your TA tells you that the experiment produces a dilute solution of NaCl waste, solid copper waste, and aqueous HCl waste. You will also be measuring out a corrosive material using weigh boats. What is the proper disposal method of each of these waste materials?
    a. NaCl(aq) and HCl(aq) in liquid waste, copper and weigh boats in solid waste
    b. NaCl(aq) down drain, HCl(aq) in liquid waste, copper in solid waste, weigh boats in material waste*
    c. NaCl(aq) down drain, HCl (aq) in liquid waste, copper in solid waste, weigh boats in trash can
    d. NaCl(aq) and HCl(aq) in liquid waste, copper in solid waste, weigh boats in material waste
    e. NaCl(aq) and HCl(aq) in liquid waste, copper in solid waste, weigh boats in trash can





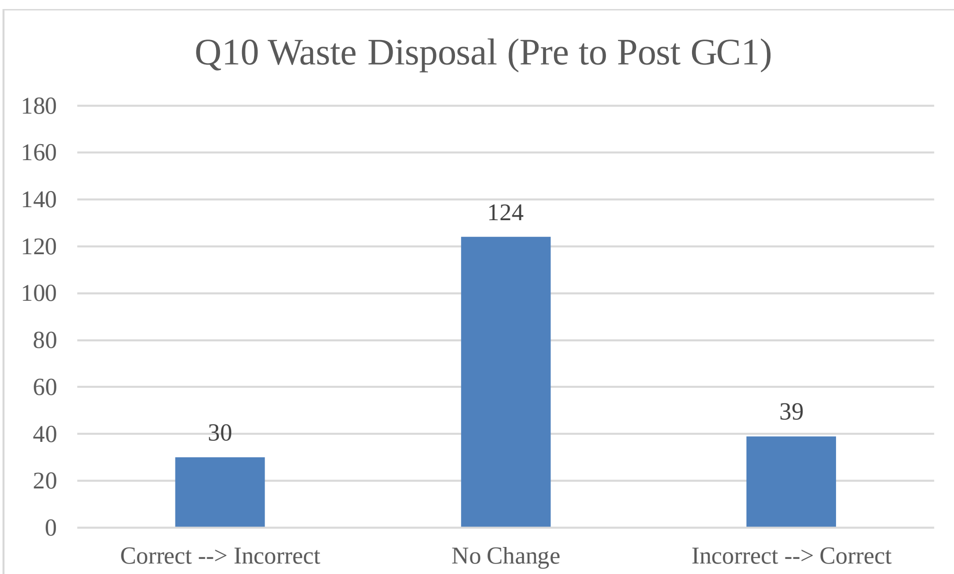


Figure 34 Q10 Waste Disposal Pre-Post Analysis

As stated previously, general chemistry laboratories at this institution do not require students to dispose of weigh paper and weigh boats in material waste containers. In the assessment, students who had never taken GC1 evenly split among the five options. After taking GC1, twenty-five percent of students chose the correct answer, and another twenty-five percent chose option C which varies only by putting the weigh boat in the trash. The students are apparently taking notice of the way the laboratory disposes of waste materials.

During the interviews, the students had a hard time differentiating between strength and concentration when it came to acids. When talking about the incredibly dangerous things that could harm them in the laboratory, the students would often cite strong acids. However, if a strong acid is very dilute then the effect is reduced down to a minor irritant. Question 11 asked the students to choose the strong acid, allowing them to choose the option they believed to be strong and forcing a choice between strong and concentrated.

10. Please choose the **strong acid** from the list below.

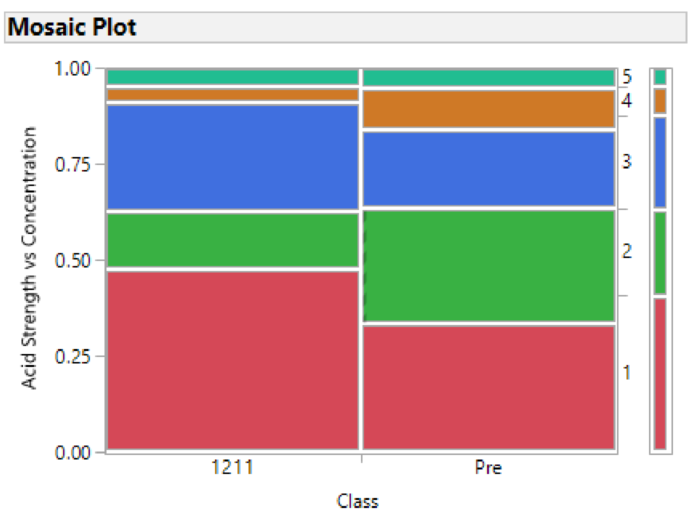
    a. 0.5 M HNO_3*

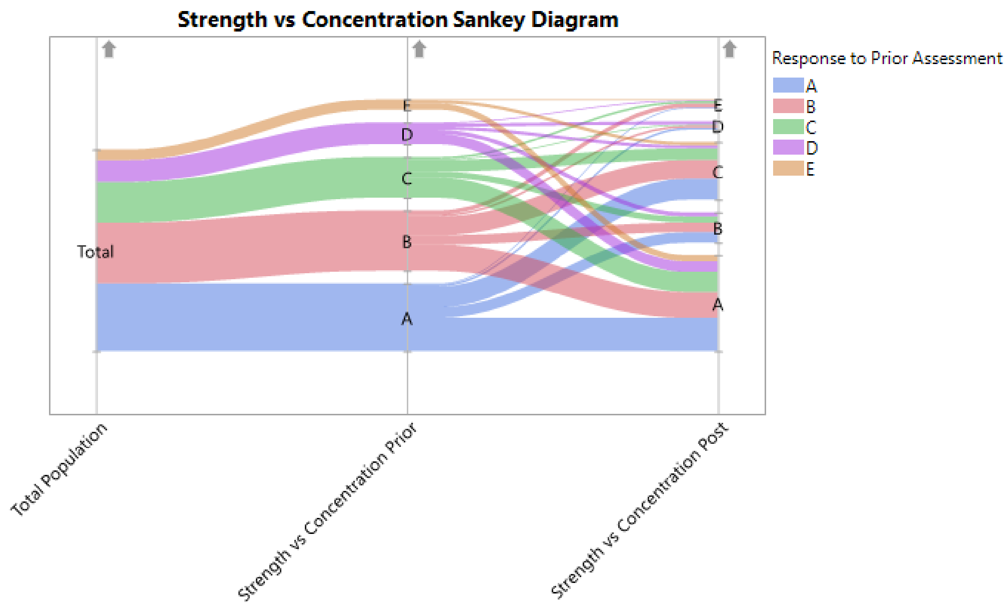
    b. 8 M CH_3COOH

    c. 3 M HF

    d. 6 M NH_3

    e. 2 M KOH





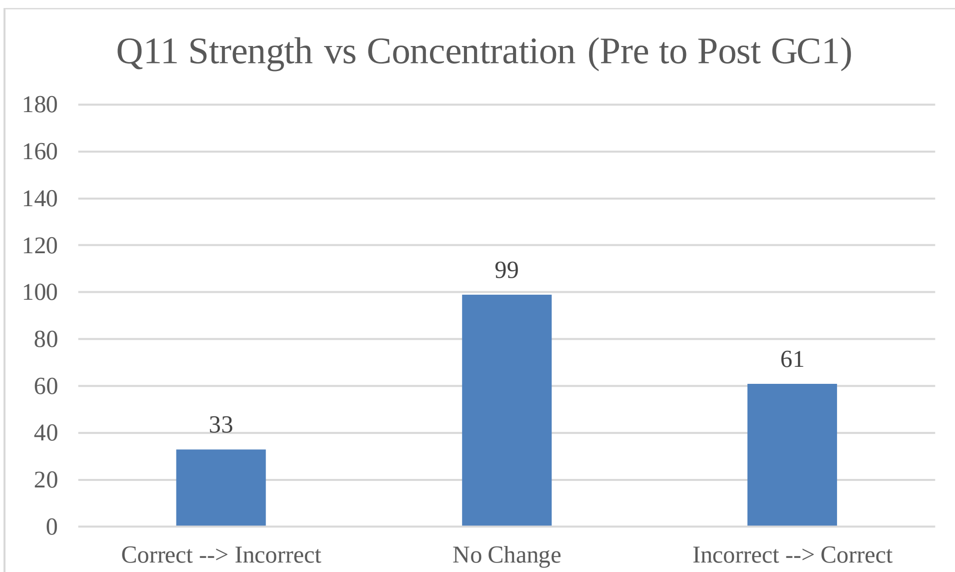


Figure 35 Q11 Strength vs. Concentration Pre-Post Analysis

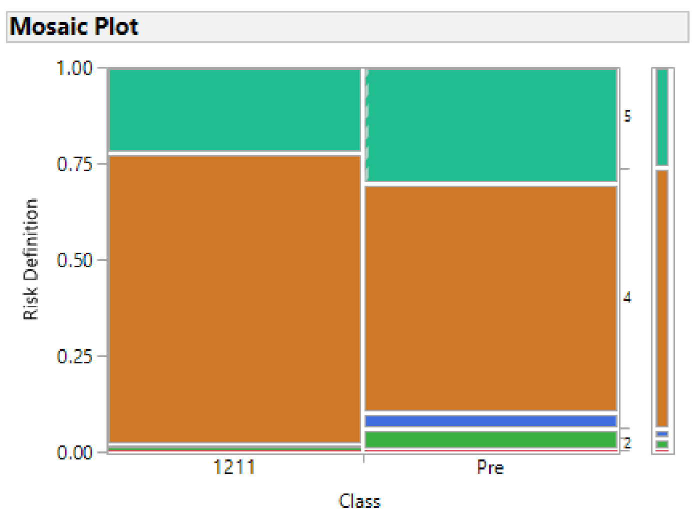
The change in response plot shows that question eleven had the highest change in response to any question on the assessment at about thirty percent. Before taking GC1, students responses agreed with the interview data. Approximately thirty percent of students chose a weak acid (CH_3COOH) as the correct answer because it has the highest concentration of all of the options. Another thirty percent of students knew that nitric acid was a strong acid before taking GC1. After taking GC1, the responses shift to mainly the correct response and option C, another weak acid. It is difficult to differentiate between the students who believe it is the correct answer because it is the most concentrated apparent acid or because they legitimately believe that hydrofluoric acid is a strong acid. Future iterations of the assessment may change option C to another weak acid to separate strong from concentrated assumptions.

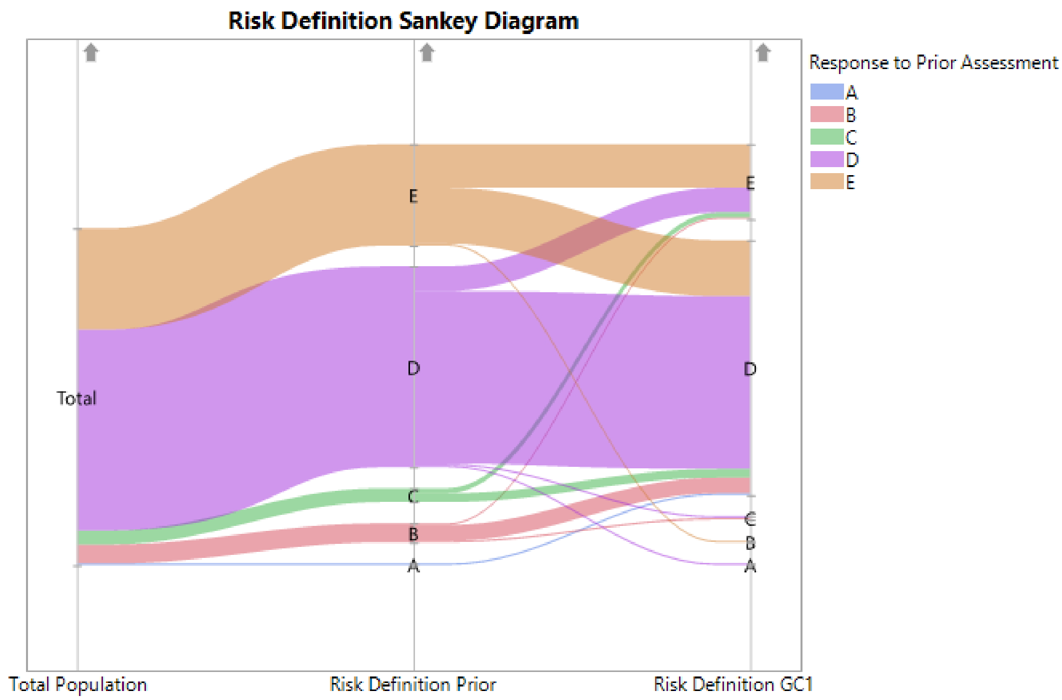
It is also important to note that students must memorize a table of strong and weak acids and bases for the GC1 lecture course. While the shift to correct responses may have some influence from the lecture course, we can say that after taking GC1, fifty percent of students still cannot identify the strong acid in a list. It is also an encouraging sign that a topic that we reinforce in lecture did have some influence over scores on a laboratory assessment. Perhaps mentioning the safety hazards of materials in lecture could aid in students knowing that materials are dangerous before coming into the laboratory.

For Question 5, we discussed how students needed to understand the difference between a hazard and a risk, so they know when they can make a situation safer and when the situation is inherently dangerous. Question 11 probes the students' knowledge on an example of a risk in the laboratory. The correct response is drinking a cup of coffee in the laboratory, and the inspiration for the correct response came from the observations. There were several instances (in the 8 AM observations especially) when students would bring coffee cups into the laboratory, set them on the bench top during pre-laboratory lecture, and forget them when they started the procedure. After the experiment was over, the student would pick up the cup of coffee and start drinking it again. The risk here is that a reagent or product could spill into the coffee cup or touch the lip of the cup while the student is working. The researcher wanted to know if students recognized this as a risk while working in the laboratory.

11. Which of the following is an example of a risk?

    a. A large chemical waste container
    b. Using a burette for a titration
    c. A strong acid in the fume hood
    d. Drinking coffee in the laboratory*
    e. A chemical that is flammable





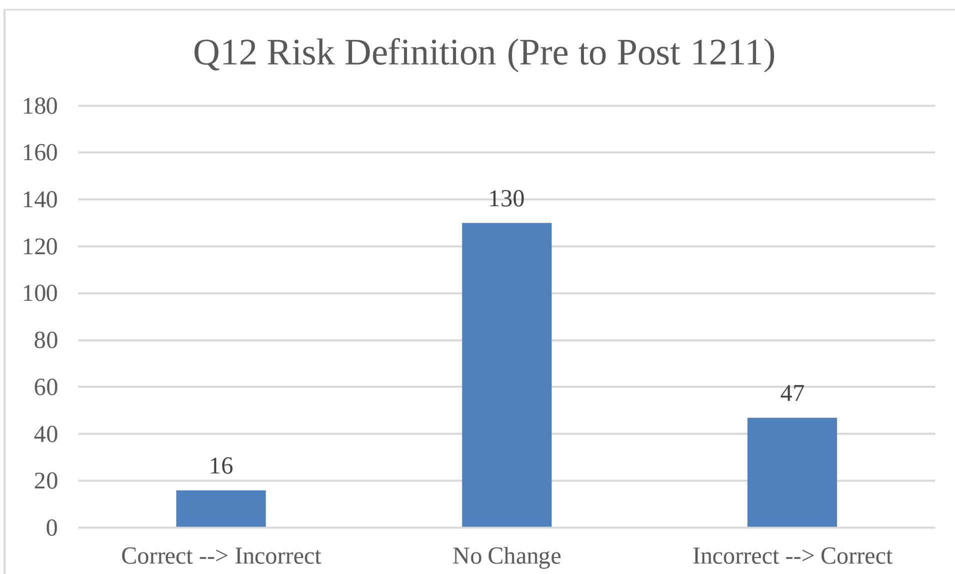


Figure 36 Q12 Risk Definition Pre-Post Analysis

Question 12 demonstrates that sometimes the colloquial definition of a term can help students to find the correct safety response. Even before taking GC1, students recognized that eating or drinking in the laboratory could put an individual at risk for consuming chemicals. After taking GC1, seventy-five percent of students recognized that drinking coffee in the laboratory was a risk while the remaining twenty-five percent believed that working with flammable materials was a risk. The flammable materials response also agrees with the interviews in that student sometimes named hazards as risks when they felt that working with a material like that could put them in unnecessary danger.

Eating and drinking in the laboratory is also something that the TAs did correct during the laboratory observations. The safety video that the students watched after the prior knowledge assessment also pointed out that students should throw away food and drinks before coming into the laboratory. Correction from the TA and remembering the safety video may be the influencing factor in the increase of correct answers.

As we discussed in the previous section, knowing the definition of inhalation and injection hazard was an area that the students had a net decrease of correct responses. The net decrease is not consistent with the full class comparison between prior knowledge and GC1. In the full class comparison, there was no significant difference between prior knowledge and GC1. In that case, the results made sense. Students received no warnings about injection hazards in the GC1 manual, and the TA notes do not include any hazards other than corrosives and inhalation. It would make sense that students would know as much about injection hazards after taking GC1 as they did before. However, a net decrease of correct responses for the same population would mean that students knew the answer before starting the class and changed it after taking the class.

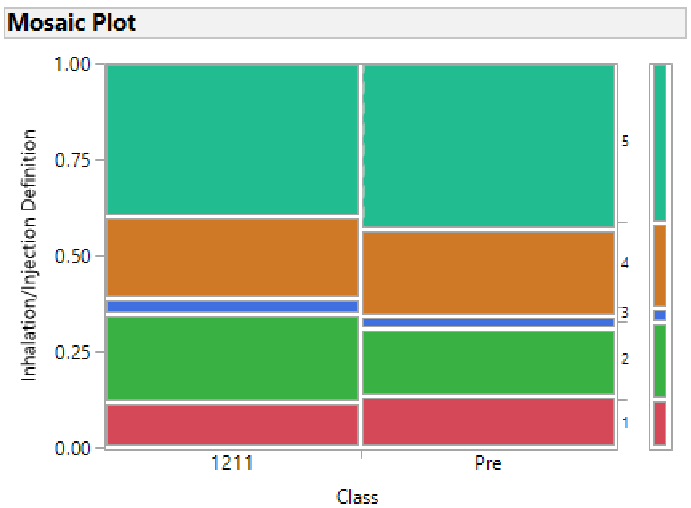
12. Your lab manual tells you that a reagent you’re working with is an **inhalation** and **injection** hazard. What is your best option to stay safe around the chemical?
    a. Keep the reagent away from your face and wear gloves

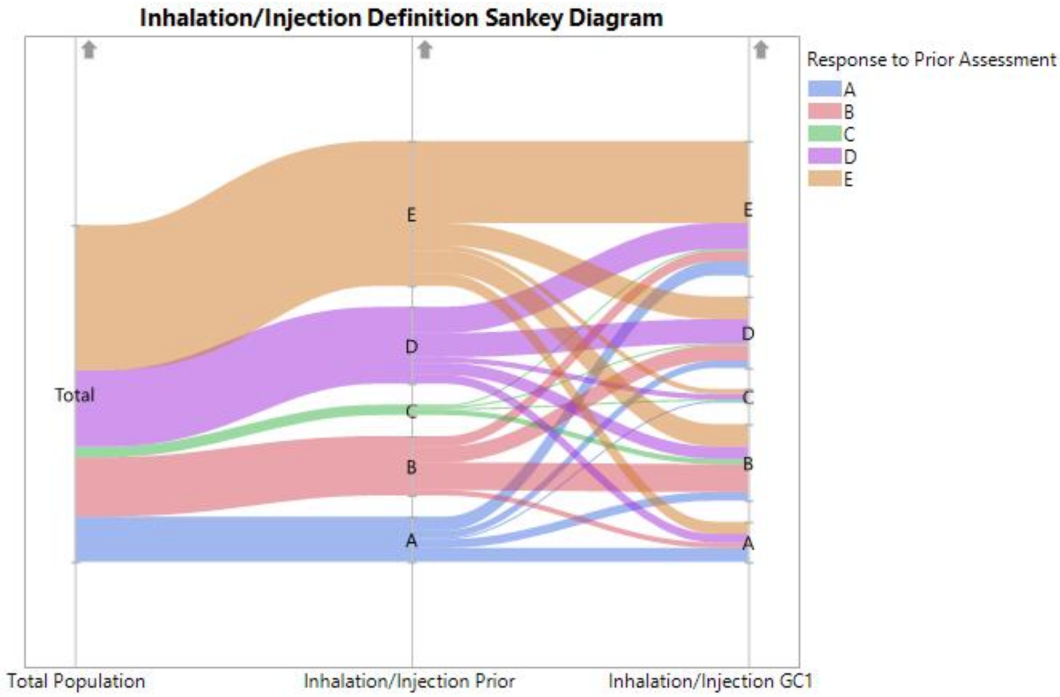
b. Keep the reagent in the fume hood and do not put the reagent into a syringe

c. Only waft the chemical toward your nose and do not eat or drink around the chemical

d. Keep the reagent in the fume hood and keep safety glasses on at all times

e. Keep the reagent in the fume hood and do not expose the reagent to open wounds*





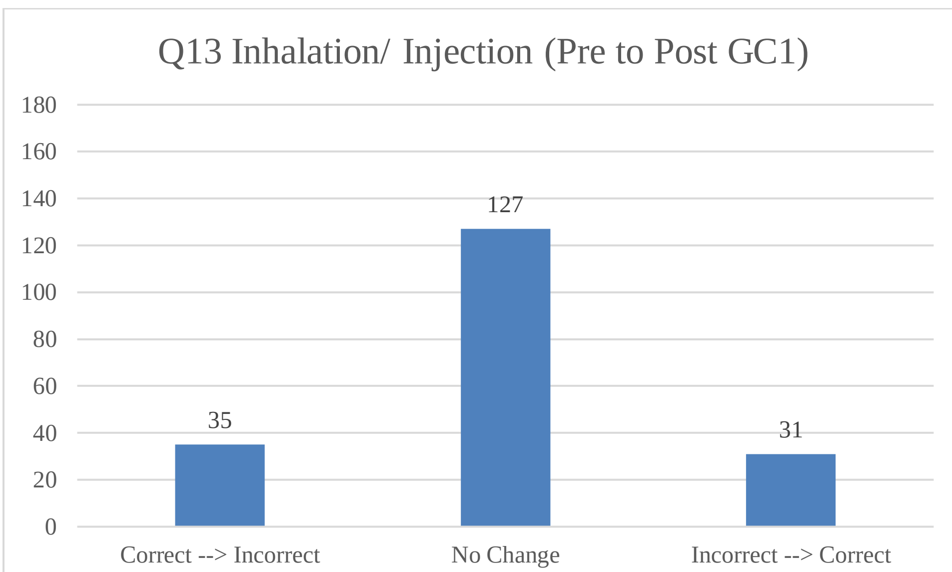


Figure 37 Q13 Inhalation/Injection Pre-Post Analysis

Before starting GC1, most students answered Question 12 with E, the correct response. However, if we look at the Sankey plot of this question, half of these students break off to respond differently after taking GC1. The most substantial portions of the broken-off group switch their answers to either B or D. In the case of B, the students are taking the word injection at its colloquial definition again. The students are familiar with the word injection connected to the word syringe, so it makes sense for them to answer with that response. Option D, on the other hand, is the vaguest response to the term injection hazard. A similar issue occurred when students did not know what hazard terms meant in the interviews. The researcher would ask the student, “How would you keep yourself safe if you were working with this material?” as an example. The student would respond with the essential PPE that the TA had told them to wear when working with any hazardous material. The students may be using this same tactic to tackle a term they do not know on the assessment.

In the manuals for GC1 and GC2, there are very few hazard warnings about solid chemicals. Students in GC1 work with iodine solid (corrosive) in Experiment 2 “The Synthesis and Decomposition of Zinc Iodide”. The lab manual provides the following warning:

> *Solid iodine is highly corrosive. You must add the solid to the test tube and then place it on the balance. Do not add the iodine over the balance. If any iodine gets on the balance pan, it will begin to corrode the metal.*

While the manual mentions that iodine is corrosive, it does not mention that solid iodine is corrosive and an irritant to skin (confirmed in the iodine safety data sheet). We also saw in the TA interviews that the TAs primarily used the manual to prepare for their classes and did not know what to do when a student spills a solid reagent onto their arm. Therefore, the students would be justified in having low scores on Question 14 because it is likely no one has informed them that solid reagents can also be hazardous.

13. While using the balance, you accidentally drop some solid reagents onto your arm. What should you do next?

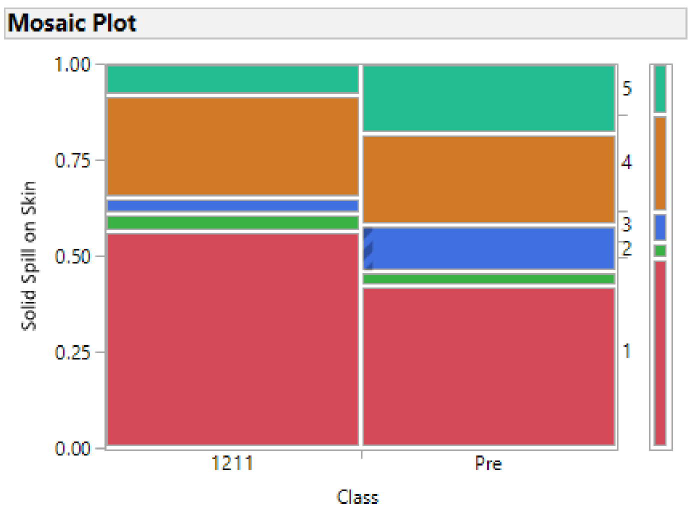
a. Rinse off your arm under the sink for 15-30 minutes (depending on the material)

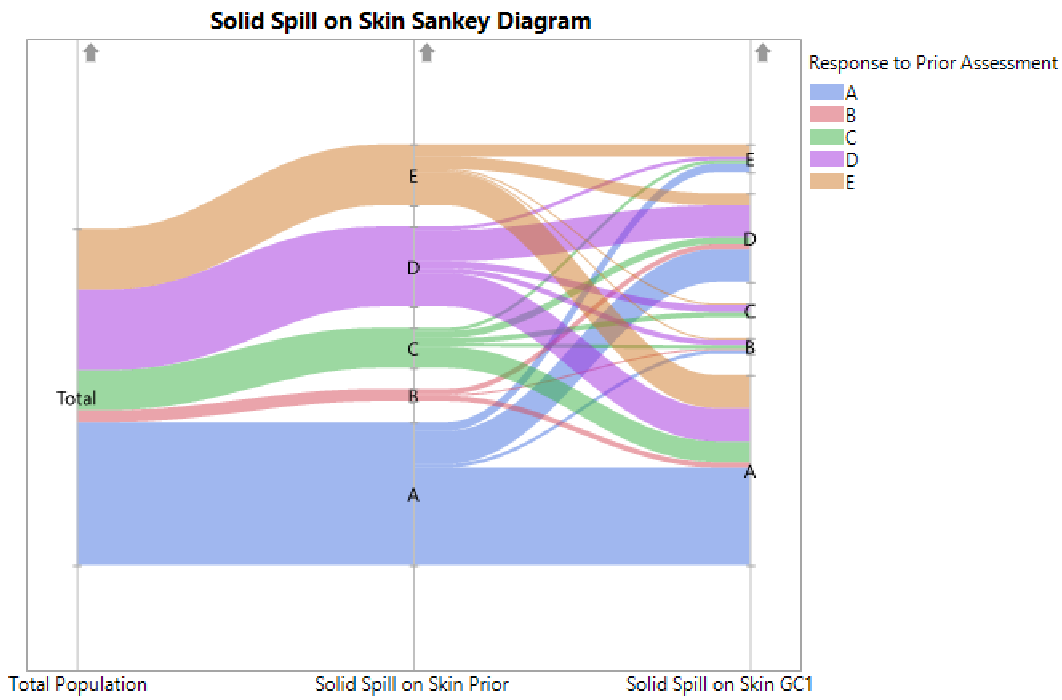
b. Scrape the excess off using a stiff surface (such as a credit card) *

c. Put a small amount of detergent on the solid to dissolve and then rinse the area well

d. Brush the material off and into the trash, rinse your arm well with water

e. Rinse the area with water while scrubbing the solid away with a towel





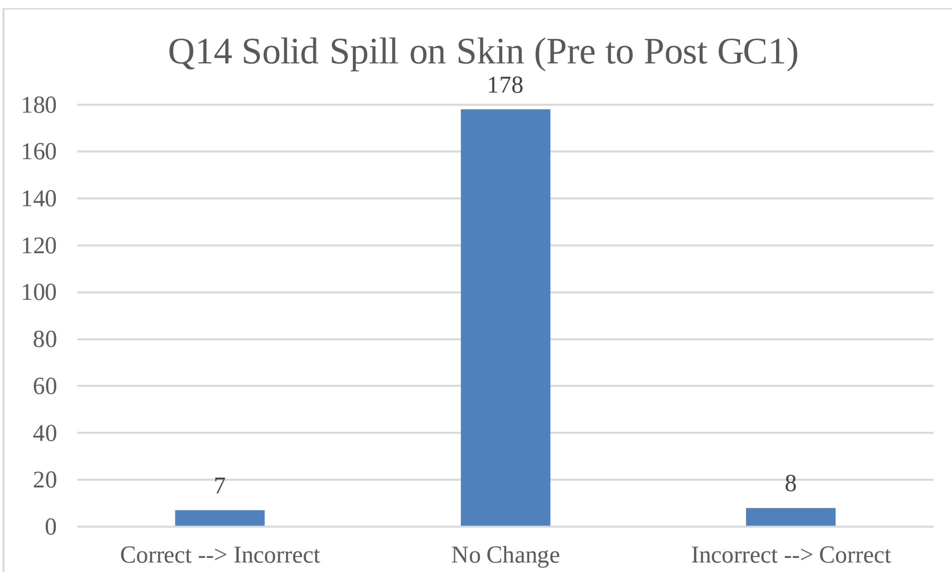


Figure 38 Q14 Solid Spill on Skin Pre-Post Analysis

Upon further review of the answer options, the researcher realizes that the correct response and option D could confuse the students taking the assessment. The ACS guidelines indicate that students should scrape off the material before they do anything else.[41] However, not including that they should scrape the material into the waste container and rinse their arm could lead to students believing that emergency response ended at getting the material off the arm mechanically. The confusion may lead students who realize the solid could be soluble to answer with option D because it has the follow-up procedures. There would be no way to determine if the students who chose option D believed that they should dispose of excess solids in the trash can. Even though we cannot separate these students, we can still look at the responses to note the trend in how students changed their answers after taking GC1.

As we expected from the TA interviews and the hazard warnings in the manual, the smallest portion of students knew what to do if a solid reagent spilled onto their arm. The highest portion of answers after taking GC1 were responses A, and D. Option A is the standard response procedure for treatment of an aqueous chemical on the skin. Many students in the interview told the researcher that the TA told them to follow this procedure (without the time component) whenever any chemical spilled onto their skin. Seven out of eight TAs also gave this response when asked about solid spills on the skin (again without the time component). Option D had the student brush the chemical off into the trash before rinsing with water. The students recognize that they need to get rid of the excess before rinsing with water, but they are ok with that excess going in the trash. The result agrees with the lab manual because there is only one experiment (Experiment 3 "The Copper Cycle") where there is a solid waste container for a reagent.

While ACS guidelines require students to know what necessary personal protective equipment (PPE) that students are required to wear in the laboratory, the researcher took the options directly from the GC1 and GC2 lab manuals. According to the GC1 laboratory manual, the students need to wear lab goggles, close-toed shoes, and long pants in the laboratory. The lab manual explicitly states that leggings are not allowed in the laboratory and that jeans cannot have any holes, rips, or tears. The lab manual does not mention why any of these clothing items are important or how a student could get hurt if they disobeyed the rules. The researcher wanted to know if students could pick the logical reasoning for wearing PPE in the laboratory.

14. Which of the following statements about personal protective equipment is **correct**?

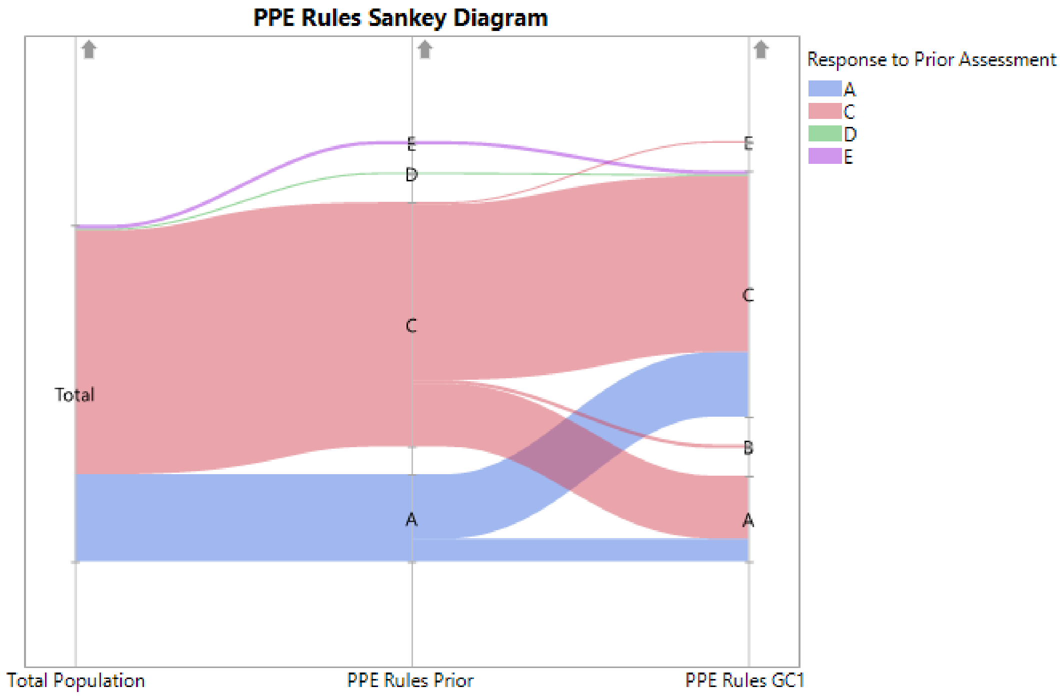
    a. You are required to wear long pants and long sleeves in the lab to limit the amount of exposed skin

    b. Leggings are allowed in general chemistry because the reagents are not concentrated or flammable

    c. Safety glasses are required to protect against chemical splashes and fumes*

    d. Holes in jeans are allowed because a chemical spill on your jeans would require a student to remove all clothing

    e. Tying up long hair is only required when working with open flame



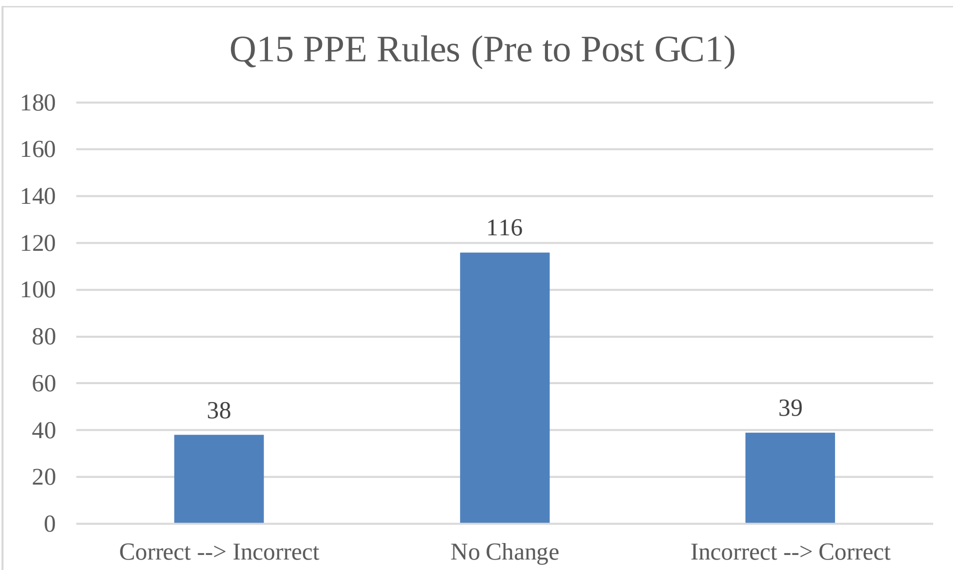


Figure 39 Q15 PPE Rules Pre-Post Analysis

The researcher realized after posting the assessment that the lab manual never explicitly states that students with long hair should tie it back while working. The researcher was going to give the students a pass who responded with option E, but a tiny percentage of the students chose that response before and after GC1. The unexpected shift in responses were the students who chose the correct answer before taking GC1 and changed to option A after GC1. The shift disagrees with the interview data where students were aware that safety goggles prevented splashes and fumes from getting in their eyes. However, after taking GC1 students are now again erring on the side of caution by saying they should cover up their exposed skin to prevent chemical spills. It is also possible that TAs may have required their students to wear long sleeves in the laboratory, but the observation data does not support this.

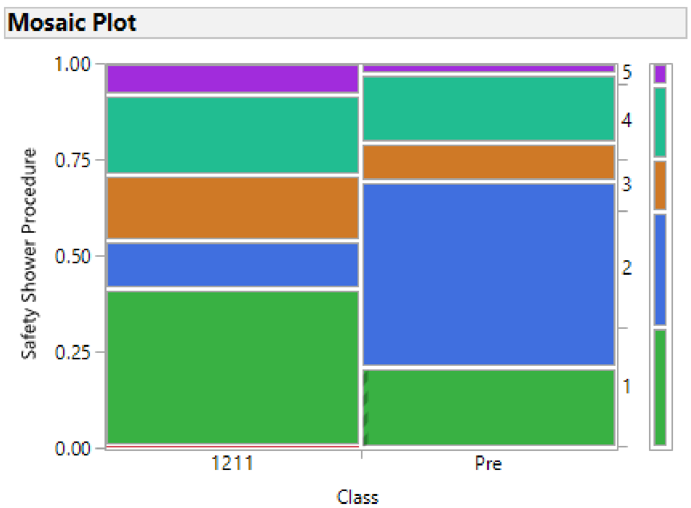
ACS guidelines have a specific order of operations for students who have to use the safety shower. First, the students should go straight to the safety shower and pull the lever to let the water pour over them. As the water rinses them, the student should remove clothing while a TA clears the other people away for modesty. If the student is wearing a sweater or sweatshirt, they should allow another person to cut the clothing off, so they do not get the chemicals on their face trying to remove it as they usually would. The student should let the water wash over them for at least 15 minutes but if pain returns they should return to the shower. The student should then immediately seek medical attention. Any clothes the student was wearing should be washed separately from other clothing or thrown away. In Question 16, the researcher wanted to understand if the students knew all these components and could identify which one the lab does not require.

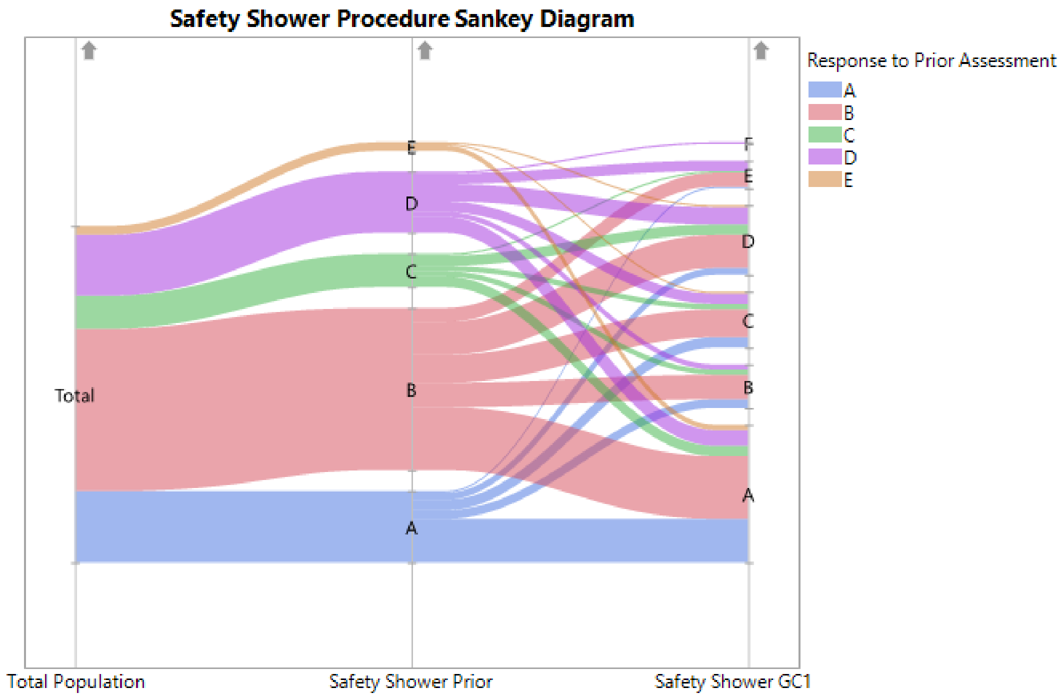
15. Which of the following is NOT a requirement for using the safety shower?

    a. Remove contacts before turning on the water*
    b. Remove all clothing while water is washing over you
    c. Wash any contaminated clothing separately from other clothing or discard it

d. Allow someone else to cut off sweaters or sweatshirts to avoid exposing your face to chemicals

e. Flush the area with water for at least 15 minutes but resume rinsing if pain returns





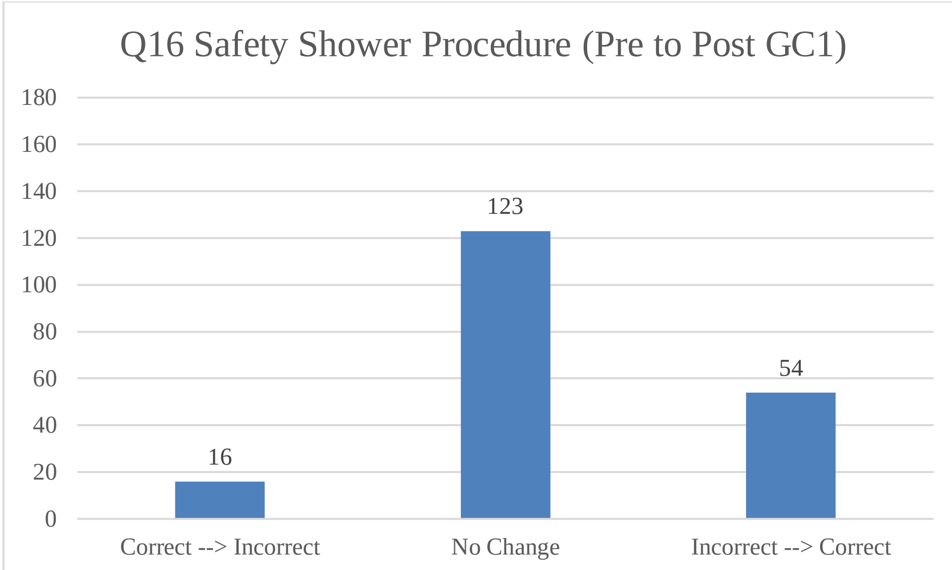


Figure 40 Q16 Safety Shower Procedure Pre-Post Analysis

During the interviews, the researcher asked the students how they would adequately use a safety shower. The students would list several of the steps we mentioned but would invariably leave some out. For instance, they would mention taking their clothes off and turning on the shower but would not mention anything about time or washing clothing separately. In the prior knowledge assessment, most students thought that the correct answer was B, which could mean that they did not see the word NOT in the question. After taking GC1, however, sixty percent of the students still chose steps in the safety shower procedure. If we look at the Sankey plot of the question, the students who responded with option B before taking GC1 spread across all possible responses after taking GC1. Half of the students who chose the correct answer in prior knowledge did not choose the correct answer after GC1.

Summary

When we combine the results of the assessment, interview, and observation analysis, we find that there need to be major changes in safety instruction for general chemistry TAs and students. In the concluding chapter of this work, we will discuss possible changes we can implement to promote meaningful learning of safety guidelines.

CHAPTER 10

RECOMMENDATIONS AND CONCLUSIONS

As we discussed in Chapter 1, the second part of the critical theory is determining viable alternative methods to the current system which may improve system outcomes. Likewise, in Chapter 3, we talked about meaningful learning, or the ability to transfer rote material into new scenarios. By its nature, the goal of safety instruction is meaningful learning: students being able to minimize risk no matter what situation comes up in the laboratory. Since meaningful learning occurs most often through active learning, we must incorporate the method into safety instruction at the curriculum and TA level.

Changing Safety Instruction at the Curriculum Level

The active learning techniques that are suited best for the curriculum level of safety instruction are asking higher order questions and inquiry-based activities. Currently in GC1 and GC2, students complete three to four online quizzes through eLC (eLearning Commons, available through the University of Georgia) over the course of a semester. The quizzes cover equations, graphs, facts, and concepts over three to four laboratories. If instead, the quizzes covered higher order safety questions and students took them the weekend before the experiment, students would likely be aware of the chemical hazards and what to do for each experiment. For example, instead of asking, “Which chemicals are we working with this week?” asking, “What should you do if you spill nitric acid on your clothes?” An important aspect of higher order questions is giving the student feedback when they choose the wrong option. If answering our last example, a student answered, “Change your shirt” then there needs to be a feedback statement such as, “If you do this there may still be nitric acid on your skin.” The student now has the opportunity to choose again while keeping in mind that chemicals can penetrate clothing.

If changes were enacted to accommodate the techniques described in this research online laboratories or online componants and inquiry-based safety instruction are a viable curriculum changes to consider. As discussed in Chapter 4, inquiry-based instruction allows the student to learn by doing, an opportunity we do not usually encourage in laboratory safety instruction. In the virtual environment, students can take risks and break guidelines without the chance of hurting themselves or others. Again, the method is only useful if the student receives feedback on their choices. For example, if a student in the virtual lab pours from a large container of concentrated acid into a 10.00-mL graduated cylinder, the acid can spill all over the counter and get on the virtual student. The feedback for the scenario is twofold: 1) the student sees the effect of pouring from a large container into a small container and 2) the program can tell the student where they went wrong and how to minimize risk.

Lastly, the critical theory requires the input of those most affected by the changes. An example comes from the 1980’s when AIDS patients took an experimental drug called AZT that had not undergone rigorous testing. As a result, AIDS patients taking AZT suffered from more pain than those without access to AZT. AIDS activists changed the tide of medical testing by refusing to accept treatment before proper vetting.[134] While the example is an extreme case, similar results previously occurred through action research in education. Action research is taking educational data while enacting curriculum changes so that the researcher can measure the change in the students' abilities or attitudes.[135] Students who help to create their curriculum cultivate intrinsic motivation and inherent interest in the subject matter, through a feeling of inclusion, changing attitudes, creating meaning, and increasing competence.[136-137]

According to Fielding, there are six patterns of a partnership between students and instructors:[138]

1. Data Sources: Students answering questions from instructors
2. Active Respondents: Discussion of the topic with the instructor
3. Co-enquirers: Coming up with ways to learn the material (with guidance from the instructor)
4. Knowledge Creators: Students teaching the material
5. Joint Authors: Students and instructors work together to plan lessons
6. Lived Democracy: Students and instructors have equal power in planning lessons

The work in the preceding chapters describes general chemistry I and II students, who are considered novices in the patterns of partnership. The level of partnership that is most familiar to the participants are data sources, seen through the fact-recall questions on the safety quiz in Chapter 3. Students at the freshmen or sophomore level, typical of these courses, can reach up to pattern three in Fielding's heirarchy.[138] When applying the research to safety instruction, GC1 and GC2 students can answer questions about safety, discuss safety with the instructor, and comment on the quality of safety instruction. Therefore, all the suggestions we made above require that the students give feedback on the instructional method.

At the curriculum level, this researcher suggests two ways to incorporate instructional feedback: 1) give students a multiple-choice survey where the lab coordinator can view the average opinion of the class and 2) lab reports include a feedback question so that TAs can report open-ended responses to the laboratory coordinator. While the former may improve upon future curriculum changes, the latter provides a better opportunity for students to engage with the material they helped to create. However, both ideas give the lab coordinator a better idea of instructional effectiveness than never taking the students' opinions into account.

Changing Safety Instruction at the TA Level

While we can incorporate changes into the curriculum level, there may not be a marked improvement in the transfer of safety knowledge until TAs reinforce safety instruction in the laboratory. The first part of changing the classroom environment is proper training for the general chemistry laboratory TAs. As we discussed in Chapter 3, the current structure of TA training is heavily focused on grading consistency and class policies with the lab coordinator only telling the TAs where the safety equipment is in the laboratory. This method left the TAs with the belief that they could not handle emergency situations that came up in their own laboratory rooms. Even the veteran TAs indicated that they only knew how to handle safety situations through trial and error. To get to a point where all the TAs know how to handle any situation that occurs in the lab, we must have a thorough and consistent TA training using the active learning techniques that we prescribed for the students.

The researcher suggests several ways to improve upon the current TA training and TA meetings. The first day of training should be dedicated to an introduction to the laboratory. Walk through all the safety items that we have in the laboratory. Get the TAs accustomed to using the safety equipment, such as pressing the eyewash to another TAs' eyes or cleaning up a spill using a spill kit. In the previous literature, this type of practice prevents individuals from freezing up in an emergency. Give the TAs a first-aid lesson specifically aimed at laboratory injuries. To make sure that they do not forget any of this information, attach instructions to the first-aid kit indicating what they can and cannot treat in the laboratory. The second and possibly third day of training should be dedicated to performing all experiments in general chemistry I (we should cover general chemistry II directly before the new students teach that semester). While running through the experiments, emphasize the chemical hazards and quiz the TAs on what they would do in certain safety situations. For example, while a TA dispenses a concentrated acid, ask what they would do if the acid splashed onto their hand. With this type of training, TAs learn the experiments and troubleshooting, as well as knowing what to do in case a student gets hurt.

Under the current system, only new general chemistry TAs must attend weekly TA meetings. As we saw in the observation data, the TA meetings led to TAs all presenting the same pre-laboratory lecture. We also discussed in the interview analysis that veteran TAs could not remember if they had learned emergency response in training and TA meetings. These TAs also had significant blind spots in their current safety knowledge. To ensure that safety information is consistent throughout all of GC1 and GC2, all TAs need to attend weekly TA meetings.

The researcher has several suggestions for organizing TA meetings. First, the coordinator should inform the TAs of all chemicals and hazards for the current experiment. The coordinator should then ask the TAs questions about emergency response procedures that are relevant to the process. The coordinator then should tell the TAs the exact pre-laboratory lecture that is appropriate for the given experiment. If the coordinator opts for the higher-order questioning technique, then they can provide a list of questions that TAs can ask students to engage them with the material. Finally, the coordinator should allow the TAs to discuss their opinions and concerns regarding the previous and current experiment. From the interviews and research, we saw that instructors are more likely to incorporate new teaching strategies if they feel they are part of the process.

We also saw in the observations that TAs tended to allow students to break safety rules and did not report safety issues because there was no oversight during experiments. To combat the issue, the researcher suggests that the lab manager or coordinator walks through the lab. During the walkthroughs, the coordinator or manager could ask the TA if they are missing any materials or struggling with the procedure while also checking that all students are wearing proper personal protective equipment and working to minimize risk. Making sure the laboratories are safe in this way could motivate TAs to monitor their students and report incidents, as they would have someone coming by to keep them in line.

During the observations, we saw that TAs tended to present safety information passively. The passive approach led to students misremembering what the TAs told them and not fully understanding the hazards of the reagents. The last way to change safety instruction in the laboratory is having the TAs incorporate an active learning style in their pre-laboratory lectures. The researcher suggests a few ideas to start using these techniques as soon as possible. The first way is to have the students prepare their own hazards table for each experiment in the semester. Send the students a blank table with columns labeled “Chemical name and concentration/Spill Response/Acute Effects/First-Aid Procedures.” Tell the students that this information is available in online safety data sheets. When the students come to the lab, check that they have this table before they walk into the lab and emphasize that it is essential to be aware of the hazards before they start working with the chemicals. Then, during pre-laboratory lecture, begin by asking the students the dangers associated with specific reagents. After the students get comfortable answering these questions, the TA can transition into asking what the students would do in those situations. For instance, if a student must work with concentrated nitric acid in an experiment, start by asking, “What are the hazards associated with concentrated nitric acid?” Then ask the students what they would do if they splashed the chemical onto their gloves or spilled it on the counter. The idea is to have the students start thinking about how they would respond to these situations, so they do not panic if it happens to them.

We also saw in Chapter 3 that students learn material meaningfully when they have to teach the material. If the TAs start with the students building their hazard table, they can also have the students present the safety information in the pre-laboratory lecture. To discourage students from only worrying about the hazard on their day to present, tell the students that any individual could be called upon to give the safety lecture. The TA should also emphasize to the students that other students in the class and the TA could ask them questions about what to do in certain situations after they have completed the lecture. According to the literature, when students know that questions are possible they tend to study the material deeper than if they only had to repeat the information back on an exam.

Keeping with the tenants of critical theory, the researcher suggests allowing feedback from students in any of the active learning methods the TA decides to use. TAs receive feedback at the end of the semester in the form of course evaluation, but this does not help the current students during the semester. The easiest way to receive weekly feedback is to distribute papers to the students with two questions: 1) What could I do to facilitate your learning and 2) What could you do to facilitate your learning? Asking for feedback in this way does not blame the TA or the student. It is also not enough to just listen to feedback; the TA also needs to either address the students' problems or come up with a way to incorporate their ideas into the curriculum. For example, if a TA decided to have students as instructors, but a student says they do not feel they have enough safety knowledge to field questions, the TA could either have an entire lesson on safety in the lab or have the students work in groups until they build their confidence. The students then should feel like they have some control over their learning and will be more receptive to current ideas.

Overall Conclusions

We have seen through this work that teaching laboratory safety in a passive manner leads to inconsistent instruction and an inability to transfer safety instruction to unfamiliar situations. Through the observations and interviews, we also learned that TAs had varied and often incorrect ideas about safety hazards and emergency response in the laboratory. To improve students' ability to transfer safety knowledge, we need to change the culture of the laboratory. Changing the culture begins with dispelling the notion that TAs know every safety guideline coming into the graduate school. The laboratory manual should either add all of the safety hazards associated with every reagent and product or require students to assemble the material themselves to inform both the TAs and the students. Finally, we need to change our method of instruction to include active learning strategies to improve students' ability to transfer safety information to different conditions.

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APPENDIX A

Below are all the chemical hazards included in GC1 experiments at the time of this research. Asterisks indicate hazard warnings that are in the lab manual. Crosses indicate those that are in the pre-lab notes distributed by the lab coordinator

Chemical/ Concentration	**Waste Disposal**	**Spill Response**	**Hazards**	**First-Aid Measures**
Cholesteryl oleyl carbonate (solid)	Dispose of in solid waste container	Vacuum or sweep material into appropriate container	Toxicological properties not fully studied	Eyewash for 15 minutes, flush skin with water 15 minutes
Cholesteryl pelargonate (solid)	Dispose of in solid waste container	Sweep up into appropriate container	Not a hazardous substance	Flush eyes with water as a precaution, wash skin with soap and water
Cholesteryl benzoate (solid)	Dispose of in solid waste container	Vacuum or sweep material into appropriate container	Mild eye and skin irritant	Eyewash for 15 minutes, flush skin with water 15 minutes
Hexamethylene diamine (solid)	Dispose of in solid waste container	Sweep or absorb material, then place into appropriate container	Causes severe skin burns and eye damage, **corrosive***, **irritant, flammable**	Eyewash for 15 minutes, flush skin with water 15 minutes
Sebacoyl chloride (4% in hexane)	Dispose of in an appropriately labeled liquid waste container	Use respiratory protective equipment, use inert adsorbent, transfer to appropriate container	Fatal in contact with skin, **environmentally damaging, flammable, health hazard, irritant**	Eyewash for 15 minutes, flush skin with water 15 minutes

Sodium bicarbonate (solid)	Dispose in trash	Vacuum or sweep material into appropriate container	Mild skin and eye irritant	Eyewash for 15 minutes, wash skin with soap and water
Sodium borate (solid)	Dispose of in solid waste container	Vacuum or sweep material into appropriate container	Mild skin and eye irritant	Eyewash for 15 minutes, wash skin with soap and water
Sucrose (solid)	Dispose in trash	Vacuum or sweep material into appropriate container	Mild skin and eye irritant	Eyewash for 15 minutes, wash skin with soap and water
Iodine (solid)	Dispose of in solid waste container	Use appropriate tools to put spilled solid in solid waste container	Very hazardous in case of skin or eye contact **irritant, corrosive***	Eyewash for 15 minutes, flush skin with water 15 minutes
Zinc (solid)	Dispose of in solid waste container	Use appropriate tools to put spilled solid in solid waste container	Mild skin and eye irritant	Eyewash for 15 minutes, wash skin with soap and water
Acetic Acid (6 M)	Dispose of in the appropriate liquid waste container	Absorb with inert dry material and dispose of in the appropriate waste container	Very hazardous in case of skin or eye contact, **irritant, corrosive**	Eyewash for 15 minutes, flush skin with water 15 minutes
Zinc iodide (solid)	Dispose of in solid waste container	Use appropriate tools to put spilled solid in solid waste container	Hazardous in case of skin or eye contact, **irritant**	Eyewash for 15 minutes, wash skin with soap and water

Nitric Acid (16 M)	Dispose of in the appropriate liquid waste container	Absorb with inert dry material and dispose of in the appropriate waste container	Very hazardous in case of skin or eye contact, **corrosive, irritant, permeator**	Eyewash for 15 minutes, flush skin with water 15 minutes
Nitrogen dioxide (gas)	Keep under fume hood	N/A	Acutely toxic if inhaled, can cause skin and eye burns, **health hazard, corrosive, irritant**	If inhaled for long period seek medical attention immediately, eyewash for 20 minutes, flush skin with water for 20 minutes
Copper nitrate trihydrate (variable)	Dispose of in the appropriate liquid waste container	Absorb with inert dry material and dispose of in the appropriate waste container	Hazardous in case of skin or eye contact, **irritant**	Eyewash for 15 minutes, flush skin with water 15 minutes
Sodium hydroxide (3 M)	Dispose of in the appropriate liquid waste container	Absorb with inert dry material and dispose of in the appropriate waste container	Causes severe burns and eye damage, **corrosive**	Eyewash for 15 minutes, flush skin with water 15 minutes
Copper hydroxide (solid)	Dispose of in solid waste container	Use appropriate tools to put spilled solid in solid waste container	Hazardous in case of eye contact, mild skin irritant, **irritant**	Eyewash for 15 minutes, wash skin with soap and water
Copper oxide (solid)	Dispose of in solid waste container	Use appropriate tools to put spilled solid in solid waste container	Hazardous in case of eye contact, mild skin irritant, **irritant**	Eyewash for 15 minutes, wash skin with soap and water

Sulfuric acid (6 M)	Dispose of in the appropriate liquid waste container	Absorb with inert dry material and dispose of in the appropriate waste container	Very hazardous in case of skin or eye contact, **corrosive, environmentally damaging**	Eyewash for 15 minutes, flush skin with water 15 minutes
Copper sulfate pentahydrate (variable)	Dispose of in the appropriate liquid waste container	Absorb with inert dry material and dispose of in the appropriate waste container	Hazardous in case of eye or skin contact, **irritant**	Eyewash for 15 minutes, flush skin with water 15 minutes
Hydrochloric acid (6 M)	Dispose of in the appropriate liquid waste container	Absorb with inert dry material and dispose of in the appropriate waste container	Causes severe skin burns and eye damage, respiratory irritation, **corrosive, irritant**	Eyewash for 15 minutes, flush skin with water 15 minutes
Hydrogen (gas)	Keep under fume hood	N/A	May explode if heated, **extremely flammable**	Remove to fresh air, if not breathing give artificial respiration, eyewash 15 minutes
Copper (solid)	Dispose of in solid waste container	Use appropriate tools to put spilled solid in solid waste container	Hazardous in case of eye contact, mildly hazardous on skin, **irritant**	Eyewash for 15 minutes, wash skin with soap and water
Sodium chloride (solid)	Dispose in trash	Use appropriate tools to put spilled solid in solid waste container	Mild skin and eye irritant	Eyewash for 15 minutes, wash skin with soap and water

Silicon dioxide (solid)	Dispose in trash	Use appropriate tools to put spilled solid in solid waste container	Mild skin and eye irritant	Eyewash for 15 minutes, wash skin with soap and water
Iron (solid filings)	Dispose of in solid waste container	Use appropriate tools to put spilled solid in solid waste container	Mild skin and eye irritant	Eyewash for 15 minutes, wash skin with soap and water
Calcium carbonate (solid)	Dispose of in solid waste container	Use appropriate tools to put spilled solid in solid waste container	Hazardous in case of eye contact, mildly hazardous on skin, **irritant**	Eyewash for 15 minutes, wash skin with soap and water
Calcium chloride (variable)	Low concentrations can be put down drain with plenty of water; high concentrations should be disposed of in liquid waste container	Absorb with inert dry material and dispose of in the appropriate waste container	Hazardous in case of eye or skin contact, **irritant**	Eyewash for 15 minutes, flush skin with water 15 minutes
Sodium thiosulfate pentahydrate (0.08 M)	Dispose of in the appropriate liquid waste container	Absorb with inert dry material and dispose of in the appropriate waste container	Mild skin and eye irritant	Eyewash for 15 minutes, wash skin with soap and water
Potassium iodide (solid)	Dispose of in solid waste container	Use appropriate tools to put spilled solid in solid waste container	Mild skin and eye irritant	Eyewash for 15 minutes, wash skin with soap and water

Potassium iodate (0.02 M)	Dispose of in the appropriate liquid waste container	Absorb with inert dry material and dispose of in the appropriate waste container	Hazardous in case of skin or eye contact, **irritant**	Eyewash for 15 minutes, flush skin with water 15 minutes
Sulfuric acid (0.5 M)	Dispose of in the appropriate liquid waste container	Absorb with inert dry material and dispose of in the appropriate waste container	Causes severe skin burns and eye damage, **corrosive**	Eyewash for 15 minutes, flush skin with water 15 minutes
Aluminum (solid)	Dispose in trash	Use appropriate tools to put spilled solid in solid waste container	Mild skin irritant	Eyewash for 15 minutes, wash skin with soap and water
Potassium hydroxide (2.0M)	Dispose of in the appropriate liquid waste container	Absorb with inert dry material and dispose of in the appropriate waste container	Very hazardous in case of skin or eye contact, **corrosive, irritant, permeator**	Eyewash for 15 minutes, flush skin with water 15 minutes
Barium nitrate (1.0M)	Dispose of in the appropriate liquid waste container	Absorb with inert dry material and dispose of in the appropriate waste container	Harmful if inhaled, causes serious eye irritation, **oxidizer, irritant**	Eyewash for 15 minutes, flush skin with water 15 minutes
Aluminon (concentration unlisted)	Dispose of in the appropriate liquid waste container	Absorb with inert dry material and dispose of in the appropriate waste container	Hazardous in case of skin or eye contact, **irritant**	Eyewash for 15 minutes, flush skin with water 15 minutes

Phosphate buffer (0.3M)	Dispose of in the appropriate liquid waste container	Absorb with inert dry material and dispose of in the appropriate waste container	Mild skin and eye irritant	Eyewash for 15 minutes, wash skin with soap and water
Ammonium molybdate-vanadate (concentration unlisted)	Dispose of in the appropriate liquid waste container	Absorb with inert dry material and dispose of in the appropriate waste container	Very hazardous in case of skin or eye contact, **corrosive, irritant, permeator**	Eyewash for 15 minutes, flush skin with water 15 minutes
Hydrochloric acid (3.0M)	Dispose of in the appropriate liquid waste container	Absorb with inert dry material and dispose of in the appropriate waste container	Causes severe skin burns and eye damage, **corrosive**	Eyewash for 15 minutes, flush skin with water 15 minutes

APPENDIX B

Below are all the chemical hazards included in GC2 experiments at the time of this research. Asterisks indicate hazard warnings that are in the lab manual. Crosses indicate those that are in the pre-lab notes distributed by the lab coordinator

Chemical/ Concentration	**Waste Disposal**	**Spill Response**	**Hazards**	**First-Aid Measures**
Hydrosoft tablet salt (solid)	Dispose of in solid waste container	Use appropriate tools to put spilled solid in solid waste container	Mild skin and eye irritant	Eyewash for 15 minutes, wash skin with soap and water
Isopropyl alcohol (concentration unlisted)	Low concentrations can be put down drain with plenty of water; high concentrations should be disposed of in liquid waste container	Absorb with inert dry material and dispose of in the appropriate waste container	Mild skin and eye irritant	Eyewash for 15 minutes, wash skin with soap and water
Sodium phosphate, tribasic (0.040M)	Dispose of in the appropriate liquid waste container	Absorb with inert dry material and dispose of in the appropriate waste container	Hazardous in case of skin or eye contact, **irritant**	Eyewash for 15 minutes, flush skin with water 15 minutes
Sodium phosphate, dibasic heptahydrate (0.040M)	Dispose of in the appropriate liquid waste container	Absorb with inert dry material and dispose of in the appropriate waste container	Mild skin and eye irritant	Eyewash for 15 minutes, wash skin with soap and water

Methyl green (concentration unlisted)	Dispose of in the appropriate liquid waste container	Absorb with inert dry material and dispose of in the appropriate waste container	Mild skin and eye irritant	Eyewash for 15 minutes, wash skin with soap and water
Iron nitrate (0.04M)	Dispose of in the appropriate liquid waste container	Absorb with inert dry material and dispose of in the appropriate waste container	Hazardous in case of skin or eye contact, **irritant**	Eyewash for 15 minutes, flush skin with water 15 minutes
Nitric acid (0.15M)	Dispose of in the appropriate liquid waste container	Absorb with inert dry material and dispose of in the appropriate waste container	Mild skin and eye irritant	Eyewash for 15 minutes, flush skin with water 15 minutes
Potassium iodide (0.04M)	Dispose of in the appropriate liquid waste container	Absorb with inert dry material and dispose of in the appropriate waste container	Mild skin and eye irritant	Eyewash for 15 minutes, wash skin with soap and water
Sodium thiosulfate (0.004M)	Dispose of in the appropriate liquid waste container	Absorb with inert dry material and dispose of in the appropriate waste container	No acute health effects	Eyewash for 15 minutes, wash skin with soap and water
Starch (no concentration listed)	Dispose of in the appropriate liquid waste container	Absorb with inert dry material and dispose of in the appropriate waste container	Mild skin and eye irritant	Eyewash for 15 minutes, wash skin with soap and water

Activated carbon (solid)	Dispose of in solid waste container	Use appropriate tools to put spilled solid in solid waste container	Mild skin and eye irritant	Eyewash for 15 minutes, wash skin with soap and water
Ferric chloride (1.0M)	Dispose of in the appropriate liquid waste container	Absorb with inert dry material and dispose of in the appropriate waste container	Hazardous in case of skin or eye contact, **irritant**	Eyewash for 15 minutes, flush skin with water 15 minutes
Iron (II) chloride (2.0M)	Dispose of in the appropriate liquid waste container	Absorb with inert dry material and dispose of in the appropriate waste container	Hazardous in case of skin or eye contact, **irritant**	Eyewash for 15 minutes, flush skin with water 15 minutes
Ammonia (1.4M)	Dispose of in the appropriate liquid waste container	Absorb with inert dry material and dispose of in the appropriate waste container	Hazardous in case of skin or eye contact, **irritant**	Eyewash for 15 minutes, flush skin with water 15 minutes
Nitric acid (2.0M)	Dispose of in the appropriate liquid waste container	Absorb with inert dry material and dispose of in the appropriate waste container	Causes severe skin burns and eye damage, respiratory irritation, **corrosive, irritant**	Eyewash for 15 minutes, flush skin with water 15 minutes
Potassium thiocyanate (0.001M)	Dispose of in the appropriate liquid waste container	Absorb with inert dry material and dispose of in the appropriate waste container	Hazardous in case of skin or eye contact, **irritant**	Eyewash for 15 minutes, wash skin with soap and water

Iron (III) nitrate (0.1M)	Dispose of in the appropriate liquid waste container	Absorb with inert dry material and dispose of in the appropriate waste container	Causes severe skin burns and eye damage, respiratory irritation, **corrosive, irritant**	Eyewash for 15 minutes, flush skin with water 15 minutes
Nitric acid (0.5M)	Dispose of in the appropriate liquid waste container	Absorb with inert dry material and dispose of in the appropriate waste container	Hazardous in case of skin or eye contact, **irritant**	Eyewash for 15 minutes, flush skin with water 15 minutes
Acetic acid (4%)	Dispose down drain with plenty of water	Absorb with inert dry material and dispose of in the appropriate waste container	Hazardous in case of skin or eye contact, **irritant**	Eyewash for 15 minutes, flush skin with water 15 minutes
Sodium hydroxide (1.0M)	Dispose of in the appropriate liquid waste container	Absorb with inert dry material and dispose of in the appropriate waste container	Causes severe skin burns and eye damage, respiratory irritation, **corrosive, irritant**	Eyewash for 15 minutes, flush skin with water 15 minutes
Barium nitrate (solid)	Dispose of in solid waste container	Use appropriate tools to put spilled solid in solid waste container	Very hazardous in case of skin or eye contact, **irritant**	Eyewash for 15 minutes, flush skin with water 15 minutes
Copper sulfate pentahydrate (solid)	Dispose of in solid waste container	Use appropriate tools to put spilled solid in solid waste container	Hazardous in case of skin or eye contact, **irritant**	Eyewash for 15 minutes, flush skin with water 15 minutes

Ammonium hydroxide (8 M)	Dispose of in the appropriate liquid waste container	Absorb with inert dry material and dispose of in the appropriate waste container	Causes severe skin burns and eye damage, respiratory irritation*, **corrosive, irritant**	Eyewash for 15 minutes, flush skin with water* 15 minutes
Ethanol (95%)	Dispose of in the appropriate liquid waste container	Absorb with inert dry material and dispose of in the appropriate waste container	Hazardous in case of skin or eye contact, **irritant**	Eyewash for 15 minutes, flush skin with water 15 minutes
Nitric acid (6 M)	Dispose of in the appropriate liquid waste container	Absorb with inert dry material and dispose of in the appropriate waste container	Causes severe skin burns and eye damage, respiratory irritation, **corrosive, irritant**	Eyewash for 15 minutes, flush skin with water* 15 minutes
Barium chloride (1 M)	Dispose of in the appropriate liquid waste container	Absorb with inert dry material and dispose of in the appropriate waste container	Mild skin and eye irritant	Eyewash for 15 minutes, flush skin with water 15 minutes
Methyl orange (no concentration given)	Dispose of in the appropriate liquid waste container	Absorb with inert dry material and dispose of in the appropriate waste container	Hazardous in case of skin or eye contact, **irritant**	Eyewash for 15 minutes, flush skin with water 15 minutes
Hydrochloric acid (1 M)	Dispose of in the appropriate liquid waste container	Absorb with inert dry material and dispose of in the appropriate waste container	Very hazardous in case of skin or eye contact, **irritant, corrosive**	Eyewash for 15 minutes, flush skin with water 15 minutes

Nitric acid (1 M)	Dispose of in the appropriate liquid waste container	Absorb with inert dry material and dispose of in the appropriate waste container	Very hazardous in case of skin or eye contact, **irritant, corrosive**	Eyewash for 15 minutes, flush skin with water 15 minutes
Titanium dioxide (solid)	Dispose of in solid waste container	Use appropriate tools to put spilled solid in solid waste container	Mild skin and eye irritant	Eyewash for 15 minutes, wash skin with soap and water
Acetic acid (1 M)	Dispose of in the appropriate liquid waste container	Absorb with inert dry material and dispose of in the appropriate waste container	Mild skin and eye irritant	Eyewash for 15 minutes, wash skin with soap and water
Iodine (0.05 M)	Dispose of in the appropriate liquid waste container	Absorb with inert dry material and dispose of in the appropriate waste container	Hazardous in case of skin or eye contact, **irritant**	Eyewash for 15 minutes, flush skin with water 15 minutes
Potassium iodide (0.5 M)	Dispose of in the appropriate liquid waste container	Absorb with inert dry material and dispose of in the appropriate waste container	Mild skin and eye irritant	Eyewash for 15 minutes, flush skin with water 15 minutes

APPENDIX C

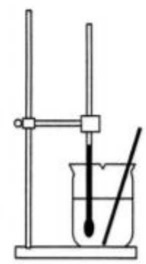
EXAMPLE OF GUIDED INQUIRY LABORATORY

DISSOLUTION REACTIONS—Exp. D-1

Name____________________ Lab Section ____________________

Lab Partner____________________

Problem Statement: How is heat energy related to chemical interactions?



I. Data Collection: Qualitative

A. Place about 25 mL of distilled water into a 50 mL beaker and suspend a 0.1 °C thermometer into the liquid, using a ring stand and a thermometer clamp. (Take care that the thermometer is not touching the bottom of the beaker, as any movement of the beaker could snap the thermometer.) Place a moderate amount (approximately 1 to 3 cm³) of anhydrous magnesium sulfate, $MgSO_4$, into the water, mix vigorously for about 15 seconds and record your observations.

Repeat this procedure using fresh distilled water with each of the following compounds and record your observations.

nitrates, Q>0

B. Sodium Nitrate, $NaNO_3$

2+ Q<0

1+ Q>0

C. Sodium Chloride, NaCl

D. Hydrated Calcium Chloride, $CaCl_2(H_2O)_2$

E. Ammonium Nitrate, NH_4NO_3

II. Data Analysis

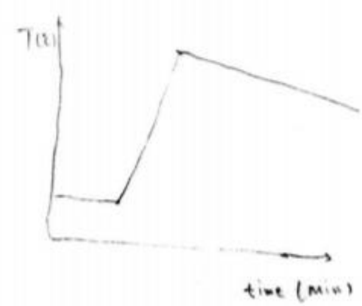
What conclusions can be drawn from these data? (e.g., What are the similarities and differences in the behavior of the several compounds? Does the data indicate any generalizations concerning all chemical reactions?)

III. Data Collection—Reaction: $MgSO_4(s) \xrightarrow{H_2O} Mg^{2+}(aq) + SO_4^{2-}(aq)$

A. Using a beaker, accurately weigh a 3 to 8 gram sample of $MgSO_4$ on the analytical balance. Record the exact mass in the table on page 49.

B. Suspend a 0.1 °C thermometer into a polystyrene cup so that it is about ½ inch from the bottom. Using a volumetric cylinder, add 100.0 mL of distilled water and stir while recording time versus temperature data in the table. (Data should probably be taken every 30 seconds.) After about 4 minutes add the $MgSO_4$ with vigorous mixing while continuing to record data. Mixing and the recording of data should continue for 5 to 10 minutes after the $MgSO_4$ has dissolved.

C. Determine ΔT, the temperature change for the reaction, from your data and explain how you did it (i.e., graph your data by plotting temperature versus time, draw the best curved line through the points, and explain what is occurring in each section of the curve. What part of the curve represents ΔT for the dissolution reaction?).



Data Table

	Trial #1	Trial #2
a. mass of beaker		
b. mass of beaker + $MgSO_4$		
c. mass of $MgSO_4$		

Time	Temp	Time	Temp

D. Calculate the heat, Q, of the reaction from the equation $Q=CM\ \Delta T$. Assume $C=4.18$ joules/gram °C and M is the mass of the water (take the water density as 1.00 grams/cm^3).

E. Repeat the experiment using a different sized sample of $MgSO_4$. Show your analysis of the data below. Collect four more sets of data from other students. Record all the data on the data summary table, page 51.

Summary of Data

	#1	#2	#3	#4	#5	#6
a. mass of $MgSO_4$	________	________	________	________	________	________
b. mass of water	________	________	________	________	________	________
c. ΔT	________	________	________	________	________	________
d. heat, Q	________	________	________	________	________	________

IV. Data Analysis

$Q \sim m_{MgSO_4}$

What pattern is shown by the data above? It might be helpful to graph the data. Give an algebraic equation that expresses this pattern.

V. Interpretation

(y = mx .)

A. How is heat energy related to chemical interactions? Use the dissolution reaction data you collected in this activity to generalize about the quantitative relationship.

B. Mental Model—Use the chemical equation: $MgSO_4(s) \xrightarrow{H_2O} Mg^{2+}(aq) + SO_4^{2-}(aq)$ to represent the dissolution reaction in part III. Use this reaction to explain how heat is released or gained by the dissolving process. Draw a picture(s) that illustrates heat gain or loss at the level of atoms and molecules. Explain how your picture(s) explains heat gain or loss.

y = mx .

IV. C.

APPENDIX D

2-YEAR COLLEGE GC LABORATORY COORDINATOR SURVEY QUESTIONS

(Questions with asterisks are open response)

1. Does your college/university currently have an option for a distance learning lab in the general chemistry curriculum?
   a. Yes
   b. No
2. (If answered Yes to Question 1) Is your current distance learning laboratory curriculum:
   a. Entirely software or online program
   b. Software or online program with chemicals that may be purchased at the grocery store
   c. Software or online program with instrumentation that may be bought/rented and chemicals that may be purchased at the grocery store
   d. Other
3. (If answered No to Question 1) Is there an experiment in the offered general chemistry lab course which uses software or an online lab program to perform the experiment, pre-lab, or post-lab?
   a. Yes
   b. No

4. (If answered Yes to Question 3) Which software or online program are you currently using in your experiment, pre-lab, or post-lab? *
5. What about this program do you find most beneficial to student learning in chemistry? *
6. What changes (if any) would you make to your current software or online program? *
7. (If answered Entirely Software or Online Program to Question 2) Which software or online laboratory program is your college/university currently using? *
8. What about the program do you believe to be the most beneficial to student learning in chemistry? *
9. What would you change (if anything) about the program that would make the program more user-friendly or more constructive for students learning in chemistry? *
10. (If answered Software or online program with chemicals that may be purchased at the grocery store to Question 2) What is the current software or online program being used in your distance-learning laboratories? *
11. What about this program do you find most beneficial to student learning in chemistry? *
12. What changes (if any) would you make to your current distance-learning software or online program? *
13. Would you consider using an entirely virtual laboratory in your distance-learning laboratory curriculum?
    a. Yes

b. No

14. (If answered Yes to Question 13) What features would you like included in the virtual lab program that you feel would best assist students in fulfilling the goals of general chemistry laboratory? *
15. (If answered No to Question 13) What would need to change in virtual laboratories before you would consider using them as part of you distance-learning curriculum? *
16. (If answered Software or online program with instrumentation that may be bought/rented and chemicals that may be purchased at the grocery store or Other to Question 2) What is the current program and instrumentation used for distance learning labs in your college/university's general chemistry courses? *
17. What about this program do you believe to be the most beneficial to student learning chemistry? *
18. What would you change (if anything) about the program that would make the program more user-friendly or more constructive for students learning general chemistry? *
19. Would you consider using an entirely virtual laboratory in your distance-learning laboratory curriculum?
    a. Yes
    b. No
20. (If answered Yes to Question 19) What features would you like included in the virtual lab program that you feel would best assist students in fulfilling the goals

of general chemistry laboratories? (e.g., integrated lab notebooks, open communication between students, programmable error, etc.) *

21. (If answered No to Question 19) What would need to change about virtual laboratories before you would consider using them as part of your distance-learning curriculum? *
22. (If answered No to Question 3) What would need to change about software or online lab programs for you (or your institution) to consider utilizing them in your general chemistry laboratory curriculum? *

APPENDIX E

UNDERGRADUATE INTERVIEW QUESTIONS

(Follow-up questions are indented)

Part 1: Laboratory Environment

1. Which lab are you currently taking, 1211 or 1212?
2. On an A-F scale, how would you grade your TA on enforcing laboratory safety?
    a. How have they earned that grade?
3. Have there been any times a chemical has been spilled in your lab?
    a. Do you recall which chemical it was?
    b. Do you remember if it was hazardous?
    c. How did your TA handle the spill?
4. Has your TA gone over what to do if a spill occurs in the lab?
5. Have there been any times in your lab that glassware was broken?
    a. Do you recall if there were any chemicals in or on the glassware when it broke?
        i. Do you recall if there were any hazards associated with the chemical?
    b. How did your TA handle the broken glassware?
6. Did your TA go through how to handle broken glassware?
7. Did your TA go through how to treat a cut from glassware with basic first-aid?
8. Do you know how to treat a cut from glassware with basic first-aid?

9. How are you most often informed that a chemical you're working with is hazardous?
    a. (If TA) What kinds of things do they tell you about the hazards?
    b. (If manual) What does the manual tell you about the hazardous chemical?
10. Did your TA tell you what to do if a large fire breaks out in the lab?
11. Do you know what to do if a large fire breaks out in the lab?

Part 2: Terms and Symbols

12. [Corrosive chemical hazard symbol is shown to participant] Tell me what this symbol means.
    a. What do the symbols look like to you?
    b. How would you take precautions if an aqueous chemical had this symbol on the bottle?
    c. How would you handle a spill on the benchtop?
13. [Hazard symbol for toxic chemical is shown to the participant] Tell me what this symbol means.
    a. What does this symbol look like to you?
    b. How would you take precautions if a solid chemical you were working with had this on the bottle?
    c. What would you do with any weigh boats or weigh paper you used with this chemical?
14. [Hazard symbol for irritant is shown to participant] Tell me what this symbol means.
    a. What does the symbol look like it could mean?

b. How would you take precautions if you saw this in your lab manual when talking about a solid you're producing?

15. [Hazard symbol for environmental hazard is shown to the participant] Tell me what this symbol means.
    a. What do these symbols look like they could mean?
    b. How would you take precautions if a solid reagent you were working with had this symbol on the bottle?
    c. Moreover, what about any weigh boats or weigh paper you use?
16. If a reagent bottle has "acute dermal toxicity" on it, what would that mean?
    a. What do the words mean individually?
        i. How would the word acute factor in?
    b. How would you take precautions if you were working with this chemical?
    c. How would you proceed if you got this chemical on your gloves?
17. What would it mean if a product you made in the lab had chronic inhalation toxicity?
    a. What do the words mean individually?
        i. How would the word chronic factor in?
    b. How would you take precautions if you were working with this chemical?
18. What is the difference between a hazard and a risk?
    a. What is a hazard?
    b. What is a risk?
19. Can you name a few possible hazards in the lab?
20. Can you name a few possible risks in the lab?

21. What are the effects that corrosives have on skin?
22. Can you remember how your TA said to treat corrosive substances on skin?
    a. What do you think this process does?
23. Can you name some corrosive chemicals?
24. There's a common statement: "The dose makes the poison." Can you explain what this means?
    a. How can we apply this to work we do in general chemistry?
25. What is personal protective equipment?
    a. What does it sound like it could mean?
    b. What personal protective equipment are you required to wear to the lab?
    c. [If they say goggles] What is the purpose of wearing goggles?
        i. How could a chemical get splashed into your eye during an experiment?
    d. [If they say long pants] What is the purpose of wearing long pants?
        i. Can you think of a type of pants that fit the length requirement but still wouldn't be appropriate to wear to the lab?
    e. [If they say close-toed shoes] What is the purpose of wearing close-toed shoes?
26. How are acid spills cleaned up?
    a. What do you think would happen if we tried to clean up an acid like a water spill?
27. What effect do strong bases have on the skin?
    a. Can you name some examples of strong bases?

28. Is there a safety shower in the lab?
    a. Where is the safety shower located?
    b. When would it be appropriate to use a safety shower?
    c. How do you properly use a safety shower?
    d. How long would you need to stay in the safety shower?
29. Is there a fire extinguisher in the lab?
    a. Where is the fire extinguisher located?
    b. When is it appropriate for a TA to use a fire extinguisher?
30. Are there eyewash stations in the lab?
    a. Where are the eyewash stations located?
    b. Did your TA go through how to use the eyewash station?
    c. How do you use the eyewash station?
31. Is there a first-aid kit in the lab?
    a. Where is the first-aid kit located?
32. There are a basic set of rules for working in the lab that apply to every experiment you do. Could you name some of those rules?
    a. Can you think of anything you're not allowed to do?
33. We have different regulatory agencies like the environmental protection agency and the occupational safety and health administration. How do you think these agencies help us stay safe in the lab?
34. What is a Safety Data Sheet?
    a. What does it sound like it could mean?
    b. Do you have access to Safety Data Sheets during the lab period?

c. Where are they located in the lab?

Part 3: Laboratory Safety in Practice

35. How would you proceed if you took too much of an aqueous chemical out of the bottle?
36. How would you prevent a spill if you were pouring a corrosive chemical into a burette for a titration?
37. How would you proceed if you took too much of a solid chemical out of the reagent bottle?
38. Why do you think your TA does not have you work individually on experiments in general chemistry?
39. If an experiment did not require you to wear gloves, how would you proceed if you splashed a chemical on your skin?
40. How do you prevent a spill when you're weighing out a solid on a balance?
41. At what points in the lab do you feel comfortable taking off your goggles?
42. There are reagents you work with in the lab that are ingestion hazards. How could a reagent be unintentionally ingested during lab?
43. How would you proceed if a reagent splashed onto your shirt during an experiment?
44. There are not any set guidelines for smartphone usage in the lab. Does your TA have any rules about using a smartphone during an experiment?
    a. What rules would you suggest for students using smartphones in the lab?
    b. How do you think smartphone usage affects safety in the lab?

45. Another situation we do not have safety guidelines for yet is computer usage. Does your TA have any rules about using computers and staying safe during lab?
    a. What rules would you suggest about using computers during lab?
    b. How do you think using a computer during lab could affect your safety?
46. If you could change anything about your lab (doesn't need to be safety related) what would you change?

APPENDIX F

TA INTERVIEW QUESTIONS

(Follow-up questions are indented)

Part 1: Background and Training

1. What discipline are you (or do you plan to do) researching?
2. Are you currently teaching general chemistry?
    a. What section are you currently teaching?
    b. What experiment was performed most recently?
3. What was the last section of general chemistry you taught?
4. How recently have you had to attend TA meetings?
5. What semester did you start teaching general chemistry?
6. Which semester were you trained to teach general chemistry?
7. Describe your departmental TA training (as much as you can remember).
8. Describe your weekly TA meetings.
9. How do/did you prepare for your first laboratory of the week?
10. What resources do you use to prepare for the lab? / Do you use any outside resources to prepare for the lab?
11. Does your pre-laboratory lecture change after the first lab of the week?
    a. How does your pre-lab lecture change?
12. What do/did you cover the first pre-lab lecture of the semester?
13. What topics do you cover during a typical pre-lab lecture?

14. Do you have a topic that is always the first thing you talk about?
15. Which guidelines do you strictly enforce during lab? (These can be administrative, ways to fill out a lab report, safety, etc.)
16. In your opinion, could a student finish an experiment using only this manual with no guidance from you?
    a. (If they say no) What are some things that have been missing from the manual in the past?

Part 2: Emergency Response Procedures

17. How would you handle a student cutting their hand on glassware in your lab?
    a. Do you recall if this ever came up in training or TA meetings?
18. How would you handle a student spilling a solid chemical on their skin?
    a. Do you recall if this ever came up in training or TA meetings?
19. How would you handle a situation where a student poured a corrosive chemical onto the cap of the waste container instead of into the waste container?
20. How would you handle a situation where a student spilled a concentrated base on their hand?
    a. Do you recall if this ever came up in training or TA meetings?
21. How would you handle a situation where a student fainted in your lab?
    a. Do you recall if this ever came up in training or TA meetings?
22. How would you handle a small electrical fire breaking out in your lab?
    a. (If they say fire extinguisher) Where is that located?
    b. Do you recall if this came up in training or TA meetings?
23. How would you handle a situation where the fire alarm goes off during lab?

    a. Do you recall if this came up in training or TA meetings?

24. How would you handle a situation where a tornado warning went off during your lab?
    a. Do you recall if this came up in training or TA meetings?
25. How would you handle a situation where you receive a campus active shooter warning during lab?
    a. Do you recall if this came up in training or TA meetings?

Part 3: Teaching Philosophy

26. Describe your experience teaching general chemistry laboratory?
    a. Would you say it is more positive or negative?
27. Before teaching this lab, did you have any desire to teach at the college level?
    a. Has this opinion changed since teaching this lab?
28. In your opinion, what are the goals of general chemistry lab?
    a. Do these goals align with UGA's general chemistry laboratory?
    b. How are they similar/different?
    c. In your opinion, are your students achieving these goals?
29. What kinds of questions most commonly come up from students?
    a. What do you believe to be the source of these questions?
30. If you were running the general chemistry lab, what would you change?

APPENDIX G

LAB PREP MANAGER INTERVIEW QUESTIONS

(Follow-up questions are indented)

Part I: Background and Training

1. What is your backround in chemistry?
2. Have you worked in a research lab?
    a. (If yes) What discipline of chemistry?
3. What were the requirements for application to your position? (Prior experience, education, etc)
4. What is your official set of duties?
    a. (If not answered within question 4) Are you ever required to cover classes when a TA does not show up or is sick?
    b. (If not answered within question 4) Are you responsible for talking with ESD about waste removal and disposal in the labs?
5. Were you present for TA training in the fall?
6. Have you been going to TA meetings since you started this position?
7. Was there any specific safety training before starting this job?
8. Were you required to be trained in the specific experiments before starting this position?
9. Do you work from a list of requirements for each experiment (for supplies, waste disposal, etc.) or do you work on the manual?

Part II: Emergency Response

10. How would you handle a situation where a TA came to you saying a student had cut their hand on glassware?
11. How would you handle a situation where a TA came to you saying a student spilled a solid chemical on their skin?
12. How would you handle a situation where a TA came to you saying a student spilled a concentrated base onto their hand?
13. How would you handle a situation where a TA came to you saying a student fainted in their lab?
14. How would you instruct TAs to handle a tornado warning going off during their lab?
15. If there were anything you could change about the lab setup at UGA, what would you change?

APPENDIX H

ASSESSMENT QUESTIONS WITH ANSWERS

(All correct answers have an asterisk next to the response)

16. Amy spills a strong base onto the benchtop while trying to pour from a beaker into a 10-milliliter graduated cylinder. What should Amy do next?
    a. Move away from the spill and tell the TA*
    b. Wipe up the spill with paper towels
    c. Find the appropriate acid to neutralize the base
    d. Dilute the base with water before wiping with a towel
    e. Have a lab partner stand near the spill to prevent others from getting hurt while she informs the TA
17. After standing over a reaction producing a significant amount of brown gas for approximately 40 minutes, you notice that your lab manual says the gas has **acute toxicity**. What is the correct response procedure?
    a. Step outside and get some fresh air
    b. Put the reaction under the fume hood to prevent further inhalation
    c. Go to the health center for treatment*
    d. Step away from the reaction and breathe deeply for 10-15 minutes
    e. Cough to clear the gas from your lungs

18. Your lab partner, Melody, has her goggles on her forehead and is leaning over your reaction beaker while it heats up on a hot plate. Suddenly, the solution boils and splashes into Melody's eye. What should you do next to help Melody?
    a. Go immediately to the TA for help
    b. Check your procedure for warnings about the reagents
    c. Wipe the excess reagents off her eyes with a paper towel
    d. Get a cold compress from the first-aid kit
    e. Lead her to the eye wash station*
19. Dr. Smith is coming up with new experiments for the general chemistry lab. Below are his options for a reagent in a synthesis. Which option would be the safest for general chemistry students to use?
    a. 10 mL of 16 M H_2SO_4
    b. 5 mL of 2 M H_2SO_4*
    c. 20 mL of 8 M H_2SO_4
    d. 3 mL of 10 M H_2SO_4
    e. 40 mL of 4 M H_2SO_4
20. Which of the following would be considered a **hazard**?
    a. A reagent that is labeled as corrosive*
    b. Picking up broken glass with your hands
    c. Pouring an acid from a large reagent bottle into a 10-mL graduated cylinder
    d. Leaning over a flame with long hair
    e. Pouring a solution while looking at your phone

21. You are swirling a solution containing a corrosive reagent when you accidentally hit the beaker on the benchtop and cut your hand on the broken glass. What should you do next?
    a. Go to the first-aid kit
    b. Grab a paper towel and begin to apply pressure
    c. Rinse the cut with water*
    d. Grab a paper towel and clean off the wound
    e. Go straight to the health center
22. This is a validation question. While many people read questions carefully, there may be those who are answering without reading. To show you have read this, please choose **yellow lion** from the choices below.
    a. Purple people eater
    b. Red dragon
    c. Pink unicorn
    d. Yellow lion*
    e. Brown cow
23. When leaning across the lab bench, you accidently inhale fumes from a solvent that has **chronic toxicity**. What should you do next?
    a. Go to the health center for treatment
    b. Put the solvent in the fume hood to prevent further inhalation*
    c. Step away from the reaction and breathe deeply for 10-15 minutes
    d. Cough to clear the fumes from your lungs
    e. Step outside and get some fresh air

24. Listed below are several situations which may occur in the lab. Which situation would require the use of a **safety data sheet**?

    a. An accident needs to be reported to the university

    b. A student is about to set up a new piece of equipment

    c. A reagent spilled onto a student's clothes*

    d. Glassware was broken in the sink

    e. Several students were not wearing their safety goggles

25. In the pre-lab lecture, your TA tells you that the experiment produces a dilute solution of NaCl waste, solid copper waste, and aqueous HCl waste. You will also be measuring out a corrosive material using weigh boats. What is the proper disposal method of each of these waste materials?

    a. NaCl(aq) and HCl(aq) in liquid waste, copper and weigh boats in solid waste

    b. NaCl(aq) down drain, HCl(aq) in liquid waste, copper in solid waste, weigh boats in material waste*

    c. NaCl(aq) down drain, HCl (aq) in liquid waste, copper in solid waste, weigh boats in trash can

    d. NaCl(aq) and HCl(aq) in liquid waste, copper in solid waste, weigh boats in material waste

    e. NaCl(aq) and HCl(aq) in liquid waste, copper in solid waste, weigh boats in trash can

26. Please choose the **strong acid** from the list below.

    a. 0.5 M HNO_3*

b. 8 M CH_3COOH

c. 3 M HF

d. 6 M NH_3

e. 2 M KOH

27. Which of the following is an example of a risk?

a. A large chemical waste container

b. Using a burette for a titration

c. A strong acid in the fume hood

d. Drinking coffee in the laboratory*

e. A chemical that is flammable

28. Your lab manual tells you that a reagent you're working with is an **inhalation** and **injection** hazard. What is your best option to stay safe around the chemical?

a. Keep the reagent away from your face and wear gloves

b. Keep the reagent in the fume hood and do not put the reagent into a syringe

c. Only waft the chemical toward your nose and do not eat or drink around the chemical

d. Keep the reagent in the fume hood and keep safety glasses on at all times

e. Keep the reagent in the fume hood and do not expose the reagent to open wounds

29. While using the balance, you accidentally drop some solid reagents onto your arm. What should you do next?

a. Rinse off your arm under the sink for 15-30 minutes (depending on the material)
b. Scrape the excess off using a stiff surface (such as a credit card) *
c. Put a small amount of detergent on the solid to dissolve and then rinse the area well
d. Brush the material off and into the trash, rinse your arm well with water
e. Rinse the area with water while scrubbing the solid away with a towel

30. Which of the following statements about personal protective equipment is **correct**?
    a. You are required to wear long pants and long sleeves in the lab to limit the amount of exposed skin
    b. Leggings are allowed in general chemistry because the reagents are not concentrated or flammable
    c. Safety glasses are required to protect against chemical splashes and fumes*
    d. Holes in jeans are allowed because a chemical spill on your jeans would require a student to remove all clothing
    e. Tying up long hair is only required when working with open flame
31. Which of the following is NOT a requirement for using the safety shower?
    a. Remove contacts before turning on the water*
    b. Remove all clothing while water is washing over you
    c. Wash any contaminated clothing separately from other clothing or discard it

d. Allow someone else to cut off sweaters or sweatshirts to avoid exposing your face to chemicals
e. Flush the area with water for at least 15 minutes but resume rinsing if pain returns