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Blended learning in chemistry laboratory courses: Enhancing learning outcomes and aligning student needs with available resources

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BLENDED LEARNING IN CHEMISTRY LABORATORY COURSES: ENHANCING LEARNING OUTCOMES AND ALIGNING STUDENT NEEDS WITH AVAILABLE RESOURCES

by

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A DISSERTATION

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MISSOURI UNIVERSITY OF SCIENCE AND TECHNOLOGY

In Partial Fulfillment of the Requirements for the Degree

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Approved
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John Hogan

ABSTRACT

Freshman science courses are intended to prepare students for the rigor and expectations of subsequent college science. While secondary education aims to prepare students for the college curriculum, many incoming freshman lack the sense of responsibility for their own learning that is essential for success in a college-level course. The freshman general-chemistry laboratory course at Missouri University of Science and Technology (Missouri S&T) was identified as a bottleneck course with a demand beyond accommodation capacity. To address the bottleneck and develop a sense of learner responsibility, a decision was made to investigate laboratory course delivery strategies. As a result of the investigation into delivery strategies, a blended freshman general-chemistry laboratory course was designed and implemented at Missouri S&T, which increased student access to the bottleneck course and improved learner engagement while meeting American Chemical Society (ACS) guidelines. The implementation of the Missouri S&T project and its continued evolution at other institutions have a great potential to provide insight on the impact of blended teaching on learner success.

This dissertation describes research and design of a blended laboratory course that economically improves capacity while intentionally focusing pedagogy to support learner success, meet industry expectations, and maintain ACS certification. To evaluate success, the project documented and analyzed student performance during the development of the transformation to a blended freshman chemistry laboratory course at Missouri S&T. The findings support the efficacy of the blended teaching model and offer a structure upon which future courses may build.

ACKNOWLEDGMENTS

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1. INTRODUCTION

1.1. THESIS

This dissertation is a compilation of three papers and additional work describing the research and design of a blended laboratory course that economically improves capacity while intentionally focusing pedagogy to support learner success, maintain American Chemical Society (ACS) certification, and conserve instructional resources.

1.2. SETTING THE STAGE

USA Today ranked Missouri University of Science and Technology (Missouri S&T) as the third best institution for pursuing an engineering degree in the U.S.[1] The intuition's academic reputation and value attract students from across the nation and around the world.

Student engagement on campus has shown a positive correlation with student success in retention and student perception. [2,3,4,5,6,7,8] From the moment students step on campus, they are bombarded with opportunities to get involved in extracurricular activities promoted by over two hundred recognized student organizations. Design projects, team activities, performance opportunities, undergraduate research, and service learning provide students at Missouri S&T with opportunities to address real-world problems while the social interactions support the development of behavioral skills.[9] Among many other degree programs, students apply these skills in fifteen different undergraduate engineering programs, the largest variety of engineering majors offered at any American university. The career fair at Missouri S&T, where over 700 employers actively recruit Missouri S&T students, is the largest of its kind in the United States. In addition to engineering degrees, Missouri S&T offer degrees in all other STEM fields as well as liberal arts and business. The Bachelor of Science in Chemistry includes three emphasis areas (biochemistry, polymer and coatings, and premedical studies), all of which are certified by the American Chemical Society.

1.2.1. Accessibility. The aforementioned reasons have contributed to Missouri enrollment steadily increasing since 2004 achieving an all-time high each year since 2007 (Figure 1.1).[10] The freshman cohort represented twenty percent of the enrolled students in the year 2014-2015 academic year (Figure 1.2).[9] Of the freshman cohort, seventy-three percent enrolled as freshman engineering students. [11] As a result, the freshman-engineering students represent the largest group on campus and face unique hurdles in their academic path.

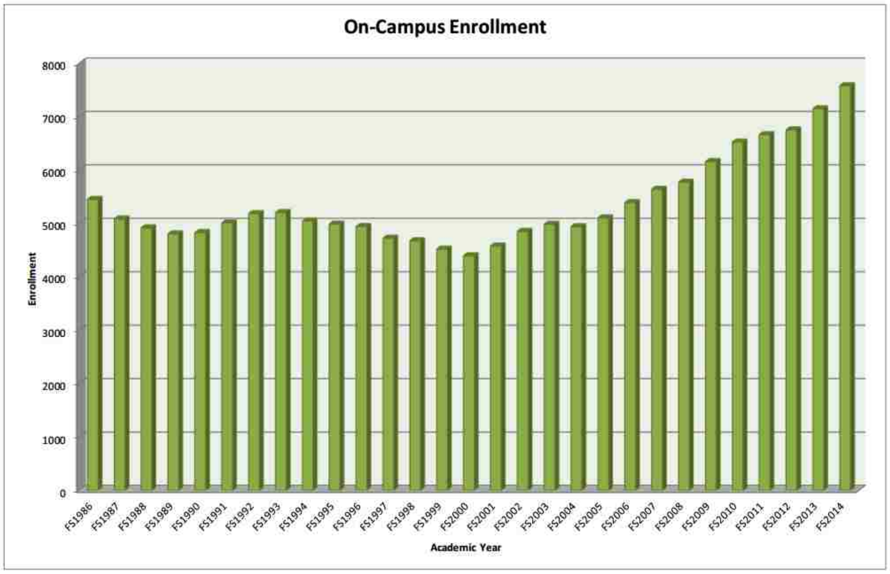


Figure 1.1. On Campus Enrollment at Missouri S&T 1986-2014

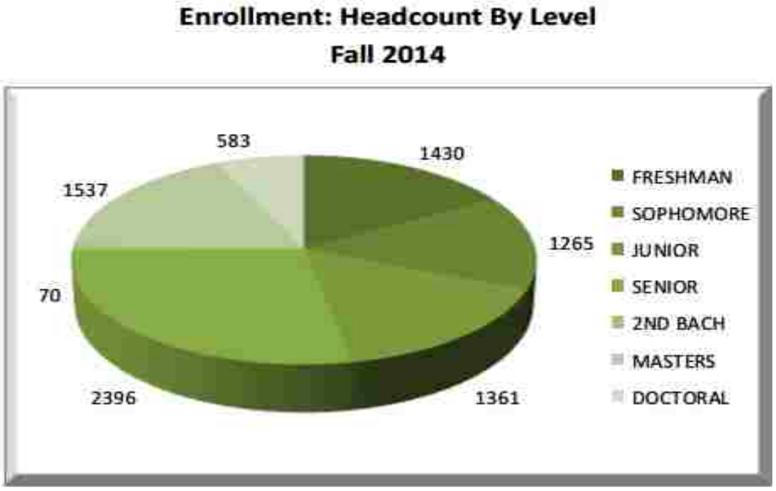
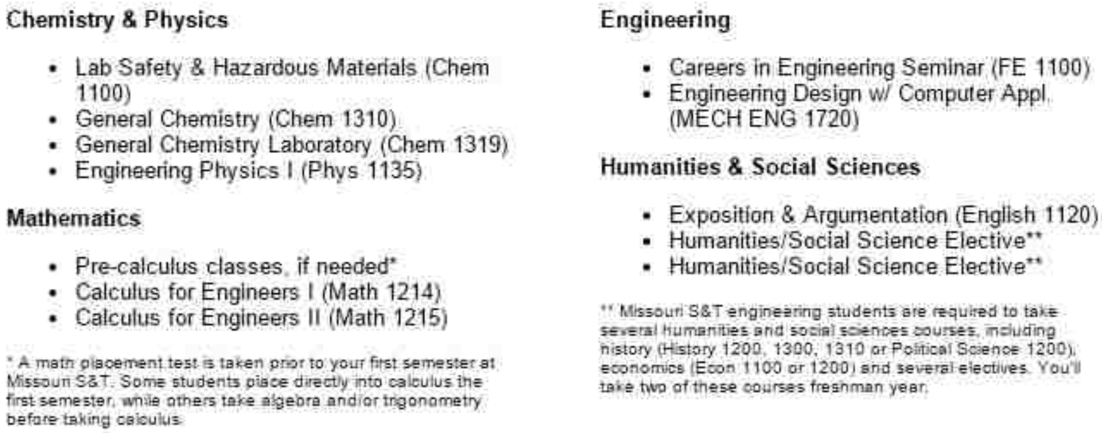


Figure 1.2. Enrollment: Headcount by Level at Missouri S&T Fall 2014

To provide broad fundamental exposure to the multiple engineering programs available at Missouri S&T, freshmen are encouraged to take the ideal courses listed in Figure 1.3. [12]



Chemistry & Physics

- Lab Safety & Hazardous Materials (Chem 1100)
- General Chemistry (Chem 1310)
- General Chemistry Laboratory (Chem 1319)
- Engineering Physics I (Phys 1135)

Mathematics

- Pre-calculus classes, if needed*
- Calculus for Engineers I (Math 1214)
- Calculus for Engineers II (Math 1215)

* A math placement test is taken prior to your first semester at Missouri S&T. Some students place directly into calculus the first semester, while others take algebra and/or trigonometry before taking calculus.

Engineering

- Careers in Engineering Seminar (FE 1100)
- Engineering Design w/ Computer Appl. (MECH ENG 1720)

Humanities & Social Sciences

- Exposition & Argumentation (English 1120)
- Humanities/Social Science Elective**
- Humanities/Social Science Elective**

** Missouri S&T engineering students are required to take several humanities and social sciences courses, including history (History 1200, 1300, 1310 or Political Science 1200), economics (Econ 1100 or 1200) and several electives. You'll take two of these courses freshman year.

Figure 1.3. Suggested Coursework for Freshman Engineers at Missouri S&T

Scheduling the fundamental courses for freshman engineering students can prove to be a challenge. Table 1.1 is an example schedule for a freshman-engineering student from fall 2014. Learners schedule their labs (italicized) and recitations (underlined) around lecture offerings. Arranging a course schedule is much like assembling a puzzle with the puzzle complexity increasing as time slots close upon capacity. Schedule changes for any of the freshman engineering courses must be done with the other required courses in mind, several of which are only offered during a few time slots and/or have assigned exam times outside of the scheduled meetings.

Some of the courses required for freshman engineers are also required for other degrees. Ninety-six percent of the 1,489 freshman students enrolled in the fall semester of 2015, for example, are enrolled in degree programs that require CHEM 1310, a four credit hour lecture and recitation course and CHEM 1319, a one credit hour laboratory course. Typically, students are encouraged to take CHEM 1310 and CHEM 1319 during the fall semester of their first year. The large number of students funneling through the sequence generates a bottleneck hindering degree completion.

Table 1.1. Example Freshman Engineering Schedule at Missouri S&T Fall 2014

	Monday	Tuesday	Wednesday	Thursday	Friday
0800					
0900	CHEM 1310		CHEM 1310		
1000		PHYSICS 1135	PHYSICS 1135	PHYSICS 1135	PHYSICS 1135
1100	FR ENG 1100	CHEM 1310		*CHEM 1319*	
1200		CHEM 1310		*CHEM 1319*	
1300	MATH 1214		MATH 1214	*CHEM 1319*	MATH 1214
1400		*MATH 1214*		MATH 1214	
1500	*PHYSICS 1135*				
1600	*PHYSICS 1135*				
1700	CHEM 1100	CHEM 1100	CHEM 1100	CHEM 1100	CHEM 1100
1800					

The freshman general chemistry lecture course (CHEM 1310) has been redesigned to allow the entire freshman cohort to enroll during the fall semester. The course has transitioned to a blended course format where students can attend class traditionally or through synchronously broadcasted lectures and/or online recitations. The blended format has allowed CHEM 1310 a dramatic capacity increase. Under the current course design, the lecture course capacity in a typical academic year is 1,526 with room for expansion.

Prior to the project discussed in this dissertation, the laboratory course was not able to serve all of the students enrolled in the lecture course. With over 1,000 students enrolled each academic year, CHEM 1319 is the largest lab course offered on the campus. Offering additional sections under the previous course pedagogy was not realistic with the physical constraints of the institution. In the fall semester of 2014, sections occurred five days a week with breaks for CHEM 1310 scheduled lectures and exams however, preparation time between labs was minimal. Using the schedule shown in Table 1.2, the course was only able to serve a maximum of 864 students.

Table 1.2. CHEM 1319 Schedule at Missouri S&T Fall 2014

	Monday	Tuesday	Wednesday	Thursday	Friday
0800		CHEM 1319		CHEM 1319	
0900	CHEM 1310		CHEM 1310		CHEM 1310 exam
1000	CHEM 1310		CHEM 1310		CHEM 1310 exam
1100		CHEM 1319		CHEM 1319	CHEM 1310 exam
1200					CHEM 1310 exam
1300	CHEM 1319				
1400		CHEM 1319	CHEM 1319	CHEM 1319	CHEM 1319
1500					
1600					
1700					
1800					

Table 1.3 shows the course enrollment for CHEM 1319 over five academic years. The “Percent Full” column uses open seats at the end of the semester after recording drops. The values indicate that the course is running near capacity at the end of the semester. Pedagogically, this is not ideal; forcing students who enroll later into residual time slots prevents students from selecting a section that is most appropriate for their schedule and learning style. The table indicates the percent of the freshman cohort served by the seats offered during the academic year.

Table 1.3. Course Enrollment for CHEM 1319 at Missouri S&T 2010-2015

Academic Year	Fall	Spring	Total	Percent Full	Percent of Freshman Cohort
2010-2011	709	235	944	97%	73%
2011-2012	702	251	953	98%	75%
2012-2013	733	226	959	91%	80%
2013-2014	744	251	995	94%	76%
2014-2015	839	216	1055	92%	81%

The prior course structure was able to increase course capacity over the last five years. Despite the increase, the course capacity still failed nearly twenty percent of the freshman cohort. These failed students accreted a population that had to take the course out of sequence or from another institution to meet their degree requirements; both situations are not ideal for student learning success and progress toward graduation. Table 1.4 illustrates the laboratory and lecture enrollment, percent full for the academic year, and the percent of the freshman cohort served by the seats offered. The department recognized a need to increase capacity in CHEM 1319 to align with CHEM 1310.

Table 1.4. Enrollment for CHEM 1310 and CHEM 1319 at Missouri S&T 2010-2015

Academic Year	Fall		Spring		Total		Percent Full		Percent of Freshman Cohort	
	1310	1319	1310	1319	1310	1319	1310	1319	1310	1319
2010-2011	758	709	285	235	1043	944	99%	97%	79%	73%
2011-2012	752	702	280	251	1032	953	98%	98%	82%	75%
2012-2013	751	733	262	226	1032*	959	75%	91%	105%	80%
2013-2014	788	744	282	251	1090*	995	72%	94%	109%	76%
2014-2015	894	839	268	216	1175*	1055	77%	92%	106%	81%
*Total includes Summer Enrollment										

1.2.2. Student Success. Student success relies heavily on the perceived value of the course.[13,14] For example when students question the value of a chemistry course for a non-chemistry major, success can be reduced to depend on external motivation based on grades rather than intrinsic motivation based on interest in the course. The value of laboratory courses is strongly tied to their relevance in corresponding lecture courses. CHEM 1310 and CHEM 1319 course topics have diverged as the course capacities grew apart. Table 1.5 shows the course schedule for both courses in a semester prior to this project.

Table 1.5. Schedule for CHEM 1310 and CHEM 1319 at Missouri S&T Spring 2014

Week	CHEM 1310 Lecture Topic	CHEM 1319 Lab Topic
1/21	Nomenclature	Safety/Glassware/Check-In/MSDS, Graphing
1/28	Measurement, Atomic Structure	Significant Figures Review, Nomenclature
2/4	Moles, Mass, Formulas	Statistical Analysis of Zinc Washers
2/11	Empirical Formulas, Combustion*	Empirical Formula and Oxidation/Reduction
2/18	Stoichiometry, Concentration	Separation of a Ternary Mixture
2/25	Chemical Reactions	Mystery of 13 Test Tubes
3/4	Gases*	Mid-Term Exam
3/11	Internal Energy, Heat, Work	Spring Recess
3/18	Enthalpy, Light	Thermochemistry and Dimensional Analysis
4/1	Electrons, Periodic Trends*	Antacid Analysis & EM Spectra Review
4/8	Lattice Energy, Lewis Structures	Colorimetry
4/15	Bonding, VSEPR Theory	Radiochemistry & Nuclear Decay
4/22	Liquids, Solids*	Dilutions/Beer’s Law
4/29	Solutions, Review	Gas Law
5/6	Colligative Properties, Review	Final Exam
5/13	Final Exam, No Class	
*Lecture Exam		

An intentional goal of the redesign is to realign the CHEM 1310 and CHEM 1319 topic schedules to improve learner success through intrinsic motivation. Table 1.6 is a schedule from the fall 2014 redesigned CHEM 1319. Laboratory activities were selected to support and/or reinforce lecture topics in a timely fashion.

Table 1.6. Schedule for CHEM 1310 and CHEM 1319 at Missouri S&T Fall 2014

Week	CHEM 1310 Lecture Topic	Redesigned CHEM 1319 Lab Topic
8/25	Nomenclature	Name Tag, Safety, Glassware
9/1	Measurement, Atomic Structure	Labor Day, no lab
9/8	Moles, Mass, Formulas	Organic Compounds
9/15	Empirical Formulas, Combustion*	Copper Cycle
9/22	Stoichiometry, Concentration	Stoichiometry of a Precipitation Reaction
9/29	Chemical Reactions	Hard Water Titration
10/6	Gases*	Boyle’s Law
10/13	Internal Energy, Heat, Work	Ionic Precipitation
10/20	Enthalpy, Light	Spectroscope
10/27	Electrons, Periodic Trends*	Flame Lab
11/3	Lattice Energy, Lewis Structures	Lewis Structures
11/10	Molecular Structure	Types of Compounds
11/17	Liquids, Solids*	Chromatography
12/1	Solutions, Review	Vinegar Titration Final
12/8	Colligative Properties, Review	Silver Bottle Final
12/15	Final Exam, No Class	

*Lecture Exam

Beyond the focus to realign the curricula of the lecture and laboratory course, the redesign team incorporated inquiry-based activities to encourage development of behavioral skills such as communication, teamwork, problem solving, critical thinking, time management, responsibility, accountability, and professionalism. Student-centered learning provides opportunities to improve these skills through interpersonal interactions.[15]

1.3. DISSERTATION OVERVIEW

This project describes the redesign of the freshman general-chemistry laboratory course at Missouri S&T. The goals of this redesign are to

- economically increase accessibility,
- intentionally design the pedagogy of the course to maximize student success, and
- maintain compliance with the Committee on Professional Training (CPT) best practices for a freshman general chemistry laboratory to support continued ACS certification of the Missouri S&T bachelor degree in chemistry.[16]

This document will discuss the alternative directions investigated, the direction chosen, relevant foundational work, project design, project phases, and the delivered product. Supporting information for work conducted that has influenced the project is in the appendices.

2. POTENTIAL SOLUTIONS

As described in Chapter 1, Missouri S&T has had record student enrollment each year since 2007, which is placing a strain on laboratory courses such as CHEM 1319. A growing student population is often motivation to evaluate and improve course offerings. The traditional response to an increase in enrollment is to increase course capacity. Procuring additional space, expanding course offerings, and/or redesigning curricula may accomplish this. Each of these options comes with positive and negative aspects; because they are traditional responses, they are available to review from historical experiences.

Synthesis of solutions requires identification of the unique needs and desired outcomes before attempting the synthesis. Success of a particular solution for a prior situation or location does not justify coercing an educator into adopting the solution. Research, evaluation and elimination, as appropriate, of all possible solutions allows the selection of a solution designed for the specific circumstances at hand. One size rarely fits all. Thus, this project started with the exploration and evaluation of the potential solutions that follow.

2.1. EXPANDED LABORATORY SCHEDULE

In the past, Missouri S&T has reacted to increases in the freshman general-chemistry laboratory course enrollment by increasing the number of time slots offered. To continue under the traditional course structure, non-traditional section times would be required. In fall of 2015, the redesigned course utilized six time slots to offer 48 sections of CHEM 1319. Under the prior course design, twelve time slots would have been required which would lead to a 36-hour commitment in the two laboratory spaces designated for CHEM 1319, not including the time required for preparing and managing the sections. In addition to the lengthy workweek for the course instructor, the time slots would have generated a scheduling nightmare for the incoming freshman cohort as the new time slots would have likely interfered with other required courses identified in Chapter 1. Expanding the offered time slots does not match student and institution preferences; additionally, it would require a change in policy or additional staff, which often reduces consistency.

Expanding the course schedule to increase the number of sections offered could increase accessibility without causing a shift in pedagogy or changing the existing adherence to ACS best practices but does not resolve scheduling conundrums. The desire to change the pedagogical structure and the lack of alignment with student demographics led the author and redesign team to pursue other options for Missouri S&T.

2.2. NEW LABORATORY SPACE

Creating new laboratory spaces is a traditional reaction to enrollment expansion. The literature is riddled with accounts dating back as far as the early 1900s, each with similar experiences. For example, in 1900, Penn State found its Chemistry Department to be lacking in laboratory space.[17] The institution chose to build new laboratories to better match enrollment. Only one year after the new space became available in 1915, the institution again reported a need for additional laboratory space.[18] This is a common experience in education. New buildings are attractive to potential students and can easily spike enrollment beyond anticipated values.

Expanding laboratory space enables departments to increase their capacity without alterations to the existing course structure, which retains the tactile laboratory experiences, compliance with ACS guidelines, and face-to-face interaction of traditional laboratory courses. Traditional course offerings are readily accepted and have research to demonstrate their efficacy.[19,20] However, new laboratories require significant funding, time, and space that are often not available when institutions are reacting to enrollment increases.

New buildings are a joy and should be treasured but they often take several years to complete even if the funds are available. The decision to build a new space requires the institution to make projections for the future: Should the new space double current capacity or aim for a twenty percent increase? How should future enrollment in the course be estimated and how should it guide building plans? Decisions for new buildings and/or renovating spaces are an important part of facility management, requiring extensive planning and serious investment. Therefore, they are not a practical short-term solution to inadequate laboratory space.

New buildings allow institutions an increase in course capacity but do not represent a timely solution, as new buildings and/or lab space require time to prepare. Because of a need to change the pedagogical structure of the freshman chemistry lab course in addition to prohibitive cost and time constraints, the author and the redesign team did not choose to pursue this option.

2.3. VIRTUAL LABORATORY COURSE

Virtual labs are an attractive option for many institutions. They allow for increased capacity relatively quickly, can be less resource-intensive than building new facilities, and have research to support efficacy.[21,22,23] Conversely, virtual labs do not offer the tactile laboratory experiences and face-to-face interaction of traditional labs. In addition, they often require curriculum changes from traditional course offerings and the ACS does not recognize virtual labs as an appropriate replacement for physical laboratory activities.

In 2013, the California State University System reported a significant effort to develop and implement virtual laboratory courses.[24] Several million dollars were dedicated to the development of virtual laboratory activities that would mimic the responsive nature of traditional activities without the burden of procuring new laboratory space.

California's experience generated an important acknowledgement: while virtual laboratory courses are a potential solution for non-majors, they are not appropriate for science and engineering majors. Although technology has advanced significantly, simulations still fall short in teaching the skills practiced in non-virtual activities. Another serious deficiency associated with virtual labs is the lack of reactive experiences available in physical laboratory activities.

The redesign team concurred with the ACS that virtual labs are an appropriate supplement but not a replacement for physical laboratory experiences. [25] Missouri S&T's strategic plan emphasizes experiential learning as a goal for the campus. Relevant literature indicates that experiential activities improve learner confidence.[26] Through tactile experiments, learners are able to gather observations to explore chemical phenomena.[20] Personal experience with the phenomena can provide a concrete foundation for chemistry concepts that previously seemed abstract.

Because virtual labs are not an appropriate substitute for traditional labs, especially for STEM majors, they are not a potential direction for Missouri S&T CHEM 1319. A virtual course would require a new course design and institutional philosophy, greatly at odds with institutional and departmental preferences. In addition, because Missouri S&T offers an ACS certified degree, virtual laboratory activities cannot be used in place of traditional activities without sacrificing ACS certification.

Virtual labs allow an increase in accessibility but only by moving non-science majors out of the traditional lab. Because of the population demographics and the desire to retain physical tactile experiences, the redesign team did not choose to pursue this option further.

2.4. ONLINE LABORATORY COURSE

The author has designed and currently delivers a completely online chemistry course with a lab component at State Fair Community College.[27] Students in the course receive a lab kit containing the reagents, equipment, and instrumentation required to complete the assigned activities. Because of the financial and ecological cost involved with the supplies, lab kits are designed, assembled, and evaluated in house each term. All course submissions and support occur digitally. This is particularly advantageous for students who would otherwise be unable to attend lab on a campus because of time or distance conflicts.

Completely online lab courses have the potential to match student needs with ACS guidelines. Online labs provide the potential direction for growth in the future if the institution desires to shift its focus from traditional campus bound students. Currently, Missouri S&T requires freshman students to live on campus with few exceptions. The practicality and perception of having an online laboratory course is not consistent with the demographics of students who choose to attend Missouri S&T.

Online laboratory courses require a significant course redesign and initial investment. Because learners are not sharing a common laboratory space, instrumentation to support ACS best practices needs to be available on an individual basis, which is a costly proposition. Additionally, each individual or pair of students requires their own reagents and equipment.

Online laboratory courses can expand accessibility and meet ACS guidelines but at a great cost. Because of the lack of compatibility with student demographics and expense, the redesign team did not choose to pursue this option any further.

2.5. BLENDED LABORATORY COURSE

Institutions have used blended teaching strategies to alleviate space limitations, improve pedagogy, and provide scheduling flexibility. William Rainey Harper College in Palatine, Illinois successfully mixed virtual labs and traditional labs in chemistry laboratory courses with a high student success rate.[28,29] Missouri S&T has transitioned the first semester general chemistry lecture course into a blended offering using a buffet model and was able to increase enrollment capacity from 1,056 in the 2010 academic year to 1,514 in the 2014 academic year.[30] State Fair Community College (SFCC) in Sedalia, Missouri has reduced strains on resources by utilizing take home laboratory activities in chemistry lab courses. SFCC noted increased content acquisition in students of blended courses.[31,32,33,34] Each entity has implemented blended teaching in a distinct fashion.

A blended course design allows for an increase in accessibility with an opportunity for intentional pedagogical change and improved compliance with ACS best practices specified in the CPT.[16] For these reasons, the team chose to redesign CHEM 1319 as a blended course.

3. BLENDED COURSE DESIGN

In the fall of 2015, Missouri S&T offered CHEM 1319 as a blended laboratory course. This chapter describes the design utilized to accomplish the course transformation. The blended laboratory course design complied with ACS best practices, increased accessibility, and intentionally focused pedagogy to support learner success.

3.1. ACS BEST PRACTICES

To ensure that the course matches industry-accepted best practices, the course design is centered on the ACS Committee for Professional Training (CPT) Guidelines for Undergraduate Professional Education in Chemistry. One of the primary goals of the CPT is to ensure "approved programs offer their students a broad-based and rigorous chemistry education that provides them with the intellectual, experimental, and communication skills necessary to become successful scientific professionals."[16] These guidelines identify promoting a culture of safety and developing fundamental laboratory skills including qualitative/quantitative solution preparation, conducting chemical measurements with appropriate laboratory equipment, keeping laboratory notes for data analysis, and writing lab reports as expectations for general chemistry laboratory courses. As a result, these guidelines serve as a foundation for the selection of laboratory activities and overall course design. Table 3.1 shows the course activities matched to the ACS suggested laboratory skills and concepts.

3.2. ACCESSIBILITY

To increase accessibility, traditional activities were chosen based on their suitability in two distinct learning environments: traditional and nontraditional laboratory spaces. Traditional activities conducted in traditional spaces are engaging, relevant to lecture content, applicable, brimming with ACS-suggested laboratory skills, experiential, filled with ACS-suggested instrumentation, relevant to the learner's world and daily live, and are assessed with a final exam focused on skills. Traditional activities conducted in nontraditional spaces require attention to safety, physical manipulation, organization, laboratory skills, creativity, engagement, engineering, and communication.

Table 3.1. CHEM 1319 Course Sections and Capacity at Missouri S&T Fall 2014 and Fall 2015

	Lab Skills									Concepts						
	Safe Practices	Keeping a Notebook	Use of Electronic Balances	Use of Volumetric Glassware	Preparation of Solutions	Measurements Using pH Electrodes	Measurements Using Spectrophotometers	Data Analysis	Report Writing	Stoichiometry	Statues of Matter	Atomic Structure	Molecular Structures and Bonding	Thermodynamics	Equilibria	Kinetics
Name Card	x												x			
Safety Contract	x															
SDS Activity	x															
Glassware Quiz	x			x												
Organic Compounds	x	x							x				x			
Flame Lab	x	x					x	x	x		x	x				
Lewis Structures	x	x							x				x			
Esterification	x	x							x		x		x			x
Paper chromatography	x	x		x	x			x	x				x		x	
Copper Cycle	x	x	x	x	x	x			x		x		x	x	x	
Gas Laws	x	x	x					x	x		x			x		
Ionic Precipitation	x	x						x	x		x		x			
Stoichiometry of Chalk	x	x	x	x	x			x	x	x	x		x			
Types of Compounds	x	x	x	x	x	x		x	x		x		x	x	x	
Titration of Hard Water	x	x	x	x	x		x	x	x	x					x	
Spectroscope and the Nature of Light	x	x					x		x							
Titration Final	x	x		x	x			x	x	x					x	
Silver Bottle Final	x		x	x	x	x			x		x			x	x	x

In the blended course, students conduct activities in traditional lab spaces and in nontraditional lab spaces, allowing them to experience the benefits of both environments. The course was structured so students would be in the traditional lab space every other week; therefore, staff and facilities handle half of the enrolled students each week, enabling Missouri S&T to greatly increase course capacity. These activities were termed “In-the-Lab” and “In-the-Commons” experiments, respectively. While the term “In-the-Lab” is self-explanatory, “In-the-Commons” was chosen to encourage students to conduct the activities in commons spaces in residential halls and elsewhere on campus.

As a result of the redesign, CHEM 1319 was able to increase capacity by 30% over the previous fall semester. In the fall 2015 semester, six time slots were capable of serving 1,152 students, compared to fall of 2014 where nine time slots had a capacity of 864 students. The redesign has increased course capacity while reducing scheduling conflicts. Table 3.2 illustrates the capacity expansion noting the reduction in time slots.

In fall 2015, the redesign team was able to avoid offering a Monday section, which historically has been a challenge because of Monday holidays and because the Monday departmental seminar series required for all chemistry graduate students to attend, including the CHEM 1319 graduate teaching assistants (GTAs). By offering CHEM 1319 on Tuesday and Thursday only, the freshman general-chemistry laboratory and recitation schedules complimented each other, reducing scheduling complexity. Table 3.3 and Table 3.4 compare the schedules for the fall 2014 and fall 2015 semesters respectively and indicate CHEM 1310 lecture and exam schedules.

Table 3.2. CHEM 1319 Course Sections and Capacity at Missouri S&T Fall 2014 and Fall 2015

Semester	Time Slots	Sections/ Time Slot	Students/ Section	Capacity
Fall 2014	9	4	24	864
Fall 2015	6	8	24	1,152

Table 3.3. CHEM 1319 Schedule at Missouri S&T Fall 2014

	Monday	Tuesday	Wednesday	Thursday	Friday
0800		CHEM 1319		CHEM 1319	
0900	CHEM 1310		CHEM 1310		CHEM 1310 exam
1000	CHEM 1310		CHEM 1310		CHEM 1310 exam
1100		CHEM 1319		CHEM 1319	CHEM 1310 exam
1200					CHEM 1310 exam
1300	CHEM 1319				
1400		CHEM 1319	CHEM 1319	CHEM 1319	CHEM 1319
1500					
1600	Department Seminar				
1700					
1800					

Table 3.4. CHEM 1319 Schedule at Missouri S&T Fall 2015

	Monday	Tuesday	Wednesday	Thursday	Friday
0800		CHEM 1319		CHEM 1319	
0900	CHEM 1310		CHEM 1310		
1000	CHEM 1310		CHEM 1310		
1100					
1200		CHEM 1319		CHEM 1319	
1300					
1400					
1500					
1600	Department Seminar*	CHEM 1319		CHEM 1319	
1700					
1800	*				

*CHEM 1310 exams held on Monday at 4, 5, and 6 pm

3.3. STUDENT SUCCESS

The transformation of course outcomes focused on improving student success through the development of behavioral skills and the alignment of course topics with CHEM 1310. The author incubated the selected experiential learning activities at SFCC to ensure student success while promoting intrinsic motivation. The incubation demonstrated student engagement and enthusiasm while allowing for an evaluation of student perception.

3.3.1. Behavioral Skill Development. By focusing pedagogy to put learners in control, course completers are guided to become interrogators instead of responders. Learners must explore activities, which provides opportunities for soft skill development. Course redesign activity selection strove to identify those activities that develop behavioral skills such as communication, teamwork, problem solving, critical thinking, time management, responsibility, accountability, and professionalism.

3.3.1.1 Communication. The course design approach revolves around communication. Peer discussion forums, instructor and TA communications, and gradable submissions require an ability to speak, listen, evaluate, and respond to individuals. The theme of communication persists throughout the semester, as learners are required to establish and maintain a schedule of meetings with their lab partner to complete In-the-Commons activities. By requiring such interactions, a cohort of peers is formed that is encouraged to develop their scientific and social communication skills.

3.3.1.2 Teamwork. The course design encourages teamwork. Several activities require learners to collaborate with individuals beyond their lab partner to compare data, share supplies, and successfully complete activities.

3.3.1.3 Problem solving and critical thinking. The course design promotes higher-order thinking. Through intentionally less precise instructions, less distinct assignments, but constant feedback, learners are encouraged to explore chemical phenomena. Instructor’s and TA’s primary roles are providing guidance and keeping the learners safe. Activities conducted in traditional lab spaces can be hindered by excessive supervision such that learners are not required to take responsibility for their learning. Instead, they rely on TAs, instructors, and prepared classmates for answers in lieu of personal responsibility. Explicit detail is removed from experimental instructions to push learners into an active engagement with the activities. For example, the construction of a spectroscope is an activity designed to promote problem solving and critical thinking. Instructions for the activity are to “construct a spectroscope”; students are required to identify appropriate instructions that are, for example, available through the internet, evaluate accessible supplies, and complete the task.

3.3.1.4 Time management. The course design requires organization. Learners must organize their own schedule for In-the-Commons meetings. Without the rigid structure of an assigned meeting time every week, learners must plan ahead and coordinate with their lab partner; this requires them to develop good time management skills in order to meet deadlines.

3.3.1.5 Responsibility. The course design develops responsibility. The blended pedagogy requires learners to take more responsibility for their success breaking with expectations students often harbor when they enter college. When students arrive on campus for the first time, they generally meet with an advisor. The student tells the advisor about their selected major and the advisor gives the student a list of courses to complete. Students sign up for courses and receive a course schedule. Then they bring their course schedule to the bookstore and receive their textbooks. These list-like interactions illustrate and reinforce expectations forged long before the learner enters the lab. Challenging such expectations during the first course meeting by making the students responsible for their own safety contract and nametag as discussed in Section 7.4 encourages learners to become responsible.

3.3.1.6 Accountability. The course design enforces consequences. When students do not complete activities correctly, the activity fails but in a safe manner. While no activity has zero risk, the activities selected involve appropriate risks and support the authenticity of the course.

3.3.1.7 Professionalism. The course design fosters a professional environment. Learners conduct authentic activities that make them feel like scientists instigating a sense of pride and ownership over their communication. The course dynamic requires learners to interact with one another in a manner that demonstrates respect. Punctuality, honoring commitments, and accepting responsibility are examples of ways that learners exhibit professional behavior.

3.3.2. Topic Alignment. The blended course honors the foundational relationship with CHEM 1310, the sister lecture course to CHEM 1319. Though students enroll in CHEM 1310 and CHEM 1319 separately, the courses are intended to be taken in parallel so that the two courses support each other. Both the content and structure of CHEM 1310 were mirrored in every possible way from the timeliness of course topics to the structure for online help. The content alignment included shifting with CHEM 1310's reordering of topics during the summer of 2015 for the fall of 2015 semester. Professor Emmalou Satterfield, the instructor for CHEM 1310 provided the topic schedule for the lecture course. Based on the provided lecture schedule, topics were identified for the laboratory course. The timing was intended to match the lecture and assessment schedule so that learners would encounter topics in the lab before or after lecture coverage and/or before assessments. Table 3.5 contains the scheduled topics for CHEM 1310 and CHEM 1319 in the fall semester of 2015.

As requested, vendors presented In-the-Commons activities as laboratory kits and supplementary content for assessment. The Education Technology division (http://edtech.mst.edu) at Missouri S&T evaluated the online content offered by the vendors. SFCC students, under the author's supervision during the summer semester of 2014, contemplated the laboratory kits and activity instructions.

A vendor initially provided In-The-Commons activity instructions. When alterations and improvements were desired, the vendor refused to acquiesce to such requests. Consequently, the author developed the future In-the-Commons activities employing customized supplies provided by select vendors. Instructions for In-the-Lab activities written by the author, incubated at SFCC, and shared with students as live documents allowed for immediate adjustment as appropriate.

Table 3.5. Schedule for CHEM 1310 Lecture and CHEM 1319 Lab at Missouri S&T Fall 2015

Week	CHEM 1310 Topic	CHEM 1319 Topic A	CHEM 1319 Topic B
8/24	Nomenclature	Safety, Name Tag, Glassware	
8/31	Atomic Structure, Empirical Formula	Flame Lab	Organic Compounds
9/7	Electronic Structure, Periodic Properties*	Organic Compounds	Flame Lab
9/14	Lewis Structures	Esters	Lewis Structures
9/21	Structure, Shape	Lewis Structures	Esters
9/28	Interactions, Solids*	Copper Cycle	Chromatography
10/5	Phases, Ideal Gases	Chromatography	Copper Cycle
10/12	Gases, Liquids	Ionic Precipitation	Gas Laws
10/19	Solutions*	Gas Laws	Ionic Precipitation
10/26	Chemical Reactions	Types of Compounds	Stoichiometry of Chalk
11/2	Combustion, Stoichiometry	Stoichiometry of Chalk	Types of Compounds
11/9	Solution, Gas Stoichiometry*	Hard Water Titration	Spectroscope
11/16	Light, Wave Nature	Spectroscope	Hard Water Titration
11/23	Thanksgiving Break		
11/30	Internal Energy, Enthalpy	Silver Bottle Final	Titration Final
12/7	Energy Changes	Titration Final	Silver Bottle Final
12/14	Final Exam, No Class		

4. PREPILOT INVESTIGATION

4.1. INTRODUCTION

This chapter is a manuscript that has been submitted to the peer-reviewed Journal *Online Learning* published by the Online Learning Consortium (OLC) titled Using blended learning experiences at a community college to transition a freshman general chemistry laboratory course at an engineering university: A data driven collaboration.

The purpose of this article is to report the efforts of a small rural community college to utilize blended learning in a chemistry program to improve compliance with ACS best practices and increase accessibility for commuting students while making pedagogical changes to enhance learner success. The department utilized several modalities over an eight-year period which allowed for an evaluation of student success for the modalities; the modalities include face-to-face, completely online with a physical lab kit, and blended variations in between the two. The evaluation suggests increased success with the blended modality. As a result of the long-term experience with the delivery choices, the blended laboratory approach was adopted for a large enrollment university in a collaboration between the two institutions.

State Fair Community College (SFCC) is a rural community college serving a 14 county area in Missouri and offering degrees including an Associate of Arts, an Associate of Science in Chemistry (University of Central Missouri partner), and an Associate of Science in Engineering (Missouri University of Science and Technology partner). Small class sizes (12-24) allow for a responsive and exploratory nature in course delivery. The chemistry courses at SFCC follow best practices as described by the ACS, incorporate modalities to improve accessibility, and intentionally apply pedagogy to focus student success. SFCC offers chemistry courses in traditional face-to-face, blended, and completely online modalities. The face-to-face modality is traditional and likely similar to those offered at other institutions and will therefore not be described. This paper describes the online and blended modalities along with an evaluation of the aggregate data for each modality and the collaboration with Missouri University of Science and Technology (Missouri S&T) that has developed.

4.2. LITERATURE REVIEW

Blended learning is a fluid term that refers to delivery strategies or pedagogical strategies.[35] The fluidity of the term has generated some challenges in the evaluation of blended courses. Since 2009, blended learning has become better defined which has allowed for some comparison between reports but the residual lack of consistency is still convoluted enough to interfere with assigning causality.[36] For this reason, the most useful information on blended learning has been provided from research between modalities within individual institutions.

In 2009, a large meta-analysis was published that indicated that blended learners appeared to outperform purely online and purely face-to-face students.[37] The study included 99 studies on comparison of modalities and though results were not completely consistent, blended learning appeared to be the most effective. Stanford has indicated that incorporating live e-learning has increase completion rates up to 94%. [38] London Metropolitan University and Bolton Institute reported improved pass rates in programing courses that had been blended.[39] A Virginia university reported that students in a blended course reported a similar sense of community compared to students in a traditional course. [40] The study concluded that the blended environment offers the convenience of an online course without removing the contact opportunities of a traditional course.

Blended learning has research to support efficacy and is gaining popularity. In 2002, Bleed suggested that courses should be transitioned to half physical campuses and half virtual campuses or 50% bricks and 50% clicks.[41] The current culture is technology driven and our courses should be designed to match. To evaluate the effectiveness of practices, active and collaborative learning, student interactions with faculty members, level of academic challenge, enriching educational experiences, and supportive campus environment should each be areas of focus.[42]

The published research has provided a foundation for educational research on blended learning and established guidelines for the evaluation of such styles. This paper focuses on blended learning in the laboratory environment, an area that is underserved in research. The claim that will be discussed is that blended laboratory experiences improve learner success and must be uniquely designed for the population served.

4.3. METHOD

4.3.1. ACS Best Practices. The American Chemical Society (ACS) does not certify two-year college chemistry programs. However, SFCC Chemistry has aimed to match the best practices provided by the ACS Committee on Professional Training (CPT).[43] In 2011, the ACS published a collection of case studies on the use of ACS Guidelines for chemistry in two-year college programs and included a section on SFCC Chemistry.[34] The case study identifies a hands-on curriculum, a culture of safety, literature research, and section capacity as some of the areas that SFCC focused on to match the industry-accepted best practices.

4.3.2. Accessibility. Students at SFCC are typically first-generation non-traditional commuting students. Figures 4.1 and 4.2 show student responses to a cost-of-attendance survey from 2008 through 2014. Students reported that they were driving five or more days a week, with about half of the students driving over twenty miles and over half reporting childcare expenses. Time and distance are serious obstacles to SFCC student attendance.

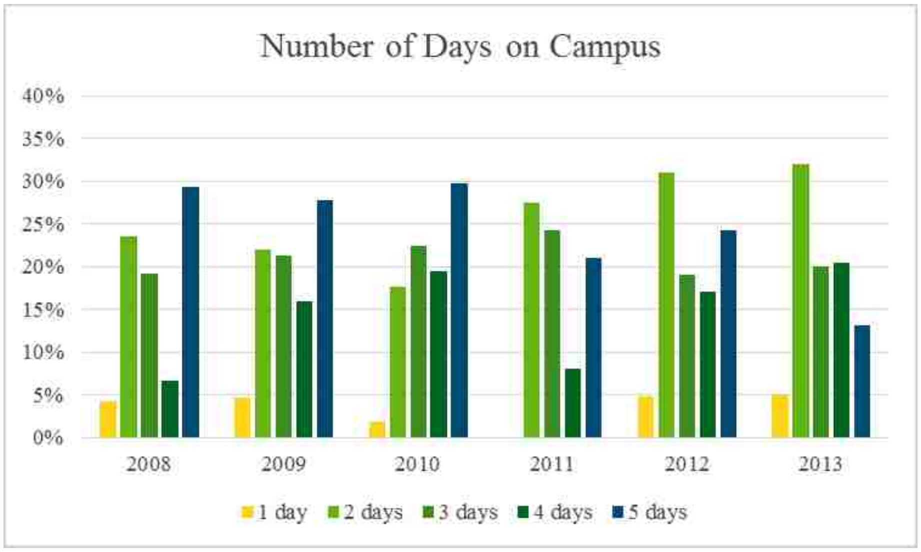


Figure 4.1. Percent of Students Reporting Number of Days on Campus at SFCC 2008-2014

Figure 4.2. Percent of Students Reporting Miles One Way to Campus at SFCC 2008-2014

4.3.3. Student Success. Typically, few of the students enrolled in chemistry courses at SFCC are science majors therefore chemistry courses strive to develop behavioral skills and science consumerism when learners are exposed to the traditional content. For this reason, chemistry courses at SFCC focus on learner-driven concept exploration directing the learner to develop skills at locating and vetting answers. Learners are allowed to influence the choice of activities increasing their acceptance of responsibility for reaching course outcomes. Blended learning provides success with the adoption of intentional pedagogical changes to provide accessibility to a commuter population.

4.3.3.1 Behavioral skill development. Employers have suggested incorporating open-ended assignments with ambiguous instructions and vague point value to develop behavioral skills.[44] Many of the activities and discussions used at SFCC begin with general statements or ideas. For example, the atomic structure discussion begins with a simple question, "What is an atom?" Students analyze their existing knowledge, synthesize an appropriate response, and then evaluate their responses against peer responses. The peer work supports an environment where teamwork and collaboration are developed. An additional example is the activity of separating of a ternary mixture consisting of salt, sand, and chalk, which begins with testable statements about the compounds involved:

- Salt is soluble in water.
- Chalk is insoluble in water but soluble in acidic solutions.
- Sand is insoluble in water and acidic solutions.

Students analyze their existing understanding of the phenomena of solubility, synthesize strategies to test the statements, and evaluate their success against peer values. All activities at SFCC support development and/or demonstration of behavioral skills. Students make decisions, provide analysis of observations, synthesize appropriate communication, and evaluate their performance with defendable conclusions. Course completers become interrogators instead of responders.

Service learning provides opportunities for behavioral skill development and improves student success.[45] Students at SFCC have led library demonstrations, career day activities, science fairs, Boy's and Girl's club activities, and Boy Scout activities with instructor guidance. In keeping with the vague point value, learners earn their reward based upon the value of their contribution in service learning projects without a set number of points possible; engaged learners earn more points.

4.3.3.2 Science consumerism. An important goal of chemistry courses at SFCC is to generate informed science consumers. An informed science consumer knows how to find appropriate scientific information to recognize and/or refute pseudoscience while avoiding emotional claims that do not have scientific support. Even though our students are not scientific professionals, such individuals frequently dominate the voting population. By incorporating science consumerism as a part of the curriculum, course completers have an opportunity to make informed choices. Part of being an informed consumer is science literacy. Learners at SFCC are required to identify and analyze primary literature research articles in a project called Science Communication (see Appendix A).

4.4. ONLINE LABORATORY SOLUTION

In fall 2010, the chemistry department designed a completely online chemistry course with lab, which required the provision of a lab kit containing all necessary reagents and instruments to students enrolled in the course. The department selected activities to match course objectives and mirror the existing course. The laboratory activities conducted in the first offering were designed by a vendor and shipped directly to the students. While the learners were able to demonstrate appropriate mastery of content, the commercial laboratory kit activities lacked instrumentation and did not match the development of behavioral skills and exploratory nature of the SFCC chemistry program. In addition to the pedagogical issues, the vendor did not accommodate return and reuse of laboratory kits, which did not match the environmental goals of the institution.

An evaluation of the first semester experience led the department to construct future laboratory kits in house.[25] The course instructors generated a spreadsheet of laboratory activities matched to all potential outcomes. The department chose activities to maintain course outcomes based on supplies available for shipment to students. Selected activities led to the generation of a packing list including appropriate shipping and packaging policies for all supplies in accordance with regulations as specified in Department of Transportation Title 49 Code of Federal Regulations. An appropriate shipping container was identified to contain the supplies and the laboratory kits were assembled. After students completed the activities, laboratory kits were returned to be evaluated by the course instructor.

The online course supported student access for those who were only able to take distance courses. The course offered an option for completion of a chemistry lab course with equivalent rigor to the on-ground offerings. While the course filled an important void, there were still significant difficulties in meeting ACS guidelines. Students in on-ground courses normally share ACS suggested instrumentation but in an online course, such instrumentation must be purchased and supplied on an individual basis. The financial and logistical constraints make this an area in need of constant reassessment and improvement. Hot plates, conductivity probes, spectrophotometers, electrophoresis equipment, pH electrodes, temperature probes, and voltage meters are examples of instrumentation that have been included throughout the evolution of the in-house laboratory kits at SFCC.

All activities in the online course focus on student success. Early activities establish the expectations of the course. Lab partners are required and cyber supervision is always available. Safety is the main concern for all laboratory courses at SFCC including the online version. The first eighth to quarter of the course is primarily focused on safety including the generation of individualized safety contracts including identification of an appropriate laboratory partner, appropriate laboratory space, and appropriate storage spaces for the laboratory kit. Students do not receive lab kits until they satisfactorily contribute to the culture of safety in the course. The safety activities include research on industry standards and group work to develop a sense of community.

4.5. BLENDED COURSE SOLUTION

In 2007, SFCC began utilizing blended course structures by expanding the laboratory space beyond the traditional classroom and conducting portions of discussions in the virtual space. The blended course structure enables learners to avoid unnecessary travel and minimizes scheduling conflicts.

The expansion of the traditional laboratory space allowed for students to conduct activities in their living environment, which supported the concept that chemistry is not something that occurs in a laboratory; chemistry is everywhere. The department identified take-home activity topics and then students researched, designed, and conducted the activities with materials in their environment. The intent of the take-home activities was to increase learner confidence in decision making while increasing their understanding of chemical phenomena.

Learners were required to be a part of the ongoing discussion and decision-making process that is the culture of safety including safety for activities conducted under cyber supervision. At the beginning of the course, learners establish and agree to a safety contract. Peer groups discussed risks for the activities conducted outside of the traditional laboratory space to develop fundamental at-home safety guidelines. The group discussions facilitated behavioral skill development by requiring individual responsibility for aspects of the discussions.

Virtual discussions enhanced and supported learner growth. For example, in one course design, the instructor began a discussion thread for each outcome of the course.

Learners responded to the thread with their best attempt to defend the claim that they had mastery of the topic at a level appropriate for the course. The instructor provided a grade and feedback to the learner. Learners then had the opportunity to research, reevaluate, and repost to the same topic in an attempt to earn a higher score. The virtual conversations allowed individual participation to be clearly monitored, recorded, and expanded upon. A positive aspect was that the more reticent learner still had a voice in the course. Learners were encouraged to share their understanding in the moment and were offered opportunities to improve through instructor feedback, student interaction, and individual research.

4.6. COLLABORATION

Missouri S&T considered the SFCC blended learning experience and results when they chose to implement a blended laboratory course. Because Missouri S&T offers an ACS certified Bachelor of Science degree, the activities needed to incorporate best practices indicated by the CPT. The SFCC blended learning experiences matched the best practices while demonstrating increased student success.

The freshman general chemistry laboratory course at Missouri S&T had become a bottleneck course due to enrollment exceeding capacity. To provide all students with an opportunity to enroll in the course at a time appropriate to their academic path, the institution chose to implement a blended course design where learners conduct activities in the traditional space and in non-traditional spaces across the campus. Missouri S&T selected activities from the SFCC repertoire based on an ability to match the redesigned course goals, including alignment with the lecture course. The differences in student and institutional demographics inhibited the direct transplant of the SFCC course to Missouri S&T. SFCC students incubated the selected activities to evaluate instructions, learner engagement, appropriateness for rigor, activity duration, outcomes, hazards, and instrumentation required. The small class sizes at SFCC allowed for responsive interaction, immediate feedback, and fluid activity improvement. SFCC students provided additional feedback through individual and group interviews upon completion of each activity.

4.7. RESULTS

Results from the experiences at SFCC indicate that as learners work autonomously outside of traditional spaces, they develop behavioral skills, which allow them to grow into self-initiating and confident learners with increased cognitive/critical thinking skills. The additional work completed by Missouri S&T on offering a blended lecture course reinforces this positive experience.[30] Figure 4.3 illustrates SFCC learner average course GPA based upon the amount of direct and digital supervision. An analysis of variance showed that the differences were statistically significant at a 90% confidence level with n=952 and an F test p value of 0.093. The multiple variations of the blended modality are a result of the institution responding to student needs over an aggregate time frame.

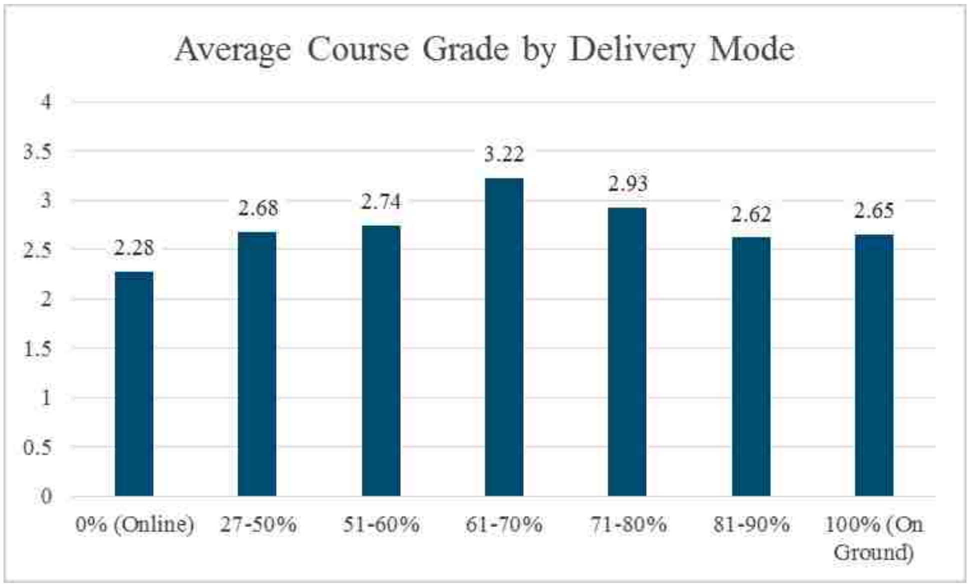


Figure 4.3. Average course grade for each delivery mode on a 4.0 scale at SFCC aggregate of 2007-2013

4.8. DISCUSSION

Not surprisingly, the completely online students were not those with the highest average GPA. The distance environment is challenging as learners often feel isolated and must rely on asynchronous support. In addition, the lab partner in the online course is generally a friend or spouse who may have never taken a college laboratory course. When the learner requires assistance, they send their request through email or the Learning Management System. The learner generally experiences a time lag before an instructor or classmate can respond. Several exchanges may be required to discern the issue. For example, multiple emails may be required for the instructor to realize that a student has assembled a portion of the apparatus upside down. The online laboratory learners exhibit a sense of pride and ownership over the skills developed in the autonomous environment because they are able to overcome these challenges.

Surprisingly, the completely on-ground learners were not those with the highest average GPA either. This seems counterintuitive; they have access to the traditional laboratory space designed for student success, synchronous interactions with their dedicated instructors and classmates, and a lab partner with an equal stake in the course. The barriers to student success in the traditional course are the same things that appear to be positive assets. The face-to-face environment removes the opportunity for learners to develop independence; learners become dependent upon intrusive instructor input or helicopter classmate. The traditional lab space removes the opportunity for learners to adapt their environment and overcome obstacles. The provided supplies remove the opportunity for creative investigation of commercially available reagents. The on-ground learners reap the benefits of the environment designed for laboratory investigations, which allows learners to experience instrumentation that is more expensive and hazardous reagents.

The blended learners earned the highest average GPA. Learners in the blended environment benefit from both the traditional laboratory environment and the autonomous environment. The blended learners exhibit a sense of pride and ownership over the skills developed in the autonomous environment because they are able to overcome these challenges and reap the benefits of the environment designed for laboratory investigations, which allows learners to experience instrumentation that is more expensive and hazardous reagents.

4.9. CONCLUSION

Blended laboratory course design improves accessibility, meets ACS best practices, and promotes student success. Offering chemistry courses using three common modalities has allowed a comparison between delivery strategies. The increased success of the blended learners over the face-to-face and the fully online learners has been illustrated. The data reported indicates that learners benefit from the positive aspects of blending the traditional laboratory space with the autonomy of a distance course. Even so, course design must be specific to the existing environment, goals identified, and resources available. The variations in delivery techniques employed by the collaboration projects is the next arena for research and reporting.

5. PROOF OF CONCEPT PILOT

5.1. INTRODUCTION

This chapter is a manuscript that has been submitted to the *Journal of Chemical Education* titled Piloting Blended Strategies to Resolve Laboratory Capacity Issues in a First-Semester General Chemistry Course.

Laboratory capacity is an issue that has plagued education for more than a century. New buildings, late night classes, and virtual labs have offered transitory relief at great expense. Missouri University of Science and Technology is employing blended strategies to increase capacity and student success. Blended strategies expand learning workspaces so that learners conduct traditional laboratory activities in both traditional and non-traditional laboratory environments. This article focuses on the proof of concept pilot results from blending the first-semester general chemistry laboratory course, which validate the adoption of this strategy for increasing student volume.

The challenge of inadequate laboratory space is an old problem. Over the years, institutions have reported and addressed the issue with a multitude of approaches. The Annual Report from Pennsylvania State College shows that the institution was having to move students out of laboratory spaces due to crowding in 1900.[17] Sixteen years later, a separate edition of the same report stated that “in spite of the large addition made to the chemistry laboratory in September 1915, it is already so crowded that satisfactory work is difficult to obtain”.[18] Nearly 100 years later, California State University system is facing the identical challenge of a lack of sufficient space in bottleneck courses.[24]

Such reports and incidents have led the development of policies and best practices. The International Code Council, Building Officials and Code Administrators, National Fire Protection Association (NFPA), and National Science Teachers Association (NSTA) have each published positions with regard to room capacity and student-instructor ratio.[46,47,48,49] Keeping these policies and best practices in mind, institutions either construct new facilities or employ imaginative solutions.[50,51,52] California State University system invested in virtual courses to double enrollment capacity in 2013.[24] Princeton University completed construction on the new Frick Chemistry Laboratory building in 2010 that will serve several hundred undergraduate students.[53] State Fair

Community College in Sedalia, Missouri has reduced strains on resources by utilizing take-home activities in chemistry laboratory courses with increased content acquisition noted in students enrolled in blended courses.[31,32,33] Cape Fear Community College in Wilmington North Carolina noted higher student test scores for students enrolled in distance chemistry courses compared to conventional students in face-to-face courses.[54]

The American Chemical Society (ACS) has stated that virtual labs are an appropriate supplement but not a suitable replacement for physical laboratory experiences.[25] California State University system agrees and identified virtual labs to be inadequate for science majors.[55] With unlimited funds, time, and space, new facilities are ideal. The majority of institutions, however, are not fortunate enough to be able to build new laboratory spaces every time that they grow past their physical space and time constraints. Each individual situation requires a tailored solution that fits the resources available with the needs of the institution. This paper presents a malleable solution to inadequate laboratory capacity; blended learning opportunities safely allow learners to conduct half of the traditional activities outside of the traditional laboratory setting, which allows for a double in capacity without sacrificing established learning goals, which are defined as the desired results that establish priorities for instruction and assessment.[30]

5.2. TRADITIONAL LABORATORY ACTIVITY CHALLENGE

At Missouri University of Science and Technology (Missouri S&T), the General Chemistry I laboratory course (CHEM 1319) usually taken during the first year has reached the point where expansion is imperative. End-of-term census numbers show that since the fall of 2010, course capacities have reached an average of 94% capacity (see Table 5.1) despite measures to increase the absolute number of students served. In the 2012-2013 academic year, Missouri S&T offered 48 more seats by increasing the number of students per section. With this increase, the section size (24 students) approached the maximum student-GTA ratio (25 students) set forth in the ACS guidelines.

For fall semester 2014 and fall semester 2015, the campus registrar requested additional sections due to increased enrollment projections. Accordingly, in the 2014-2015 academic year, the course incorporated an additional 96 seats making the laboratory space occupied five days a week in morning, afternoon, and evening sessions leaving little to no time for experiment preparation and set up.

Table 5.1. Students enrolled in CHEM 1319 based on end-of-semester census

Academic Year	Seats Offered	Student Enrollment in CHEM 1319, [a]N	Enrollment Relative to Capacity, %
2010-2011	1008	944	94%
2011-2012	1008	953	95%
2012-2013	1056	959	91%
2013-2014	1056	995	94%
2014-2015	1152	1055	92%

[a]General Chemistry I laboratory course, corequisite yet independent of Chemistry I lecture course (CHEM 1310)

Even with the added sections and the increased section size, the Chemistry Department was unable to accommodate all students enrolled in the co-requisite but independent General Chemistry I lecture course (CHEM 1310). With the current scheduling and space limitations, additional seats are not practical, and the disparity between enrollments in CHEM 1319 and CHEM 1310 has swelled. The lecture- and recitation-based CHEM 1310 has recently undergone a whole-course redesign, which significantly increased the available seats from 1056 in the academic year 2010-2011 to 1514 in the academic year 2013-2014 (see Table 5.2).[30,56]

The lecture course is now a buffet-style blended course that allows students to choose between attending the lecture face-to-face in the classroom or synchronously online from a location of their choice. The recitation portion of the course offers similar options, collaboratively face-to-face or independently online. Because CHEM 1310 and CHEM 1319 are complementary parallel courses, it is highly desirable that both courses serve the same number of students. This is particularly important because all science and engineering majors at Missouri S&T require both courses in their undergraduate degree programs. For example, in the fall of 2013, the number of full-time freshmen engineering undergraduates at Missouri S&T was 1,386. While CHEM 1310 could accommodate all of the students in the cohort, CHEM 1319 could only serve 76% of the population in that academic year.

Table 5.2. Students Enrolled in CHEM 1310 Based on End-of-Semester Census Data

Academic Year	Seats Offered	Students Enrolled in CHEM 1310 [a]N	Enrollment Relative to Capacity, %
2010-2011	1056	1043	99%
2011-2012	1056	1032	98%
2012-2013	1056	1032	98%
2013-2014	1479	1090	74%
2014-2015	1479	1141	77%

[a]General Chemistry I laboratory course, corequisite yet independent of Chemistry I lecture course (CHEM 1310)

The lecture course is now a buffet-style blended course that allows students to choose between attending the lecture face-to-face in the classroom or synchronously online from a location of their choice. The recitation portion of the course offers similar options, collaboratively face-to-face or independently online. Because CHEM 1310 and CHEM 1319 are complementary parallel courses, it is highly desirable that both courses serve the same number of students. This is particularly important because all science and engineering majors at Missouri S&T require both courses in their undergraduate degree programs. For example, in the fall of 2013, the number of full-time freshmen engineering undergraduates at Missouri S&T was 1,386. While CHEM 1310 could accommodate all of the students in the cohort, CHEM 1319 could only serve 76% of the population in that academic year.

5.3. TRADITONAL LABORATORY ACTIVITY SOLUTION

Because additional space and time slots are not available, Missouri S&T decided to seek alternative methods to increase course capacity. An ideal solution should retain an experiential learning format to align with the campus strategic plan, improve learner confidence, and improve content acquisition.[57,58,59] The solution should circumvent the physical space limitations while allowing the course to continue meeting NSTA and NFPA best practices regarding student-to-teacher ratio and physical space per student.[48, 49]

Before exploring potential solutions, the department recognized specific criteria. Foremost, the experiments conducted need to support the learning objectives identified in the related lecture/recitation course.[60,61] Several of the selected laboratory experiments are only suitable for a traditional laboratory setting because of the instrumentation and chemical hazards associated with the activities. However, some of the activities do not require complex instrumentation, hazardous materials, or even direct supervision while still reinforcing key concepts presented in the lecture. These less hazardous activities naturally lend themselves to a less supervised environment in which students work in a more self-directed and independent manner.

With the above requirements and limitations in mind, a blended laboratory course was designed in which students would conduct half of their activities in the traditional laboratory space (In-the-Lab activities) and the other half in common spaces (In-the-Commons activities). A blended course delivery format allows for a more efficient use of the available space and time slots, effectively doubling the student throughput without sacrificing the traditional laboratory experience. All of the activities involve physical manipulation of reagents and/or equipment to observe the explored chemical phenomena and develop hands-on laboratory skills. Students conduct the more hazardous activities In-the-Lab and experience the less hazardous activities In-the–Commons providing additional opportunities to develop non-cognitive skills and self-reliance. The course retains the same number of meeting hours; however, half of the hours occur outside of the traditional laboratory environment.

5.4. COURSE ORGANIZATION

Each week, half of the students work in the traditional laboratory space while the other half work in pairs outside of the traditional laboratory space to perform a separate but related activity. The following week, the two groups trade and conduct the other activity. This arrangement allows doubling the course capacity without compromising the physical, experiential, and hands-on nature of traditional laboratory activities. Supplies for In-the-Commons activities are packaged in kits that contain all reagents and materials necessary for the activity. For safety and expense concerns, only plastic versions of traditional lab glassware (such as beakers, graduated cylinders, etc.) are provided in the check-out kits, while regular glassware is used for In-the-Lab activities. The kits are checked out at the end of an In-the-Lab activity and returned two weeks later at the beginning of the next In-the-Lab activity. To keep track of the kits, an inventory system is employed utilizing a magnetic card swipe, a barcode reader, and a spreadsheet program. To check out a kit, both student lab partners must swipe their student ID cards before a graduate laboratory assistant scans the barcode affixed to the outside of the kit. The acquired information is automatically saved in a specially designed electronic spreadsheet.

Students are required to work with their lab partner for In-the-Lab activities and strongly encouraged to do the same for In-the-Commons activities. Collaboration and consultation between sets of partners is condoned for In-the-Commons activities as the development of interpersonal, collaborative skills is one of most important behavioral skills fostered with the blended lab model. All electronic submissions of homework required the inclusion of a unique name card in the submitted images to indicate lab participants present.

Before choosing appropriate laboratory activities, the department identified concepts that would best align with the lecture/recitation course CHEM 1310 and then selected activities to direct the learning environment to allow students to rotate between In-the-Lab and In-the-Commons work areas. In essence, pairing activities involving minimal-risk instrumentation with activities of greater-risk instrumentation supported a rotating schedule. Each of the activities chosen for this course is broad enough in scope to address topics covered in two weeks of the lecture course. Students who perform the activity in the first week may receive an introductory treatment of the topic in lecture and recitation, while students performing the activity the following week may have already received a more thorough treatment of the topic by that time. Both scenarios complement and support the lecture material: the former in providing scaffolding for the more rigorous and detailed treatment of the material in the lecture course, and the latter in reviewing and concretizing the information.

Activities were selected based upon their inclusion of tactile, authentic, and responsive characteristics. In the experience of the investigators, activities with these qualities were deemed most likely to effect the desired learning outcomes. Tactile activities maximize learner involvement and engage as many of the students' senses as possible through visual color changes, audible fizzing, palpable temperature changes, and noticeable odors. Authentic activities enable learners to feel like real scientists, applying their knowledge to conduct scientific investigations involving real-world problems and techniques.[62] Responsive activities are sensitive to missteps in following written instructions, meaning that a misinterpretation could result in a less successful activity. Such opportunities to fail must allow learners to experience the consequences of their actions while minimizing the possibility of generating a hazardous situation or environment.

No special prelab videos or extra instructions were provided for the In-the-Commons activities because an intended learning objective is to encourage independent research of topics and techniques.[63] To compensate for the intentional reduction of immediate supervision during the In-the-Commons activities, cyber supervision was provided during the regular laboratory hours via the communication platform Google Hangouts and asynchronously through the Piazza discussion forum.[64,65] Piazza proved to be particularly useful for this model, as students' questions are submitted in the format of an internet forum, where other students can view, discuss, and answer them.

Missouri S&T's administration anticipated that students would often choose to conduct assigned In-the-Commons activities in the common spaces of residential housing facilities; therefore, the project included a review of the residential housing contracts to identify and resolve conflicting policies. Environmental Health and Safety personnel met with project members to verify that all activities conducted In-the-Commons provide a sufficient level of student safety, protection of property, and minimal environmental impact; the parties reached a consensus before the beginning of the course pilot.

The course redesign has three stages: an initial proof-of-concept pilot launched in the fall of 2014, an expanded logistical pilot in the spring of 2015, and the full implementation for all CHEM 1319 sections in the fall of 2015. The proof-of-concept pilot offered an opportunity to directly compare identical traditional laboratory activities being conducted In-the-Lab and In-the-Commons. Additional information gathered included an evaluation of learner success, suitability of laboratory procedures, and general feedback on the design of the course.

5.5. INCUBATION

State Fair Community College piloted each of the laboratory activities in this project. The small class size and longer meeting times allowed for synchronous communication and instant feedback from students about the activities. These debriefing activities optimized alignment with CHEM 1310 curriculum and developed outcome measurement tools (rubrics) for the experiments. The debriefing provided direction to optimize activity instructions and teaching assistant training with an eye to the full transformation in fall of 2015, which would serve more than 1000 students.

5.6. FALL 2014 PILOT

In the fall of 2014, two sections conducted the redesigned activities in two fashions; one section conducted all activities under traditional supervision In-the-Lab while the other section alternated between conducting their activities In-the-Commons and In-the-Lab (see Table 5.3).

The “blended” section experienced the rotation, and the “face-to-face” section conducted all activities in the traditional laboratory setting. The “pilot” included both the blended section (24 students) and face-to-face section (23 students). The “traditional” sections encompassed the remaining CHEM 1319 sections that were not a part of the pilot (total of 790 students). The blended and face-to-face sections employed the same teaching assistants to reduce variables and bias.

Table 5.3. Schedule, Topic, and Venue Distribution of the Fall 2014 Mini-Pilot Labs

2014 Date Lab Was Offered	Laboratory Topic Investigated by All Students	Laboratory Venue Usage by Student Groups[a] Face-to-Face and Blended
8/25	Name Tag, Safety, Glassware	Lab setting for Face-to-Face and Blended groups
9/1	Labor Day, no lab	---
9/8	Organic Compounds	Commons setting for Blended group
9/15	Copper Cycle	Lab setting for Face-to-Face and Blended groups
9/22	Stoichiometry of a Precipitation Reaction	Commons setting for Blended group
9/29	Hard Water Titration	Lab setting for Face-to-Face and Blended groups
10/6	Boyle's Law	Commons setting for Blended group
10/13	Ionic Precipitation	Lab setting for Face-to-Face and Blended groups
10/20	Spectroscope	Commons setting for Blended group
10/27	Flame Lab	Lab setting for Face-to-Face and Blended groups
11/3	Lewis Structures	Commons setting for Blended group
11/10	Types of Compounds	Lab setting for Face-to-Face and Blended groups
11/17	Chromatography	Commons setting for Blended group
11/24	Thanksgiving Break	---
12/1	Vinegar Titration Final	Commons setting for Blended group
12/8	Silver Bottle Final	Lab setting for Face-to-Face and Blended groups
12/15	Final Exam, No Class	

[a] Face-to-Face group students conducted all of their labs in the traditional laboratory space; Blended group students conducted 7 labs in the traditional laboratory space and 7 outside of it.

No distinctions between the traditional and pilot sections were made in the course catalog in order to generate a representative sample of students. When the instructor notified enrolled students about the pilot, students were given the opportunity to switch to a traditional section; however, no student opted to withdraw from the pilot.

The pilot was evaluated using a pre-/posttest consisting of 22 multiple-choice questions (possible score range is 0-22) designed to probe student misconceptions about chemical phenomena encountered in most general chemistry curricula. The test was based on the Chemical Concepts Inventory developed by Doug Mulford for his M.S. Thesis.[57] In addition, CHEM 1310 (General Chemistry I lecture) performance was used as an independent measure of student success in CHEM 1319 (General Chemistry laboratory), since the primary purpose of the redesigned lab course is to support and complement the lecture course. At Missouri S&T students earn separate grades for CHEM 1310 and CHEM 1319. A comparison of the CHEM 1310 grades and the pre-/posttest performance for the traditional and the pilot sections supports that the students in the pilot were not at a disadvantage.

As indicated by Table 5.4 and Table 5.5, the pilot students had an average pre/posttest score difference of 0.619, and traditional students had an average pre/posttest score difference of 0.930. Figure 5.1 shows the distribution of percentage of students who earned the indicated difference between individual pre/posttest scores. The distribution of students is very similar between the two delivery modes, demonstrating that the redesign appears to offer a similar opportunity for student success. While there is some variation in the pre/posttest scores, the changes are not of statistical significance and possibly related to the small number of students in the pilot.

Table 5.4. Pilot Pretest and Posttest Score Average, Minimum, and Maximum

Parameters	Student Scores[a] by Instrument (N=47)	
	Pretest	Posttest
Average	9.84	10.483
Minimum	4	2
Maximum	17	15

[a]The possible range of the scores is 0-22

Table 5.5. Traditional Pretest and Posttest Score Average, Minimum, and Maximum

Parameters	Student Scores[a] by Instrument (N=790)	
	Pretest	Posttest
Average	10.048	10.978
Minimum	1	2
Maximum	19	19

[a]The possible range of the scores is 0-22

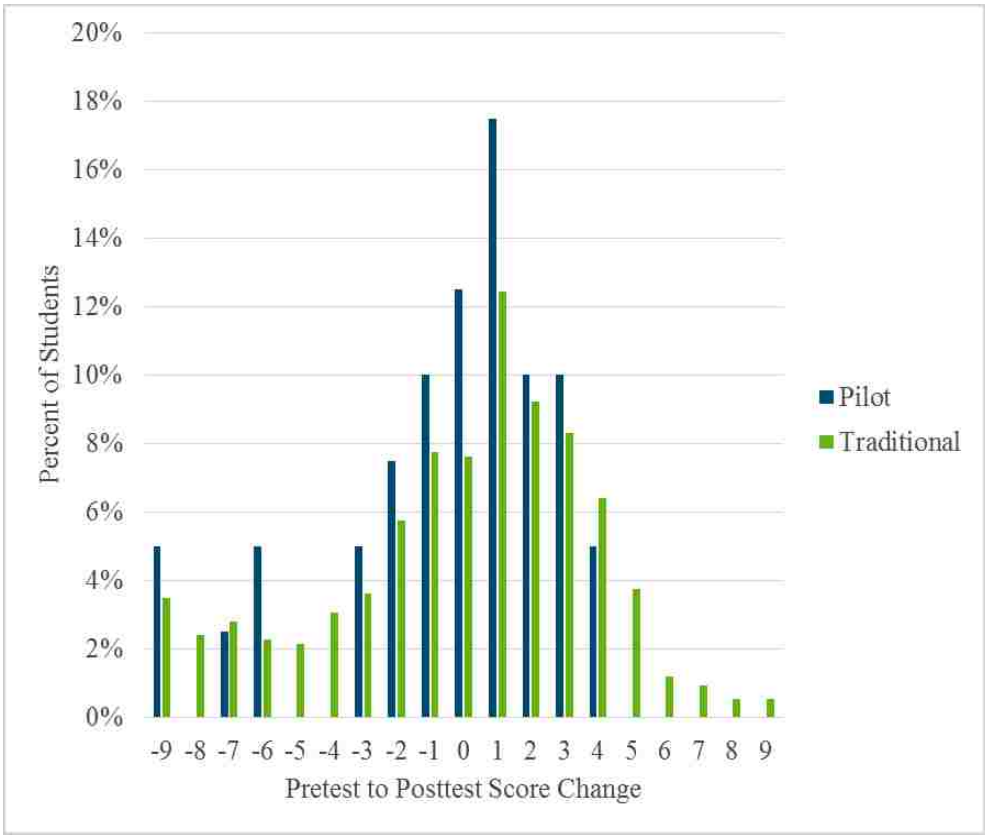


Figure 5.1. Percent of students with difference between Posttest and Pretest score

Figure 5.2 and Figure 5.3 show that the grade distribution between the two modes of delivery are similar. The largest disparity between the traditional and pilot data occurs in the percentage of drops at the end of the course (Figure 5.3) from 11% of the traditional students compared to only 5% of the pilot students. This variation in percentage of drops could easily be incidental (p value >0.05); on the other hand, it may indicate that the redesign offers a greater opportunity for increased intrinsic motivation.

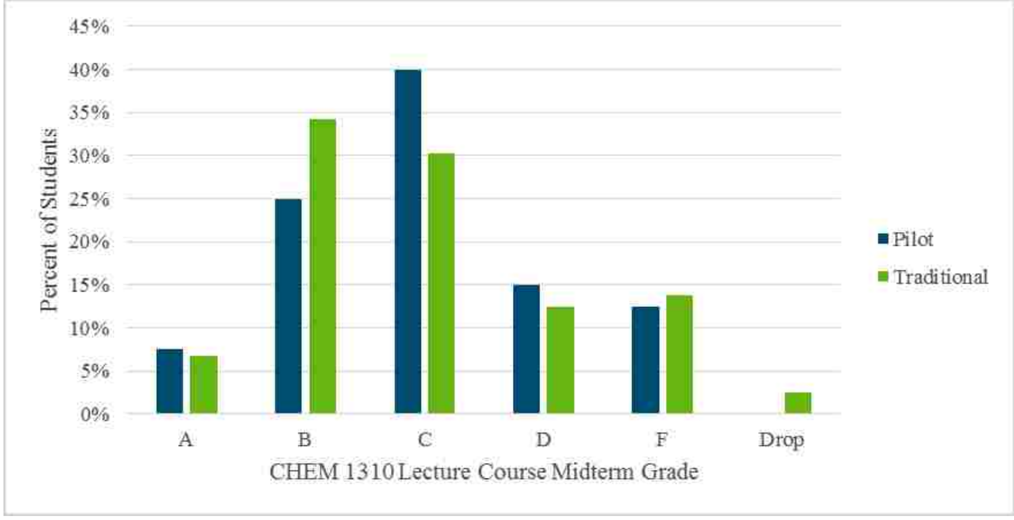


Figure 5.2. Percent of students with 1310 Midterm Grades

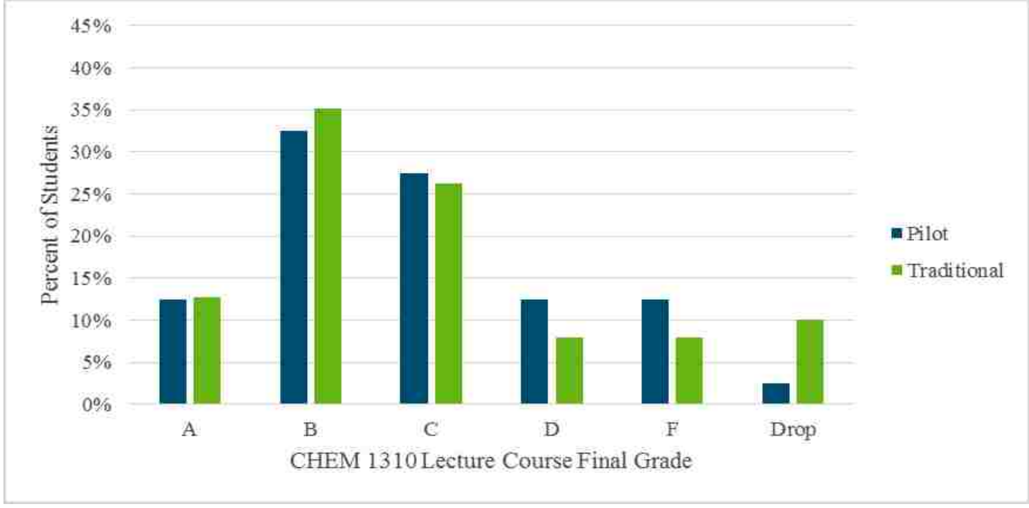


Figure 5.3. Percent of students with 1310 Final Grades

Encouraging information from the mini-pilot came in the form of student feedback. Students offered written and video-recorded feedback about both styles of activities. Learners appreciated:

- the connection between the parallel lecture course content and laboratory activities of the pilot course.
- opportunities to collaborate beyond immediate partners in the course.
- experiencing team-building skills in the course.
- the independent and self-directed nature of In-the-Commons activities.
- the scheduling flexibility of In-the-Commons activities.
- the reduction of intrusive supervision during In-the-Commons activities.
- the freedom to try different approaches during In-the-Commons activities.
- the authentic environment, which encouraged them to research and explore concepts beyond the graded portion of the course.

Some students expressed frustration that the In-the-Commons and In-the-Lab activity instructions were obviously from two distinct sources. The compilation of negligible negative feedback does not indicate that all students were completely satisfied with the course; quite probably, those with negative feedback to offer felt disinclined to participate in the voluntary feedback process.

Additional anecdotal evidence included instructor observations that students in the blended section appeared to be more independent and efficient than those of the face-to-face section. Otherwise, the face-to-face and blended sections did not produce measurable differences in collected data, which seems to support that the blended design offers an appropriate solution to increase capacity. Missouri S&T intends to track grades and success of the pilot students in future courses to see if the participation in the pilot had a measurable impact on their overall success.

5.7. CONCLUSION

In the past, a common response to inadequate laboratory teaching space has been to physically expand available space or offer sections at less traditional times. Many institutions lack the funds necessary for either response leading to the examination of alternative solutions.

The anticipated traditional laboratory strategy is becoming difficult to offer at an adequate volume. Blended courses can double physical space capacity while retaining the desirable payoffs of traditional laboratory activities. Furthermore, the data presented supports that blended activities are as effective as traditional offerings with a potential added benefit of improved soft-skill development in participants.

While this article only addresses a blended first-semester general chemistry laboratory course, the concept is applicable to courses of various sizes and disciplines. Hence, blended laboratory activities offer a practical and customizable option for institutions.

6. LOGISTICAL PILOT

Investigation of organization and preparation requirements occurred in the logistical pilot. The first deployment of an oscillating schedule including preparation, dispersal, and retrieval of In-the-Commons materials. The goal of the logistical pilot was to elucidate requirements for full-scale implementation.

6.1. SCHEDULE

In spring 2015, students of four sections experienced the blended redesigned course. Each week, the student of two sections conducted In-the-Lab activities while those of the other two sections conducted In-the-Commons activities. During the following meeting, each section conducted the other style of activity resulting in an oscillation between In-the-Lab and In-the-Commons activities. As a result, sections conducted activities in a different order, activities were conducted over two weeks, and each lab group occupied the traditional lab space every other week. Table 6.1 shows the oscillation of activities between the two sections alongside the lecture course topics.

During the logistical pilot, two TAs jointly supported all four sections. This required both TAs to support two different activities and track the requirements for two student cohorts in any given week, a cumbersome task. Therefore, future TAs would be assigned the same schedule as their students, enabling the TAs to oscillate with their students.

Table 6.1. Schedule for CHEM 1310 Lecture and CHEM 1319 Lab at Missouri S&T Fall 2014

Week	CHEM 1310 Topic	CHEM 1319 Topic A	CHEM 1319 Topic B
1/19	Nomenclature	MLK Day, No Lab	
1/26	Units, Percent, Fractions, Density	Safety, Name Tag, Glassware	
2/2	Moles, Mass, Formulas	Copper Cycle	Organic Compounds

Table 6.1. Schedule for CHEM 1310 Lecture and CHEM 1319 Lab at Missouri S&T Fall 2014 (cont.)

2/9	Empirical Formulas, Combustion*	Organic Compounds	Copper Cycle
2/16	Stoichiometry, Concentrations	Hard Water Titration	Stoichiometry of a Precipitation Reaction
2/23	Chemical Reactions	Stoichiometry of a Precipitation Reaction	Hard Water Titration
3/2	Gases*	Ionic Precipitation	Boyle’s Law
3/9	Internal Energy, Heat, Work	Boyle’s Law	Ionic Precipitation
3/16	Enthalpy, Light	Flame Lab	Spectroscope
3/30	Wave Nature, Electrons, Periodic Trends*	Spectroscope	Flame Lab
4/6	Lattice Energy, Lewis Structures	Types of Compounds	Lewis Structures
4/13	Molecular Structure	Lewis Structures	Types of Compounds
4/20	Liquids, Solids*	Chromatography	Chromatography
4/27	Solutions, Review	Silver Bottle Final	Titration Final
5/4	Colligative Properties, Review	Titration Final	Silver Bottle Final
5/11	Final Exam, No Class		

6.2. STUDENT FEEDBACK

Students in the logistical pilot offered feedback through voluntary studies in the Learning Management System, Canvas. Surveys were set up as anonymous short answer questions on the use of Canvas, the blended course design, the overall course redesign, and each laboratory activity. Student responses were coded as “Positive” for the use of words such as “liked”, “loved”, “enjoyed”, and similar positive words. Student responses were coded as “Negative” for the use of words such as “hated”, “did not like”, “do not continue”, and similar negative words. The lack of either type of word or inclusion of both types of words resulted in student responses being coded as “Neutral”. Figures 6.1, 6.2, and 6.3 illustrate the range of responses received by the students.

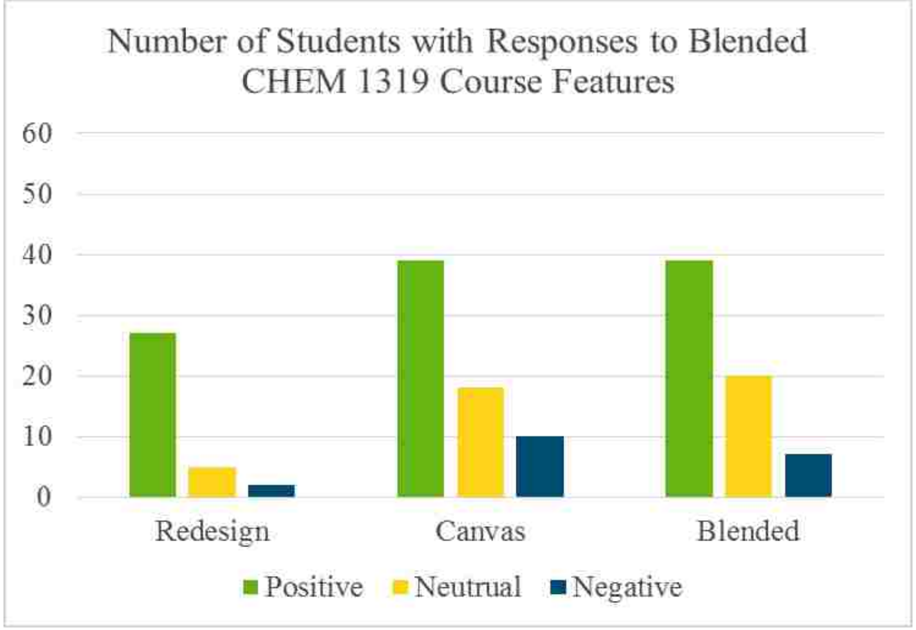


Figure 6.1. Number of students with Responses to Blended CHEM 1319 Course Features

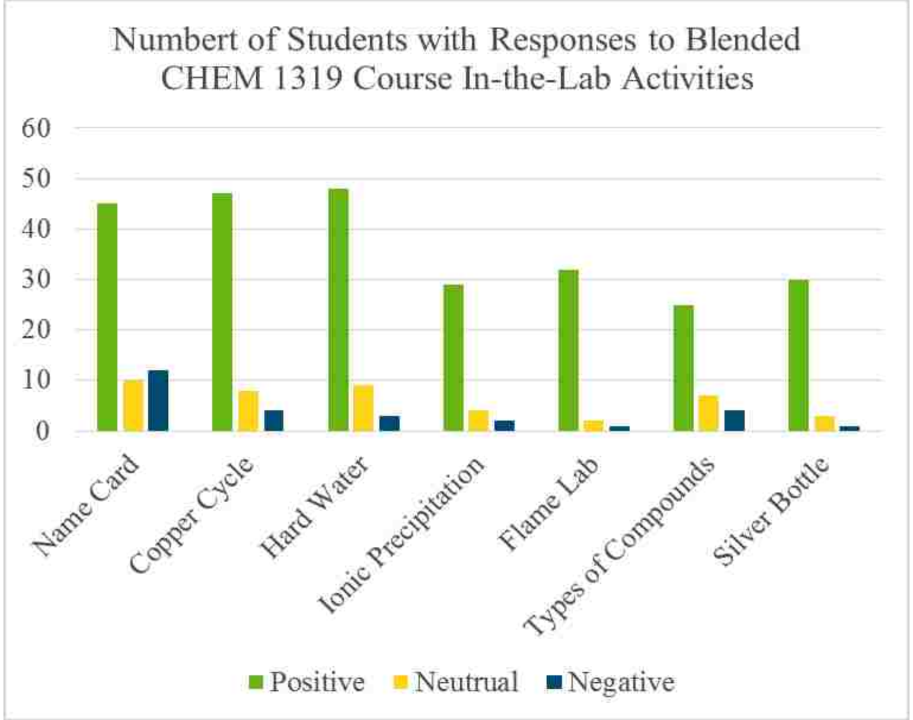


Figure 6.2. Number of students with Responses to Blended CHEM 1319 Course In-the-Lab-Activities

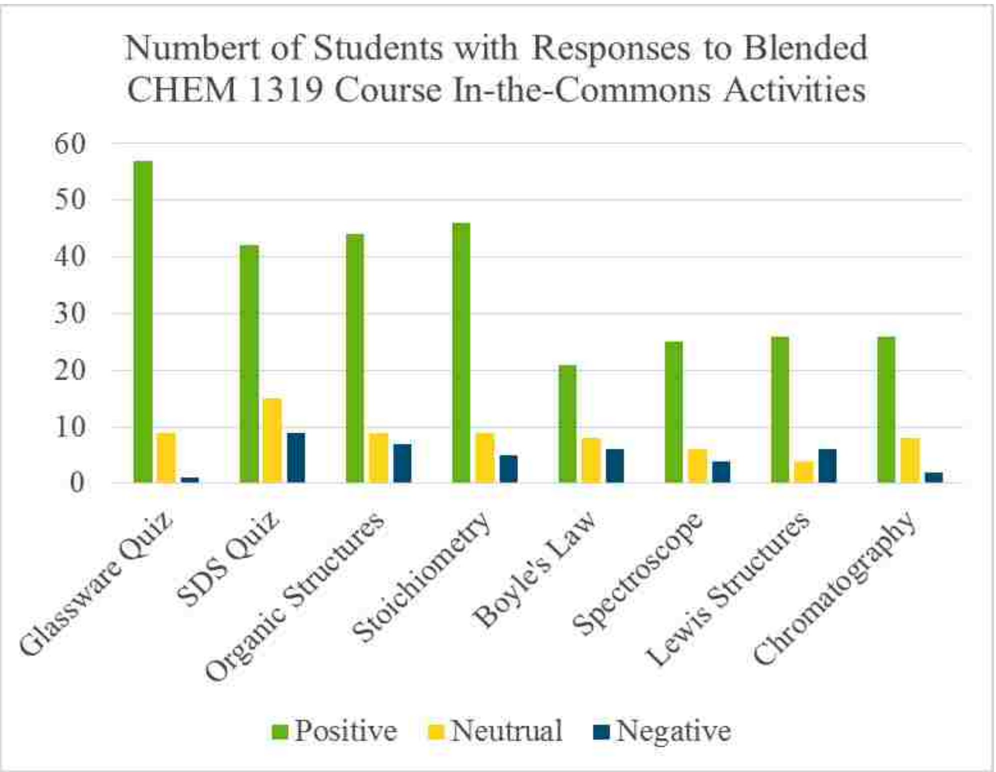


Figure 6.3. Number of students with Responses to Blended CHEM 1319 Course In-the-Commons Activities

While some students had strong negative responses to the course features, the majority of the students responded positively. One of the common complaints about the course was that it was no longer applicable for those students who had already completed CHEM 1310 Freshman General Chemistry Lecture and were unable to enroll in CHEM 1319 during the same semester due to a lack of available seats. The responses provided valuable feedback that was used to redesign activities for the full-scale implementation.

6.3. LIVING LAB MANUAL

A goal of the redesign was to reduce the environmental strain that the course previously had placed on the institution. Rather than using physical lab manuals with paper submissions, the author developed and delivered instructions as live documents. The live document instructions allowed learners to comment on, request changes to, and use a chat feature within the documents. Real time updates to these live documents ensure instructions match supply dynamics and address learner concerns, additionally still providing the learners with a sense of inclusion.

Some students, however, circumvented this process and undermined the value of the live documents by downloading and printing instructions, resulting in confusion due to the multiple editions present. Blocking downloading and printing options inhibited the circulation of outdated versions on campus.

6.4. STUDENT SUBMISSIONS AND EVALUATIONS

During the logistical pilot, student submissions were collected digitally (via the LMS) to reduce the environmental strain of the course. The online grading allowed for the course instructors and learner to access submissions, evaluations, feedback, and grades on a real time scale, reducing the lag experienced with paper grading. When learners failed to earn points assigned, TAs provided direct and detailed written feedback in addition to points indicated on the rubric. The feedback not only provided insight for students, but also supported TA involvement in the evaluation of student submissions. In the full-scale implementation, TAs collaborated to design rubrics and grading schema with guidelines of course objectives supporting TA training efforts.

6.5. IN-THE-COMMONS KIT CHECK-IN AND CHECK-OUT

During the logistical pilot, a paper tracking system was used to record the check-in and check-out of In-the-Commons kits. Students dropped off kits for the previous In-the-Commons activity and picked up kits for the upcoming In-the-Commons activity during their In-the-Lab sessions. All exchanges were made in the traditional lab space with the TAs. A challenge experienced was the lack of instruction and supplies for proper return of spent In-the-Commons kits during the logistical pilot. The adverse experiences guided return procedures and provisions for the full-scale implementation, which was essential to the safety and hygiene of the course.

During the logistical pilot, TAs recognized a need to require a synchronization of lab-kit checkout by both partners. The potential duplication of lab-kit checkout threatened to impose inventory depletion on the course. In the full-scale implementation, lab partners were required to check kits out together emphasizing shared responsibility while avoiding inventory depletion.

Conducting the supply check-in and checkout on paper was inefficient which identified the need and prompted subsequent design of an electronic system. For the full-scale implementation, barcodes recorded distribution of In-the-Commons kits. A barcode scanner and student ID-card reader obtained from the Missouri S&T Curtis Laws Wilson Library collected the pertinent data. The author programmed an Excel spreadsheet to generate a record consisting of date and time, student ID of both lab partners, and the kit barcode for each checkout. In-the-Commons TAs assignments included processing In-the-Commons supplies in a dedicated space separate from the laboratory.

6.6. SUPPLIES

SFCC provided instrumentation for the logistical pilot. Utilizing instrumentation already owned by another institution provided Missouri S&T the opportunity to postpone instrumentation purchases and allowed experience to direct and support decisions.

During the logistical pilot, In-the-Commons kits were prepared in a dedicated space. Materials purchased from a vendor arrived packaged as fully assembled kits with enough supplies for one pair of students to conduct a complete set of In-the-Commons activities. To remove the storage liability from the students, each kit was disassembled, sorted, labeled, stored, and then re-packaged for individual distribution of single In-the-Commons activities. A significant amount of time was spent each week assembling supplies for students. For full-scale implementation, the redesign team decided to purchase partially assembled single-experiment kits, which made the final assembly by the TAs much easier and more economical.

Frequently used laboratory supplies were provided for each pair of laboratory partners at the beginning of the semester and stored in individual drawers in the lab. Combination locks were supplied and an electronic record of all combinations maintained by the CHEM 1319 course advisors and TAs. Prior to the redesign, these records were rather poorly kept in a three-ring binder. Students who lost or forgot their combination experienced no consequences for their lack of responsibility other than starting their experiment a few minutes late. In contrast, their TA, already busy with taking attendance and getting the experiment underway, would be required to stop what they were doing, find and notify the other TA in the room, and leave the lab to obtain the binder from the stockroom. To remove this burden, students could bring their own locks or purchase one from the department supply for a small fee. The new lock policy eliminated the need to maintain extensive records and remove rotating the lock locations at the end of each semester. In accordance with the pedagogical concept of the redesign, students were held responsible for securing the supplies and providing their own lock.

6.7. ORGANIZATION OF SPACE

For the logistical pilot, a dedicated space simulated the organization of a stockroom for the redesigned blended lab to avoid interfering with the existing course delivery. Prior to the course redesign, the CHEM 1319 stockroom had become a catchall storage area where unused supplies accumulated (see Figure 6.4). In the full-scale implementation, the stockroom operated as a central location for learner support as well as TA work and training (see Figure 6.5). To facilitate the new purpose, all current supplies in the stockroom were removed and only supplies required for the full-scale implementation were returned. A new organizational schema was put in place to support the full-scale implementation.

Figure 6.4. CHEM 1319 Stockroom Prior to Full-Scale Implementation at Missouri S&T

Figure 6.5. CHEM 1319 Stockroom after Full-Scale Implementation at Missouri S&T

7. DELIVERED PRODUCT

In fall 2015, Missouri S&T offered CHEM 1319 as a blended course. The blended course design fulfilled ACS best practices and employed intentional pedagogical design teaching learners to assume responsibility for their learning. Missouri S&T was able to serve 940 students in six time lots offered over two days.

7.1. STUDENT SUCCESS

Figure 7.1 and Figure 7.2 show the CHEM 1310 final grades for fall 2014 and fall 2015, respectively. Figure 7.1 includes the students enrolled in CHEM 1310 but not enrolled in a lab section to provide a comparison for the fall 2015 CHEM 1310 students not enrolled in the lab. While there are difficulties comparing students enrolled in different semesters, the students in the fall 2015 blended lab appear to have similar success compared to those enrolled in the fall 2014 pilot. The occurrence of drops is higher for the fall 2015 blended-lab students compared to the fall 2014 Pilot but it is lower than the drops for the fall 2014 non-pilot students. Because of several changes made to the CHEM 1310 schedule in the fall 2015 semester and because student success has a tendency to vary considerably between semesters, several years of data will need to be aggregated before any meaningful data-supported claims can be made. It should be mentioned however that an additional 86 students were able to take CHEM 1310 and CHEM 1319 in parallel during the fall 2015 semester and that students who take the two courses in parallel appear to be significantly more successful (Figure 7.2).

7.2. COURSE DESCRIPTION

The design team led the full-scale implementation of the blended course. The lead instructor from the pilot semesters was co-lead instructor to model the desired pedagogical approach to the course. The lead TA from the pilot semesters acted as head TA to support incoming TAs and provide appropriate training in the new course.

The blended laboratory course designed for CHEM 1319 at Missouri S&T used the schedule exemplified in Table 7.1. During the summer semester of 2015, CHEM 1310 topic rearrangement occurred to better support learner comprehension. The CHEM

1319 design team quickly shifted the lab schedule to match the rearrangement. With the absence of Monday sections, an additional laboratory activity was available in the fall 2015 schedule that was not present in the pilots.

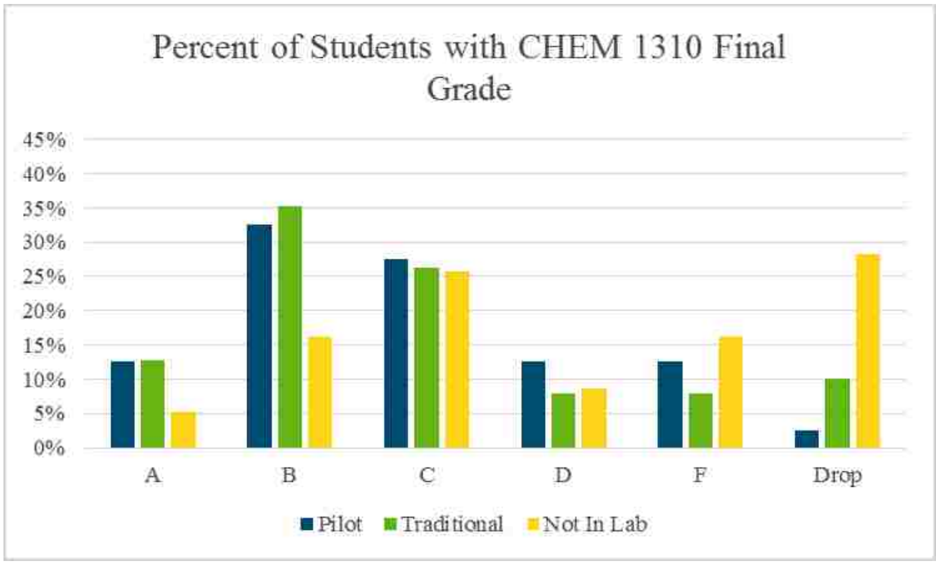


Figure 7.1. Fall 2014 Percent of students with 1310 Final Grades

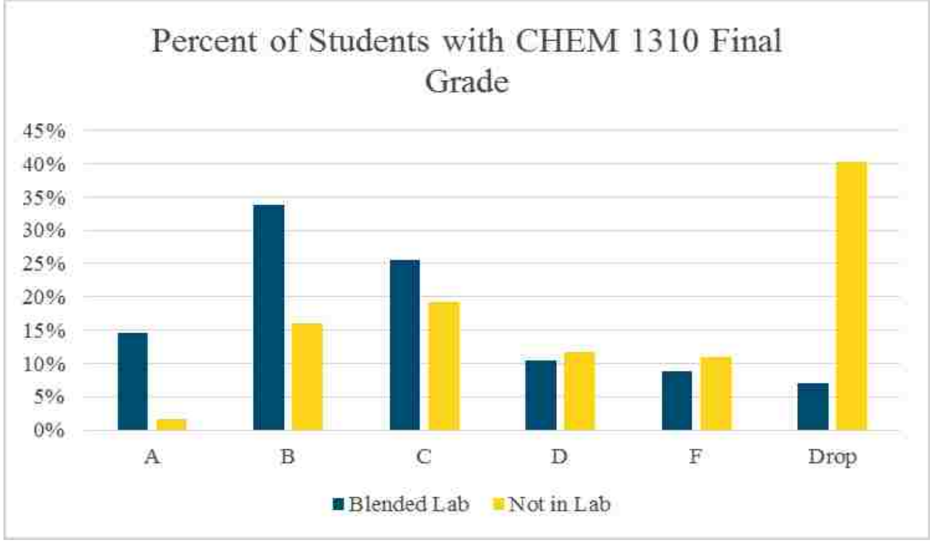


Figure 7.2. Fall 2015 Percent of students with 1310 Final Grades

Table 7.1. Schedule for CHEM 1310 Lecture and CHEM 1319 Lab at Missouri S&T Fall 2015

Week	CHEM 1310 Topic	CHEM 1319 Topic A	CHEM 1319 Topic B
8/24	Nomenclature	Safety, Name Tag, Glassware	
8/31	Atomic Structure, Empirical Formula	Flame Lab	Organic Compounds
9/7	Electronic Structure, Periodic Properties	Organic Compounds	Flame Lab
9/14	Lewis Structures	Esters	Lewis Structures
9/21	Structure, Shape	Lewis Structures	Esters
9/28	Interactions, Solids	Copper Cycle	Chromatography
10/5	Phases, Ideal Gases	Chromatography	Copper Cycle
10/12	Gases, Liquids	Ionic Precipitation	Gas Laws
10/19	Solutions	Gas Laws	Ionic Precipitation
10/26	Chemical Reactions	Types of Compounds	Stoichiometry of Chalk
11/2	Combustion, Stoichiometry	Stoichiometry of Chalk	Types of Compounds
11/9	Solution, Gas Stoichiometry	Hard Water Titration	Spectroscope
11/16	Light, Wave Nature	Spectroscope	Hard Water Titration
11/30	Internal Energy, Enthalpy	Silver Bottle Final	Titration Final
12/7	Energy Changes	Titration Final	Silver Bottle Final
12/14	Final Exam, No Class		

7.3. TEACHING ASSISTANTS

The course redesign required a modification of TA roles, responsibilities, and expectations. With half of the activities conducted away from the traditional lab space, only half of the scheduled TA time would now be in the lab directly interacting with learners. The other half of the scheduled TA time would now be dedicated to cyber support, laboratory set up, training, and grading.

Google Hangouts (https://hangouts.google.com), a chat feature in the living lab manual, Piazza Discussion Board (https://piazza.com), and email provided the cyber support. The chat feature, Piazza, and email were the forms of support that students seemed to prefer. The chat feature in the living lab manual was available anytime that the students had a copy of the live lab instructions open and was a convenient avenue for students to seek assistance and collaborate. Piazza and email are two avenues that parallel the lecture course's support structure. Cyber support for learners occurred in a mentoring environment with experienced TAs available to model positive and productive interactions outside of the more hectic environment of the lab.

The modification of TA assignments has the potential to support the development of a graduate student cohort and a new training program/protocol for incoming TAs.

7.4. LEARNING MANAGEMENT SYSTEM

Activity instructions were organized and disseminated through the Canvas Learning Management System (LMS) providing a portal to live documents, which ensured that learners always had the most recent edition of instructions.[66] An important feature of Canvas LMS to the project was that it provided a platform, which allowed access to instructions, submissions, feedback, and grades at a single terminal. Previously, the course instructor had to locate and corral individual paper submissions from multiple TAs over sections spread across the week. Grades were recorded and transmitted by TAs to the course instructor generating a convoluted trail for the instructor and TAs to maneuver. In addition, the amount of paperwork often prevented students from receiving timely feedback.

7.5. ACTIVITIES

7.5.1. Week 1. The safety contract and SDS activities conducted in the first week of the course establish expectations for learners. The choice for students to construct their own contract emphasized that the learners are responsible for pursuing safety; though guidance is available, answers would not be provided. Group participation was intentionally a part of the grade for their safety contract to emphasize that learners are responsible for maintaining a culture of safety with their peers. A desired outcome of the course is to develop a cohort of peers. Safety is a topic continually discussed and monitored throughout the semester. During the semester, students receive constant feedback and points for maintaining the culture of safety.

In-the-Lab activities are engaging. The name card activity establishes course expectations (See Appendix C). The chemical phenomena in the activity provides the option for the course instructor to focus on several concepts such as polarity, chromophores, favorable collisions, and bonds to name a few. The flexibility of the assignment is a theme throughout the course with activities easily rearranged or refocused to support a dynamic course with assignments that do not have a singular predetermined answer. The name cards generated are unique to each enrolled student just as future activities must be unique to and submitted by each enrolled student. The activity is messy and foreshadows the potential for wardrobe to be ruined during laboratory activities and the necessity for protective clothing. Instructions for the activity are succinct and devoid of explanations of what the learner should expect, a pattern consistent in upcoming assignments. The submission for the name card requires a unique image in Canvas graded by their TA with a grading rubric, which introduces the learners to the LMS, submission procedures, and requires image compression, as do the future submissions.

In-the-Commons activities require attention to safety. All activities are appropriate for discussions on safety though In-the-Commons typically do not require the same level of personal protective equipment (PPE) as the In-the-Lab activities. By conducting activities with higher levels of hazard in the traditional lab space, learners are more alert to the reasons why PPEs are required. This is not to say that the activities conducted In-the-Commons are any less appropriate to the course, but they are activities that can be safely conducted away from the direct supervision found in the traditional laboratory space but under cyber supervision. As designed, the division of activities enhances the culture of safety on the campus.

7.5.2. Weeks 2-3. In-the-Lab activities are relevant to lecture content. The flame lab is a high impact activity with direct application to lecture topics, obvious hazards, opportunities for learners to utilize multiple instruments, and inclusion of ACS suggested laboratory skills (see Appendix D). The open flame and heated metal support the claim that learners must wear an appropriate wardrobe when they are in the laboratory space.

The use of handheld spectrophotometers allows learners to develop the skill of using instrumentation and collecting numerical data. Collection of qualitative and quantitative data demonstrates the value of each type of data along with the relationship between visible light and its associated wavelength. The activity requires calculations for energy as covered in the lecture course, reinforcing the connection between lecture and lab. The activity is authentic as it relates to recognizable phenomena in fireworks. As an In-the-Lab activity, the flame lab fulfills a desire for learners to experience appropriate hazard while exploring chemical phenomena and using appropriate instrumentation.

In-the-Commons activities require physical manipulation. The organic compounds activity can be conducted anywhere (see Appendix E) without the need for direct supervision in this activity, students use molecular modeling kits to assemble assigned organic compounds providing practice with organic nomenclature and formulas. The skills to manipulate plastic spheres and sticks are not a concern and the hazards are minimal. Even though the physical skills are not significant, the activity is fundamentally valuable. Molecule kit activities are a traditional investigation in laboratory courses. Conducting molecular modeling in the traditional lab space, students are generally required to wear appropriate lab attire because lab spaces, particularly at the freshman level, have inherent dangers in them such as accidental contact with chemical residues or broken glassware. These hazards are not as obvious as fire, concentrated nitric acid, or poisonous gases. By moving this style of activity to non-traditional spaces, the relocation achieves removal of the lab space hazards allowing the students to evaluate the hazards of the activity and choose appropriate attire. This respects the learner by showing confidence in their abilities and allows the students to take ownership of the safety culture. Students expressed excitement about molecular modeling to the lead instructor as they made models of pharmaceuticals, dyes, and other molecules of interest not assigned.

7.5.3. Weeks 4-5. In-the-Lab activities are applicable. The ester lab is a high impact activity with obvious hazards, skill development opportunities, and direct connections to students' lives (see Appendix F). Concentrated sulfuric acid and flammable compounds require an attention to appropriate chemical handling. Learners are able to develop skills such as wafting, use of electronic balances, and use of hot water baths. The organic synthesis has multiple content connections such as organic nomenclature, line-structure drawings, the use of catalysts, evidence of reactions, Lewis structures, reaction equations, and reversible reactions. The activity is authentic outside of the laboratory course as ester synthesis produces medicines, occurs in nature, and is detectable with the human senses. The activity can be easily modified by changing the esters synthesized to maintain the novelty of the activity and consume potential stockroom surpluses. A failure to follow instructions results in an unsuccessful product, which reinforces the idea that there are consequences for missteps.

In-the-Commons activities require organization. The Lewis Structures activity provides students an opportunity to physically manipulate molecule kits to gain experience with a three-dimensional model of Lewis Structures, transfer models to a two dimensional rendering, and apply VSEPR information to models (see Appendix G). Learners submit organized observations in preparation of generating a full lab report for their In-the-Commons final.

7.5.4. Weeks 6-7. In-the-Lab activities are brimming with ACS-suggested laboratory skills. The copper cycle is a high impact activity involving obvious hazards with multiple outcome and topic connections (see Appendix H). The use of corrosives and generation of poisonous gases are just a few examples of hazards that learners recognize making safety equipment and PPE requirements obvious. The translation of learner observations to reaction equations provide a real-life demonstration of lecture word problem assessments that require the learner to convert observations into reaction equations. The copper cycle assimilates several lecture topics such as ionic compounds, strong acids, strong bases, precipitation reactions, dehydration reactions, Lewis acid base reactions and redox reactions that contribute to the experience of the learner. The activity has the potential to include a multitude of laboratory skills including solution preparation, dilution, gravity filtration, decanting, quantitative transfers, product washing, product drying, use of volumetric glassware, use of ventilation for hazardous gases, use of heating instruments, identification of reaction completion, and conducting pH measurements. Beyond the tactile laboratory skills, learners record and organize observations, generate reaction equations based on observations, and apply chemical nomenclature upon the completion of the activity. The copper cycle is an activity rich in laboratory skill opportunities and applications to multiple content topics.

In-the-Commons activities require laboratory skills. Paper chromatography is an activity with application to current laboratory procedures; chromatography provides students an opportunity to demonstrate lab skills, gather observations, conduct calculations with limited oversight, and communicate organized data (see Appendix I). Additionally, students are required to research background information to construct an introduction in preparation of generating a full lab report for their In-the-Commons final.

7.5.5. Weeks 8-9. In-the-Lab activities are experiential. Ionic precipitation is an activity which demonstrates solubility rules, allowing learners to gather and communicate data, demonstrate inorganic nomenclature skills, demonstrate an ability to synthesize solubility guidelines, and demonstrate an ability to compare their observations with known information (see Appendix J). Students submit balanced net ionic reaction equations, appropriate IUPAC names for solids formed, and a synthesis of how their results matchup with provided solubility guidelines.

In-the-Commons activities require creativity. Design of the Gas Law activity forces learners to explore the relationships between volume, pressure, and temperature (see Appendix K). Student provisions include a capped syringe (volume), a thermometer (temperature), and a portable electronic balance (pressure). The expectation is that with these supplies, students develop their own procedure, gather data, demonstrate graphing skills, and complete calculations. This activity was identified as beneficial but in need of continued development to provide learners with appropriate instruction to support learning without removing the exploratory nature of the activity. The learners must report their procedure or method in preparation of generating a full lab report for their In-the-Commons final.

7.5.6. Weeks 10-11. In-the Lab activities are filled with ACS suggested instrumentation. The types of compounds activity provides students with an opportunity to use pH meters, temperature probes, conductivity probes, electronic balances, volumetric glassware, and spreadsheets while gathering data from a variety of compounds (see Appendix L). They practice Lewis-structure drawings, deduce intermolecular bonds, and use data to observe the effect of intermolecular forces; additionally, they demonstrate an ability to organize and effectively communicate data.

In-the-Commons activities require engagement. The stoichiometry of chalk activity allows learners to mathematically calculate mass from number of moles, quantitatively prepare solutions, use gravity filtration, dry to a consistent mass, and perform data analysis on the precipitation reaction of sodium carbonate and calcium chloride to generate chalk (see Appendix M). While anecdotally a lackluster activity in the lab, learners have returned from this as an In-the-Commons activity expressing excitement and confidence over the skills mastered. This stoichiometry activity is particularly successful because of learner buy-in and because the learners develop a conclusion in preparation of generating a full lab report for their In-the-Commons final.

7.5.7. Weeks 12-13. In-the Lab activities are relevant to the learner's world and daily life. The hard water titration activity provides an opportunity to manipulate unit conversions and experience a titration procedure (see Appendix N). The activity is relevant as students analyze a personal water sample for testing.

In-the-Commons activities require engineering. Learners are required to construct and utilize a spectroscope (see Appendix O). They must find their own procedures and materials to construct the spectroscope and then provide observations using their spectroscope on direct, reflected, and filtered light. The activity gives learners the opportunity to physically manipulate the basic components in a spectrophotometer and collect original observations from different light sources. An understanding of the basic components of a spectrophotometer is applicable across a plethora of fields; electromagnetic radiation is everywhere and the evaluation of such radiation provides insight on subjects from medical conditions to scientific concepts. The spectroscope activity provides learners with opportunities to gain insight on a topic foundational to many methods of investigation. Learners submit a discussion in preparation of generating a full lab report for their In-the-Commons final.

7.5.8. Weeks 14-15. In-the-Lab activities are assessed with a final exam focused on skills. As a laboratory final, learners conduct the silver bottle exam (see Appendix P). They prepare Tollen’s reagent and, with the help of dextrose, coat the interior of a glass bottle with a precipitation of silver metal. They must remove the potentially explosive hazard of the spent reaction bath as a part of the activity. Finally, learners must demonstrate mastery in safety, hygiene, use of volumetric glassware, use of electronic balances, measurement of pH, gravity filtration, solution preparation, and teamwork to be successful in the exam.

In-the-Commons activities require communication. As a laboratory final, learners conduct an acid-base titration (see Appendix Q). They use a syringe with stopcock as a burette to determine the concentration of a solution and must submit a full laboratory report over the activity demonstrating their complete reporting skills. They must provide an introduction, observations, data analysis, discussion, and conclusion over the activity. Learners must demonstrate mastery in safety, hygiene, background research, communicating organized observations, data manipulation, data analysis, constructing a discussion, and drawing a defensible conclusion to be successful in the exam.

8. CONCLUSION AND FUTURE WORK

This project successfully increased accessibility in the freshman general chemistry laboratory course. As a result of this project, CHEM 1319 had a 130% capacity increase in the fall of 2015 and was able to offer a seat to each student enrolled in CHEM 1310.

This project intentionally focused pedagogy to support learner success. The course is composed of pedagogically focused activities, which have demonstrated student success and compliance with ACS guidelines. As described in Chapter 7, the additional seats provided an opportunity for additional students to experience the pedagogical benefit of enrolling in CHEM 1310 and CHEM 1319 in parallel. Student final grades provide evidence that co-enrolling in these two courses increases learner success.

The project designed a course that meets ACS guidelines. As described in Chapter 7, the activities incorporate ACS required instrumentation and outcomes which allows for Missouri S&T to support the ACS certification of the Bachelor of Science degrees in Chemistry.

This document has described the design and development of the blended laboratory course at Missouri S&T. The proof of concept and logistical pilots confirmed the decision for a blended course; the document also identifies the challenges encountered and solutions employed. Future opportunities for research have been identified and are described in this section.

8.1. FUTURE WORK

8.1.1. Online Instruction Delivery. Live documents have a potential for further research and optimization. The impact of responsive real-time editing capacity on large-enrollment courses has not been documented. While live documents are a green alternative to traditional laboratory manuals, there appear to be improvements available in the nuances of actual deployment. Learner interactions through live documents are another area that has not been researched and optimized; specifically, the chat feature was very popular in during this project but lacks a means of capturing student participation.

8.1.2. Teaching Assistant Training Program. During the project, a paradigm shift occurred with the lead TA. Familiarity with the project led to recognition of an opportunity to change the approach for training and supporting TAs. In particular, during the fall 2015 deployment, the nature of the TA assignments generated a sense of community and cohesiveness, noted as a neglected area ripe for research and development. Research has reported that graduate students have higher rates for mental illness that may be mitigated by intentional TA training.[67] A survey has been developed by the lead TA to further identify and develop formal TA training and support practices.

Because TAs work in the stockroom, the blended course design has eliminated the need for stockroom workers. TAs will be responsible for their own grading, so the need for graders has also be eliminated (see Table 8.1).

Table 8.1. Comparison of Student Employees Between Traditional and Blended Design

Semester	Traditional	Blended
Sections Offered	36	48
Time Slots	9	6
Sections/GTA	3	3
Sections/Grader	3	0
Sections/Stockroom ULA	3	0
Sections/Stockroom GTA	3	0
Stockroom ULA/Time Slot	2	0
Stockroom GTA/Time Slot	2	0
Sections/GTA in Training	0	6

Redirection of the funds resulted in development of a training program where incoming TAs will be trained through a shadowing and mentorship program rather than working solely in the stockroom or grading assignments. The TA training program will allow a TA-in-training to be assigned to each lab space to shadow a pair of TAs. The TA-in-training will participate in both In-the-Lab and In-the-Commons support. Even with the redirection of funds, a significant reduction in the cost of student employment (see Table 8.2) results from the redesign. The blended design does not remove the need for instructors, and supply costs depend mainly on the choice of laboratory activities not on the delivery of the activities. Hence, course redesign does not significantly influence such costs.

Table 8.2. Comparison of Student Employees Between Traditional and Blended Design

	Traditional #	Blended #	Cost Per	Total Cost Traditional	Total Cost Blended
GTA	12	16	$9,000.99	$108,011.88	$144,015.84
Grader	12	0	$8,550.94	$102,611.28	$0
Stockroom ULA	6	0	$3,118.58	$18,711.50	$0
Stockroom GTA	6	0	$8,550.94	$51,305.64	$0
GTA in Training	0	8	$8,550.94	$0	$68,407.52
			Total	$280,640.30	$211,423.36
			Student Capacity	864	1152
			Cost/Student	$324.82	$184.40

8.1.3. Partnerships. The implementation of the Missouri S&T product and continued evolution of the underlying philosophy of the product at other institutions has great potential to provide further information on blended courses. Research opportunities exist through intra- and intercampus partnership development.

Each participant in such relationships brings a unique set of circumstances to elucidate areas for improving the culture of learning. The project team continues to refine blended learning at Sacred Heart High School (Sedalia, MO). Missouri S&T freshman physics approached the team in a tentative fashion about possible applications in their circumstances. Additionally the team continues to employ blended learning strategies at State Fair Community College (Sedalia, MO).

8.2. CONCLUSION

The success of this project was dependent on the customization of a solution generated from prior experience and knowledge to bridge specific shortcomings and performance gaps in CHEM 1319 at Missouri S&T. Rather than serving as blueprint for transplant, this dissertation identifies and illustrates the key phases of the project, which are exploration of potential solutions, investigation of relevant experiences, identification of desired goals, engineering trials, identification of gaps, and validation of achievements.

APPENDIX A.

SCIENCE COMMUNICATION ASSIGNMENT AND RUBRIC

The goal of this assignment is to gain an awareness of peer-reviewed literature and an understanding of how we know what we know. Failure to attempt a task will result in a 10% reduction in the assignment grade. The learner will construct a model from found/re-use/recycled material of a molecule approved by the instructor. The learner will locate at least three research articles that are related to the molecule. The molecule will be presented to the class during a class meeting, which will include a PowerPoint presentation.

The tasks in this assignment include the following and may be augmented by your instructor as required.

- Selection of molecule
  - You need to select a molecule for which you will conduct research and construct a model.
  - The molecule should
    - be something that interests you.
    - have at least 20 atoms in CHEM 101 and at least 20 carbons for higher rubric courses.
    - be of sufficient complexity (a straight chain simple molecule will be difficult to obtain maximum points on as will a large very complicated molecule).
  - Avoid common molecules such as but not limited to: glucose, fructose, aspirin, aspartame, ascorbic acid, and sucrose.
  - Do not be frustrated that you require multiple attempts. The first post should help to narrow your conversation to an area that you are interested in. Subsequent attempts should narrow your focus to help you select an appropriate molecule.
  - Your instructors will provide feedback to help you chose an appropriate molecule. A failure is not implied if the instructor does not approve your first choice. The goal of this task is to select an appropriate molecule that will support your success in the assignment. The instructor will intervene with guidance based on several semesters of experience.

- Central atom VSEPR
    - post an image of the pet molecule’s line drawing
    - post an image of the pet molecule’s Lewis structure
        - to convert a line drawing to a Lewis structure you should recognize that all line bends and ends are carbons
        - redraw your molecule with a carbon at each bend with a line connecting each atom as indicated in the line drawing
        - include the other atoms (O and N) in their proper place
        - every carbon will have four bonds so “missing” bonds are “H”
        - add the missing bonds and attach a “H” to each new bond
        - every “N” and “O” will already have the proper number of “H” atoms attached
        - every “N” and “O” will have an octet of electrons and the missing electrons will be unshared pair”
        - place the missing electrons on the “N” and “O” atoms as required
        - you should have a proper Lewis structure at this point; count all of the atoms to validate this claim;
        - submit an image of your Lewis structure in the discussion board (please understand you may have to do it more than once)
        - You should review the Lewis rules we use for simple molecules (but they are a challenge for the pet molecule)
    - identify all central atoms and the molecular geometry of the central atoms in a table or chart
        - number all of the central atoms on a Lewis drawing of your molecule
            - a central atom has two or more atoms attached
        - make a table with four columns
            - central atom’s number
            - molecular geometry
            - bond angles
            - hybridization

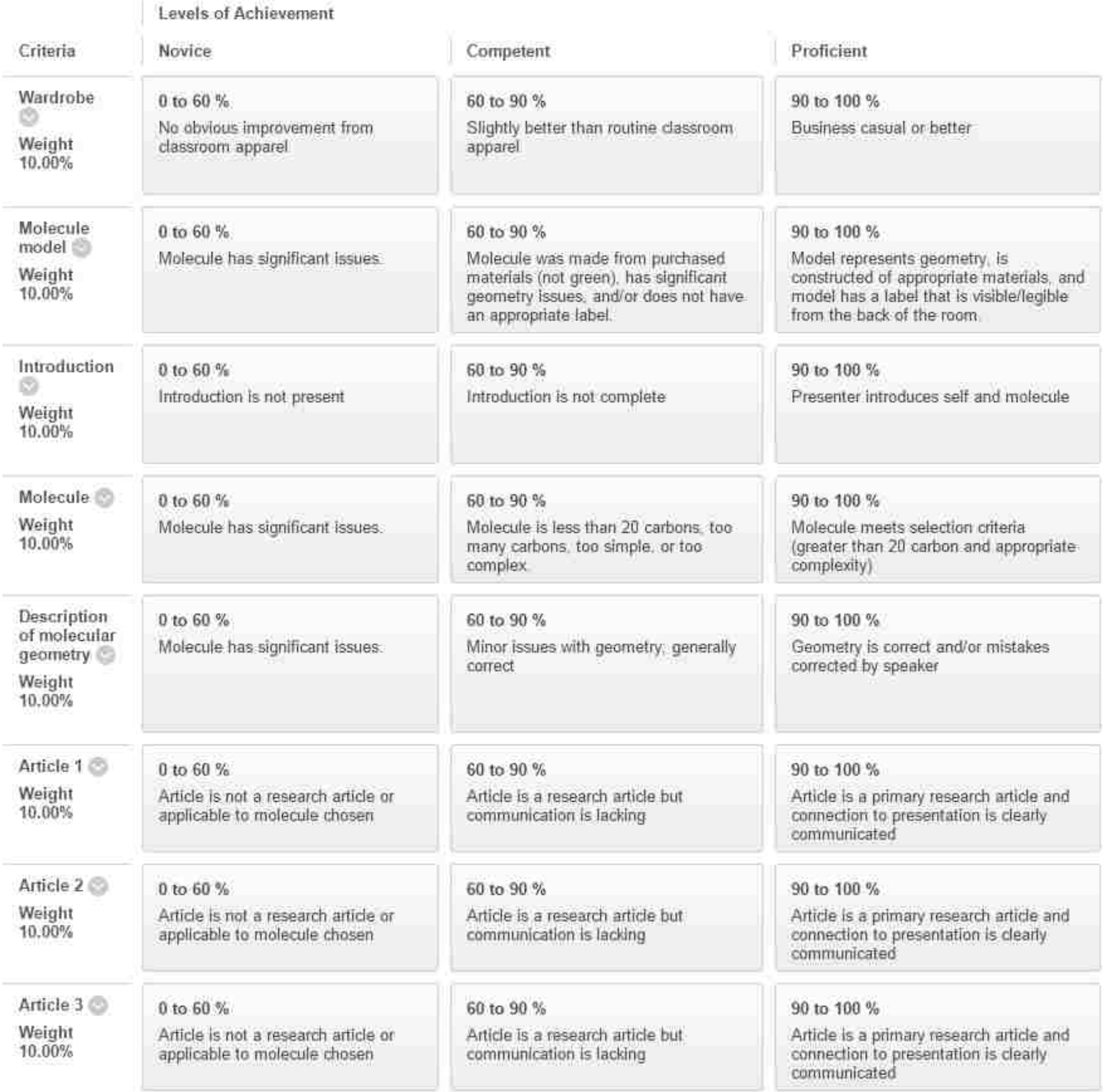
    - write a central atom's number in the first line of the first column
    - count the number of areas of electron density around the central atom
        - each unshared pair of electrons is one area of electron density
        - each single bond is one area of electron density
        - each double bond is one area of electron density
        - each triple bond is one area of electron density
    - count the number of atoms attached to the central atom being investigated
    - look on the VSEPR table to find the molecular geometry and place the answer in the second column
    - look on the VSEPR table to find the bond angles and place the answer in the third column
    - look on the VSEPR table to find the hybridization and place the answer in the fourth column
    - repeat for each central atom in your molecule
        - you may condense your table by including multiple central atoms on an individual line so long as the remaining column entries are identical and the instructor can understand your table
- Construct a model of your molecule using a commercial molecular modeling kit and submit an image
    - all double bonds will require two connecting devices
    - all triple bonds will require three connecting devices
    - traditionally, single bond and double bond connecting devices are different lengths
        - the single bonds will be shorter and stiffer
        - the double bonds and triple bonds will be longer and more flexible
    - the traditional colors in commercial molecular modeling kits are

      - black for carbon
      - red for oxygen
      - white for hydrogen
      - blue for nitrogen
      - yellow for sulfur
- Three primary literature articles
  - Find 3 science research articles that have been published in a peer-reviewed journal about the molecule that you have chosen
    - You are looking for actual research articles, so the articles should be about experiments
    - Experiments require data (numbers)
    - Surveys and case reviews are not appropriate for this assignment even though they can generate data
    - This assignment is harder than many expect; many
      - think that they are writing a position paper (you are not)
      - assume that they understand what is acceptable for a research article (generally untrue)
    - The chosen format for the citation must be used for all three submissions and the annotated bibliography
      - we are not extremely concerned about which format you choose
        - every peer-reviewed journal has a preferred style
        - you may use MLA, APA or any other style;
      - however you may not use et. al for additional authors
        - you must list every author
        - Minimum requirements are:
        - all of the authors names
        - the title of the article
        - complete title of the journal
        - publication information (as available)
        - date article was retrieved

    - Good primary literature articles generally
      - have long titles with words that require a dictionary
      - have an abstract
      - include most of the parts in a typical lab report
      - talk about their own data
        - not from surveys
        - not from case review
  - We recommend that you start by posting the citation for your first primary literature article. You may need to go through several posts before you get a research article. Just keep trying and we will help steer you in the right direction.
  - After your first article is approved, you should find your other two.
- Review your approved articles using A Miniature Guide for Students and Faculty to Scientific Thinking by R. Paul and L. Elder (ISBN 0944583180)
  - To review the articles, you will use the 8 questions generally found on page 14 of the pamphlet (may be different if you have a different edition) that describe how to analyze a scientific research article.
    - The pamphlet gives several ideas about what the questions seek to elucidate so you should read the entire pamphlet.
  - The annotated bibliography should be succinct and clearly contain the answers to the eight questions for each article.
    - Avoid the temptation to editorialize or incorporate your opinion, the purpose of this activity is to direct you to where we store “what we think we know”.
    - Peer-reviewed is still subject to all of the human misconceptions but it is our current attempt to minimize subjectivity in what should be objective.
    - If you struggle with locating the answers, remember to use a dictionary to bring the vocabulary into perspective.
  - The format of the annotated bibliography-
    - First good citation of a good primary literature research article

        - Very nice paragraph that answers the 8 questions from the Scientific Thinker’s pamphlet that flows, is easy to read, and clearly answers the 8 questions from the Scientific Thinker’s pamphlet.
        - Second good citation of a good primary literature research article
        - Very nice paragraph that answers the 8 questions from the Scientific Thinker’s pamphlet that flows, is easy to read, and clearly answers the 8 questions from the Scientific Thinker’s pamphlet.
        - Third good citation of a good primary literature research article
        - Very nice paragraph that answers the 8 questions from the Scientific Thinker’s pamphlet that flows, is easy to read, and clearly answers the 8 questions from the Scientific Thinker’s pamphlet.
- Found Material Molecular Model
    - Construct a model of your molecule from found/re-used/re-purposed material.
    - The use of Styrofoam balls will reduce your grade.
    - The model must not be flat in particular tetrahedral centers must be reasonably presented.
    - Submit an image of your found material molecular model
        - if you need to correct the model, submit a new image.
    - You will need to present your model to the class at the end of the semester
- PowerPoint
    - Your slideshow must include
        - VSEPR information about your molecule
        - Information about the construction of your molecule
        - Your annotated bibliography
        - A labeled image of your found material molecule model
- Presentation

- For in class presentations, you will give a formal presentation during your scheduled meeting; this typically occurs during the week before finals.
- For online sections, submit either a video of your presentation for your pet molecule or a PowerPoint with voiceover for your pet molecule.



	Levels of Achievement		
Criteria	Novice	Competent	Proficient
Wardrobe Weight 10.00%	0 to 60 % No obvious improvement from classroom apparel	60 to 90 % Slightly better than routine classroom apparel	90 to 100 % Business casual or better
Molecule model Weight 10.00%	0 to 60 % Molecule has significant issues.	60 to 90 % Molecule was made from purchased materials (not green), has significant geometry issues, and/or does not have an appropriate label.	90 to 100 % Model represents geometry, is constructed of appropriate materials, and model has a label that is visible/legible from the back of the room.
Introduction Weight 10.00%	0 to 60 % Introduction is not present	60 to 90 % Introduction is not complete	90 to 100 % Presenter introduces self and molecule
Molecule Weight 10.00%	0 to 60 % Molecule has significant issues.	60 to 90 % Molecule is less than 20 carbons, too many carbons, too simple, or too complex.	90 to 100 % Molecule meets selection criteria (greater than 20 carbon and appropriate complexity)
Description of molecular geometry Weight 10.00%	0 to 60 % Molecule has significant issues.	60 to 90 % Minor issues with geometry; generally correct	90 to 100 % Geometry is correct and/or mistakes corrected by speaker
Article 1 Weight 10.00%	0 to 60 % Article is not a research article or applicable to molecule chosen	60 to 90 % Article is a research article but communication is lacking	90 to 100 % Article is a primary research article and connection to presentation is clearly communicated
Article 2 Weight 10.00%	0 to 60 % Article is not a research article or applicable to molecule chosen	60 to 90 % Article is a research article but communication is lacking	90 to 100 % Article is a primary research article and connection to presentation is clearly communicated
Article 3 Weight 10.00%	0 to 60 % Article is not a research article or applicable to molecule chosen	60 to 90 % Article is a research article but communication is lacking	90 to 100 % Article is a primary research article and connection to presentation is clearly communicated

APPENDIX B.

EXPLODING MISCONCEPTIONS: DEVELOPING A CULTURE OF SAFETY THROUGH LEARNER DRIVEN ACTIVITIES

Introduction

This appendix is a manuscript that has been submitted to the peer-reviewed *Journal of Chemical Health and Safety* titled Exploding misconceptions: Developing a culture of safety through learner driven activities.

On the first day of class, many students enter freshman laboratory courses with an opinion that someone else will provide them with everything they need; a mentality often carried over into future courses and workplaces. This presumption causes frustration and unrealistic expectations when not addressed. On the contrary, a first activity of designing a safety contract, continued with an SDS activity, and reinforced by a strict wardrobe expectation refutes the misconception that instructors will hand answers to learners. Rather than providing answers for students, the program provides opportunities to construct appropriate tools establishing individual responsibility, teamwork, and research to develop a culture of safety in the lab. This communication describes safety activities that guide student choices to enhance the culture of safety at Missouri University of Science and Technology (Rolla, MO), State Fair Community College (Sedalia, MO), and Sacred Heart High School (Sedalia, MO).

The phrase “culture of safety” has been subject to significant debate and discussion over the past few decades, which has led to a deterioration of a consistent definition.[68,69,70] This paper does not intend to analyze the ongoing conversation but because “culture of safety” is the central theme explored in specific situations it will require a clear definition. In the context of this document, the term “culture of safety” refers to the collective attitude, practices, and expectations of a group to maintain a safe environment. To build and maintain a culture of safety, individual responsibility and understanding is essential. A culture of safety enables groups to conduct hazardous activities in a safe fashion. In this document, the culture of safety is described for an academic chemistry laboratory setting.

The evaluation of a culture of safety is an abstruse task. Attitude surveys notoriously depend upon individual perceptions of desired responses (both positive and negative). To measure practices, a coding method is required that convert observations to measureable data. Expectations are typically evaluated using surveys, a method subject to the whims of individual moods and unlikely to gain a conclusive perspective on group expectations beyond a collection of individual responses. Because of these challenges, the effectiveness of the culture of safety in this document will focus on the achievements and common feedback collected over the time period described.

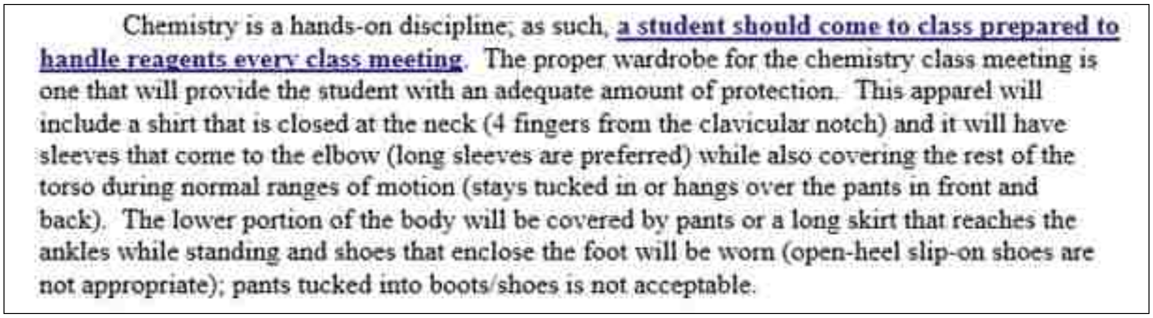
Two activities will dominate the discussion in this document: development of a Safety Data Sheet (SDS) database and the construction of safety contracts. While other activities have also been successful in the experience of the authors, these particular activities have consistently shown themselves to be valuable tools in the academic environments described. The authors have adapted the activities for different laboratory environments from high schools (Sacred Heart High School, Sedalia, MO) to Community Colleges (State Fair Community College, Sedalia, MO) to research-intensive PhD-granting institutions (Missouri University of Science and Technology, Rolla, MO). While even broader application of the general concept may be envisioned, such as in vocational schools or industry settings, the authors will focus in this document only on modifications applicable to the institutions mentioned above.

Building a Culture of Safety at State Fair Community College

In 2005, State Fair Community College (SFCC) began implementing practices to build a culture of safety on campus. In chemistry courses, students became responsible for research, design, and implementation of safe practices under the supervision of an experienced industrial hygienist. The focus on safety and safe practices carried beyond the chemistry classroom and across the campus as students and instructor interacted with other faculty and staff. Through conversations and interactions, safety became a prevailing mindset on campus. The administration actively recognized and encouraged the developing culture of safety by supporting course modifications, activity choices, instructor discretion, and the financial provisions required for best practices. An example of administrative support is the concurrence with the enforcement of appropriate wardrobe in the chemistry laboratory.

While not a novel concept, the SFCC Chemistry Department believes that enforcing wardrobe requirements are crucial building blocks for a culture of safety. Students in SFCC Chemistry must adhere to a defined set of rules regarding appropriate clothing for the laboratory environment. By encouraging learners to think about what constitutes a safe wardrobe, safety becomes a conscious choice that occurs as a part of class preparation. Individual learners have to make a cognizant choice to adhere to the guidelines prior to each meeting. Exhibit 1 is an excerpt from the course syllabus containing an example of the specific language used to discuss proper laboratory attire for all chemistry sections at SFCC.

Exhibit 1: Example syllabus language on wardrobe



Chemistry is a hands-on discipline; as such, **a student should come to class prepared to handle reagents every class meeting**. The proper wardrobe for the chemistry class meeting is one that will provide the student with an adequate amount of protection. This apparel will include a shirt that is closed at the neck (4 fingers from the clavicular notch) and it will have sleeves that come to the elbow (long sleeves are preferred) while also covering the rest of the torso during normal ranges of motion (stays tucked in or hangs over the pants in front and back). The lower portion of the body will be covered by pants or a long skirt that reaches the ankles while standing and shoes that enclose the foot will be worn (open-heel slip-on shoes are not appropriate); pants tucked into boots/shoes is not acceptable.

Long-standing instructor experience drove each of the provided wardrobe stipulations. For instance, “four fingers from the clavicular notch” evolved from students tugging a blouse up and asking, “What’s wrong with my shirt?” Despite the lack of research to support the specific boundary, the requirement provides a consistent benchmark to evaluate one’s wardrobe. Students don safety when preparing for their day; choosing their wardrobe mentally prepares them for participation in a culture of safety in the lab space. When students do not comply with wardrobe requirements, instructors deny access to the lab space until deficiencies are corrected, even on the first day of class. By supporting wardrobe enforcement, the institution places a priority on safety.[34]

In the SFCC chemistry laboratory program, building a culture of safety required an evaluation of the inherited laboratory space and supplies, which the learners conducted under instructor guidance. This included a complete inventory of supplies on hand, identification of appropriate storage guidelines, and evaluation of safety equipment. Students employed similar tactics in all laboratory activities where, under instructor guidance, learners would propose an activity, compose an inventory of the hazards involved, identify appropriate supplies, and evaluate available and appropriate safety procedures. Upon identification of safety deficiencies, participants would safely stop all activities and evolutions, so that safety-issue resolution could become the focus. Because of the small class sizes, individual faculty members were able to conduct this added safety training in a just-in-time fashion.

The small chemistry class sizes at SFCC created an environment that allowed instructors to tailor the course schedule to the desires and needs of the students enrolled. This matched the goals of the chemistry program to provide students with an exploratory course brimming with real world experiences as a mechanism to develop behavioral skills.[2,3,4,6,7,8,42] As a result, students claimed to feel like scientists. For example, water quality testing was often conducted in the course, and students would sample local bodies of water as part of the statewide Missouri Stream Team program. For these and other activities, the culture of safety was critical to support an exploration of chemical phenomena; without such culture, activities would be limited to those with very low hazards and minimal risks. The enhanced culture of safety enabled students to explore a wide variety of phenomena which even included fire and explosions.[71] The course instructor reserved the ability to veto activities that did not support learning outcomes that justified the hazards associated. For example, the "whoosh bottle"-experiment illustrates a combustion reaction and the optimal relationship between oxygen and fuel but, in the opinion of the course instructor, the learning outcomes do not justify the associated hazards.[72,73,74] The course instructor also suspended activities, which due to attitude or other deficiencies on the part of the entire class presented an unacceptable hazard despite the fact that the instructor conducted the same activities with previous learner groups.

The culture of safety at SFCC initially employed just-in-time training that fostered individual responsibility and understanding. The learner groups demonstrated appropriate safety attitude, practices, and industry-standard expectations through laboratory preparation. One example of such particular preparation is the development of an SDS database.

Development of an SDS database

In the genesis of the SDS database at SFCC, each student was required to make an entry for each compound (reagents and products) in the upcoming laboratory prior to conducting any activity. Each student recorded SDS entries in a laboratory notebook, which was then evaluated by the course instructor at the beginning of the lab meeting. When students did not complete the required entries, the instructor denied access to the lab space until the learner updated their database. In the initial form, the SDS database was cumbersome and required a significant length of time for appropriate evaluation.

Each entry included an answers to four questions based on information from an SDS on the indicated compound. The four questions are assessments of student ability to locate and extract information from an SDS but do not necessarily refer to the most important sections of the SDS. The ability to locate and extract appropriate information is crucial as learner's peers often view chemistry course completers as experts. The SDS activity provides learners with the opportunity to develop research skills that create awareness of risks but at the same time counteract unfounded phobias associated with chemical compounds. Overall, the SDS activity greatly contributes to an enhanced culture of safety.

While the four questions are not aimed at communicating all information available on an SDS, the questions narrow student focus and support the development of skills. If students include all-important information on an SDS, they will need to record the majority if not the entirety of each SDS, which would make the database overwhelmingly large and unwieldy. Narrowing the focus and selecting key pieces of information allows learners to develop skills in evaluating and interpreting information available on an SDS.

For each entry, students indicate the selected compound, identify the SDS source, and then report four specific pieces of information communicated in the SDS. The questions focus on the following issues:

1. How much of the compound will it take to kill me (Section 11)?
2. How do I prevent exposures to this compound (Section 8)?
3. What do I do if I am exposed to the compound (Section 4)?
4. How do I protect the rest of the world from the compound (Section 13)?

The first question investigates toxicity and spurs a discussion on the meaning of LD50 values (i.e., the lethal dose for half the population). While many other hazards are available for investigation, the LD50 is typically one that is consistently available for compounds and provides some insight into where the information has come from. For example, the LD50 frequently reported for sodium chloride is 3000 mg/kg oral rat, which allows for a class conversation on a compound relevant to learners.[75] Learners can calculate the amount of salt that 100 kg adults would need to ingest in one exposure to reach the lethal dose for half the population. The indicated animal provides a conversation on how lethal doses are determined. The method of administration is another conversation opportunity provided by the first question. When an SDS does not indicate LD50, students are required to validate the lack of information by locating at least two additional SDS sources, which generates a conversation about consistency in information and practices. Toxicity and lethal dose are extreme values allowing an opportunity to bring the potential loss of life to the front of the learner's mind, which in the experience of the authors generates a healthy respect for reagents. Other hazards exist such as blindness or disfigurement; however, they are not included for the sake of brevity and in a desire to force the learner to evaluate and respond specifically to the requested information.

The second question identifies PPE (Personal Protective Equipment) and leads to a discussion of situation-based exposure. Again, the example of sodium chloride is a powerful conversation, as many SDS suggest skin and eye protection, which however is seldom used when salting food.[75] The exploration of PPE supports the reasoning for wardrobe requirements in the laboratory space.

The third question allows for a review of common first-aid procedures, particularly focusing on ingestion and the presence or absence of induced vomiting. While laboratory spaces ban food and drink, ingestion is an area that does not have common first-aid procedures. The possibility of accidental ingestion should be low but ingestion is a situation that requires prior knowledge of appropriate response. The example of sodium chloride is again a useful opportunity, as there are contradictory suggestions from various sources.[76],[77] The fourth question exposes students to convoluted legal language and reinforces the idea that environmental impact is important. The typical language is “Please review all federal, state and local regulations that may apply before proceeding” which does not clearly inform beginning chemistry students how to properly dispose of a compound.[75] The presence of this question improves student recognition of the need to control waste disposal after the activity has concluded; students demonstrate a heightened awareness of environmental impact by asking the instructor when they are unsure what to do with a compound.

When chemistry courses at SFCC moved to a hybrid format in 2007, the SDS database became a shared repository in the online course LMS (Learning Management System) that the instructor would evaluate outside of the scheduled laboratory meetings. Students divided the responsibility and were each required to contribute entries. To ensure that they had read all entries, each student was required to post a response to each entry. The SDS database continued to be a weekly assignment for learners in the hybrid format. On the positive side, the weekly assignment allowed SDS information to be a consistent theme. On the negative side, learners commented that the self-regulated division of work became tedious and because each learner only contributed a new entry every few weeks, the assignment was not regular and easily forgotten.

The SDS database activity continued to evolve in 2010 when SFCC began offering a completely online chemistry course with lab. The chemistry program designed the online course to maintain the exploratory nature of the campus-bound course and best practices indicated by the American Chemical Society.[43] The expansion of the laboratory environment to include asynchronous non-traditional laboratory spaces (student homes) led to a need for formal activities that foster a culture of safety. Training could not occur in the just-in-time fashion mentioned earlier because of the geographic distances and the lack of a structured schedule for laboratory activities. For this reason, the SDS database transitioned to a structured assignment that had to be completed at the beginning of the course before students receive their laboratory kit of laboratory supplies and reagents. When the database was not complete, the instructors denied learner access to laboratory supplies.

The online course required the shipment of reagents to the student homes. The chemistry program intentionally focused on American Chemical Society best practices of manipulating reagents across all delivery modes by retaining appropriate reagent use in the online course.[75] Assigning a database of reagents based on supplies included in the laboratory kits and adding a section for reagents typically found in the student's home made it possible to identify potentially hazardous interactions and alert students of potential hazards from household solutions which could adversely react with reagents from their lab kits. The activity also supported the development of a community in the asynchronous distance-learning environment as students worked together to construct the database.

The chemistry program incorporated the online version of the SDS database into the campus bound sections allowing learners to maintain responsibility for their own division of work but permitting the database to be mostly complete at the beginning of the semester. Occasional new entries were required throughout the semester, but those occasions were rare and did not appear to be as tedious as the weekly assignments in the prior iteration.

In summary, the SDS database allowed instructors to identify best practices for hazard awareness and the handling of reagents. Instructors denied learners access to the lab materials and/or lab space if learners did not demonstrate appropriate responsibility and understanding by participating in the SDS database. Learners commented that the SDS database was a useful tool to heighten awareness of the hazards associated with the compounds in the laboratory space. Learners also mentioned that the SDS database provided comfort with the understanding of expectations for handling reagents. As a group assignment, the SDS activity reinforced appropriate attitudes, practices, and expectations for chemical handling. Even so, the distance-learning environment of the online course provoked an additional formalized assignment to communicate attitude, practices, and expectations for all laboratory activities beyond those associated specifically with chemical handling.

Safety Contract Construction

In the traditional chemistry course offerings prior to 2007, the chemistry program did not use safety contracts. The course instructor was present for all activities and chose to incorporate on-the-job training of safe practices rather than providing students with a contract. The chemistry program carried over the practice into the hybrid format, as an instructor was still able to physically meet with all students and ensure that learners carried out best practices. In the online course, however, the chemistry program recognized a need for a new approach. The program maintained that a generalized standard contract would not be sufficient; many students had admitted to merely skimming through such contracts, signing, and then forgetting the little contract content explored. It was at this point that the safety contract assignment was developed.

One of the first activities that students complete in the SFCC online chemistry course is the development of a safety contract that is specific to their needs, learning goals, and level of knowledge. The instructors act as overseers in the activity realizing that incoming students often lack such discernment. The result of the activity is that learners not only understand the contents of their contracts, but also have a vested interest in adherence. Learners decide which items are reasonable and important enough to include in the contract that they will follow for the remainder of the course.

To begin the activity, instructors direct learners to share a contract that the learner thinks is appropriate. In the online course, the sharing occurs in a discussion forum or other group tool through the online course LMS. The shared contract should be one already used somewhere else and therefore must have a reference. Students are not limited to prior laboratory courses that they may have taken but can use any resource available (other academic contracts, industrial contracts, etc.). It is important though that credit is given with an appropriate citation. The contract may not duplicate another classmate's selection, so learners must read the found contracts already posted.

After the learner posts their unique found contract, they begin the process of altering the contract to fit their specific environment. All changes require a reference so that learners demonstrate an ability to find information to support their claims. For example, if the learner adds wardrobe requirements, where are the requirements coming from? The instructor allows learners to cite individuals as references as long as they can defend the credibility of the source. Students are required to include citations from a variety of sources such as the course syllabus or academic and industrial sources. They are encouraged to find multiple sources for individual items to validate inclusion; just because one person says an item should be included does not mean that the rest of the safety community agrees. The process allows learners to gain insight into industrial hygiene practices. The instructor provides the following guidelines to communicate expectations of the final product.

The submitted final safety contract must

- be 1 page with 1 inch margins, 12 point font, and citations listed on a separate page.
- address appropriate wardrobe and personal protection equipment
- incorporate general guidelines to stay safe (such as never work alone, behave responsibly, no horseplay, etc.)
- indicate appropriate personal storage guidelines for equipment and reagents
- indicate an awareness of hazards and disposal procedures for compounds.

The length of the safety contract is limited so that learners evaluate each item in their safety contract and select those appraised to have the most value or importance. The wardrobe requirement and personal protection equipment provide an opportunity to discuss the types of protection that will be used and why. Glove protocol, safety glasses vs. goggles, and laboratory coats are examples of items that learners often debate for this requirement. The general guidelines to stay safe are intentionally ambiguous so that learners can discuss what they perceive as necessary. For example, online students often include fume hoods despite the lack of such equipment in their home laboratory space. Learners are required to indicate that they will never work alone and identify a specific laboratory partner who must agree to the safety contract. The appropriate storage guidelines allow instructors to communicate the importance of avoiding accidental contamination of food spaces and the need to maintain security of the laboratory kit from unauthorized access. Learners indicate their selected laboratory space allowing the instructor to communicate the importance of having appropriate access to running water and exits. An example that demonstrates the importance of this item is a student who proposed to lock themselves in a basement with no windows or running water for all activities so that external interference or disturbance of the activities would not be possible. However, this would also exclude necessary assistance in case of an accident. The hazard and disposal guideline is also intentionally ambiguous often resulting in learners indicating that they will reference the SDS database. The learners must indicate that they will not dispose of any items without the explicit consent of the instructor. The disposal requirement was included because several found safety contracts indicate disposal of spent liquid reagents down the drain and spent solids in the trash. Because the chemistry program desires to foster increased awareness and respect of environmental impact and the opportunity to validate lab completion, learners are required to indicate that they may not dispose materials in the household trash or down the drain without explicit instructor consent.

The edited found contract is a first draft of the learner's contract. In general, first drafts reveal students' lack of understanding about the desired culture of safety. Therefore, in a second step, students provide feedback to each other with the instructor interacting as a facilitator and only interjecting in cases of severe misconceptions. Students engage in conversations with each other about why specific items were included or omitted and, consequently, they locate less trite sources. Once the conversations have reached a point where ownership starts to materialize, most students are ready to generate their second draft.

While a good second draft usually demonstrates maturity in comprehension of safety, it generally lacks foresight and follow-through. Students engage in peer discussions steered by the instructor toward specific omissions or excessive inclusions. The lack of appropriate wardrobe and never working alone are examples of specific omissions that would lead to the instructor not accepting a contract. The learners or instructor challenges the inclusion of items that are unavailable in their workspace or unnecessary items such as respirators or fume hoods for online students as excessive and inappropriate. If other students do not recognize such cases, the instructor asks leading questions to demonstrate the impractical nature of the safety clause in question. For example, if an online student indicates that they will always don a respirator when conducting activities during which gas may evolve, the instructor will ask about pets and small children in the home being unprotected, what type of respirator the student owns, and the associated rating. The intention of this line of questioning is to lead learners to recognize that such equipment is impractical, unnecessary, and should not be included in their contract. Under the guidance of the instructor, students learn to adjust guidelines to the specific parameters of their location, the upcoming exploratory tasks, and the materials they will handle. Once the students personalize their information, most of them generate a third draft.

A good contract begins to emerge at this point but is often so inclusive that it is cumbersome. Students prune the contract so it includes the most important points but does not attempt to encompass all possible scenarios. Students should realize that they cannot plan for every individual circumstance but should develop general guidelines to aid them in making safe choices. The contract is restricted to one page so that students will evaluate the items in the contract. In the process of generating multiple drafts, students realize that the safety contract is not only a prerequisite to conduct exploratory activities but an exploratory activity in itself. In addition, the multiple drafts support the concept that the instructors do not expect students to know answers right away but that learners should develop an appropriate response and engage in conversation to improve their comprehension.

To indicate that the students agree to follow their contract, they submit the contract into a digital drop box within the online course LMS. This allows the instructor to assign points for work submitted and provides an accessible, digitally signed record of student agreements. Instructors have the ability to provide private feedback for correction if the contract is not adequate. Instructors assign scores in a binary fashion; accepted contracts receive a score of 100% and unacceptable contracts receive a 0%. Students with unacceptable contracts are required to correct deficiencies. The instructor “accepts” the contract by providing a score of 100%. Instructors deny learners with unacceptable contracts access to laboratory materials until their contract meets course requirements.

The instructors recognized an opportunity to incorporate the online version of the safety contract activity into the campus bound sections of chemistry. For the online students, each learner was required to generate a unique contract specific to their environment. For the campus bound students, each section was required to generate a shared contract for their shared environment. Rather than communicating drafts and revisions in the online course LMS, the campus bound sections construct their contract in the laboratory space during their first meeting. Learners are encouraged to use laptops, cellular phones, and any other resources available to support the activity. The instructor accepts or rejects the contract in the classroom. If the group of learners is unable to generate an acceptable safety contract during the first meeting, the safety contract becomes a homework assignment completed in a similar format described for the online students with the exception that all learners in the entire section must agree to the final version of the contract. Instructors deny learners with an unacceptable contract access to the laboratory space until their contract meets course requirements.

The safety contract activity allows instructors to demonstrate due diligence. Instructors deny learners access to the lab space and/or lab supplies if they do not demonstrate appropriate responsibility and understanding by participating in the safety contract construction. As a group assignment, the safety contract activity reinforces appropriate attitudes, practices, and expectations for laboratory practices.

Based on the anecdotal evidence collected through numerous student interactions, the authors feel that this process has been successful in developing a culture of safety in the asynchronous environment and has improved student ownership in synchronous and blended environments. In reflective journals, several students have commented that while they initially were frustrated and confused by the safety contract activity, they came to a realization that they had haphazardly signed and returned previous contracts without a second thought. Learners appreciated the constructed contracts because, in their opinion, the constructed contract held more weight, as the contract was drafted for the learners by the learners.

Conclusion

Students at SFCC lead conversations about ongoing decisions that go into keeping one’s self and others around them safe. The participation in a culture of safety has to become a daily decision-making process modeled by instructors that should become second nature to the learner. Safety must come first; other areas of the course are not important if the learner is unable to return to or complete the course. The involvement of faculty and staff on campus is crucial to the culture of safety. Without positive examples, enforcement of consequences, and guidance, learners generally will not recognize safety as a priority. In contributing to the culture of safety, learners must not only be aware of how to keep themselves safe, but also be a part of the conversation about what safety is and how to stay safe. Learners should have ownership over the safety of their learning space. Developing their own safety contract, SDS database, and being personally responsible for their wardrobe are three important components that contribute to learners recognizing their responsibility and the importance of the safety culture at SFCC.

The discussed activities are not appropriate for all circumstances but provide ideas that readers can tailor to the needs of any situation. The authors have successfully tailored SDS database and safety contract activities to other laboratory environments from high school to PhD-granting institutions. Industrial environments can incorporate similar practices where individuals are included in the discussion and design of safe practices. Individual activities do not build a culture of safety; however, the intentional focus by a group to solidify a singular attitude, practice, and expectation on safety fosters the development and improvement of such a culture.

APPENDIX C.

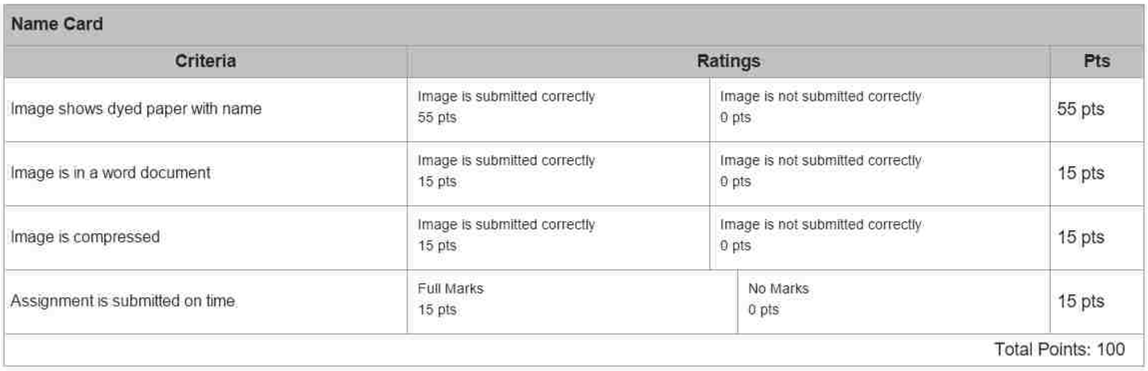
NAME CARD ASSIGNMENT AND RUBRIC

Materials needed:

- Shaving cream
- Food dyes
- Toothpicks
- Paper (1/2 sheets)
- Squeegee
- Paper towels
- Sharpie marker

1. Read all of the instructions before beginning the activity.
2. Spray a pile of shaving cream about the size of a fist on the lab table.
3. Spread a layer of shaving cream about one cm thick.
4. Choose dye color(s) and add 5-10 drops of dye to the shaving cream.
5. Drag a toothpick through the dyes on the shaving cream to make a design.
6. Lay the paper on top of the design.
7. Gently press the paper down to ensure that the design transfers.
8. Quickly and carefully, lift the paper off the shaving cream.
9. Use a squeegee or another flat stiff surface to remove the shaving cream from the paper (shaving cream should be rinsed down the drain rather than into a trashcan).
11. Use a damp paper towel to clean the workspace.
12. Fold the paper to make a standing nameplate.
13. Use a Sharpie or dry erase marker to write your name on the nameplate.
14. Make sure that you keep your nameplate for the entire semester. Display your nameplate during every class meeting and in all images posted in Canvas. Follow the instructions in Canvas to display your nameplate

Once you have made your name card, please submit an image of you with your name card as your profile picture.



Name Card

Criteria	Ratings		Pts
Image shows dyed paper with name	Image is submitted correctly 55 pts	Image is not submitted correctly 0 pts	55 pts
Image is in a word document	Image is submitted correctly 15 pts	Image is not submitted correctly 0 pts	15 pts
Image is compressed	Image is submitted correctly 15 pts	Image is not submitted correctly 0 pts	15 pts
Assignment is submitted on time	Full Marks 15 pts	No Marks 0 pts	15 pts

Total Points: 100

APPENDIX D.

FLAME LAB ASSIGNMENT AND RUBRIC

This activity is an opportunity to confirm **the claim** that **electrons exist in discrete energy shells**. Thermal energy or electrical potential can be used to excite the electrons of an element to a higher state; the decay energy discharged when the electron returns to a lower energy state may occur in the visible portion of spectrum which can be recorded. **Report how data collected does or does not support this claim, make sure to include all of the data**.

Collect observations with the unaided eye, a cobalt lens and use a spectroscope to record the wavelength of the emission for each ion provided. The cobalt lens filters out lower energy wavelengths (in particular Bunsen et al developed the lens to filter out sodium emission); record if a “change” or “no-change” is observed when the observed emission is filtered by the cobalt lens (compare the sodium and the potassium spectra if you are not sure). Colorblind individuals can still observe wavelength with the spectroscope and change/no-change with the cobalt lens. **Record a data table with all 3 types of observations including the wavelengths. The table should list all of the known ions observed and the proposed identity of the unknown.**

There are 11 workstations, which can be completed in any order. There is a “thirteenth” station, which is an LED “tree” to help you discover how to use the spectroscope and how to recognize the wavelength of an emission. The LED “tree” does not have to be reported it is only for your aid and assistance.

Seven (7) of the workstations have a solution that contains one of the following ions: Li, Na, K, Ca, Sr, Cu I, or B. One station’s solution is labeled as “unknown”. Using the directions below, thermally excite the solution with a Bunsen burner. Record observations for all 7 solutions in a data table. Make sure the data includes the wavelengths observed in nm, a description of the observations of the unaided eye and using the cobalt filter. For each ion, calculate the energy associated with at least one of the wavelengths ($E=h\nu$ $c=\lambda\nu$). **Your data table should have at least five columns: solution Id, unaided spectra (naked eye observation), cobalt filter results (what it looks like through a cobalt filter), wavelengths observed (using spectroscope), and energy for at least one wavelength.**

For the unknown solution, please compare the unaided eye, spectroscope, and cobalt filter observations of the unknown solution with the known solutions and provide a possible identification for the unknown solution. **Make sure to provided evidence from the data table to defend this claim.**

An electric discharge system is at the ninth station. When using the electrical discharge lamps, please do not touch the glass envelope of the discharge lamps as that will shorten the lifespan of the lamp. Discharge power supplies typically operate at 20 kV so be careful. Do not leave the lamp energized for more than 30 seconds and it must have a 20 second rest in between. **The data table should list all 3 types of observations (naked eye, cobalt filter, & wavelength in nm) for these evolutions; you must observe the emission of H2, He, N2, Ne, Ar, Xe, & Hg.**

At the tenth station you will color a periodic table using 4 colors to indicate the location of the "s", "p", "d", & "f" orbitals. **You will need to submit your periodic table in Canvas.**

The eleventh station requires you to hand write the electron configuration of the first 75 elements. **You must have a TA signature on your electron configuration to earn points.**

To generate thermal emission spectra:

1. place a wire loop into the Bunsen burner flame (top of the blue cone is the hottest portion of the flame) until the wire loop is a bright "cherry red"
2. quench the loop with the 1 M hydrochloric acid at the station to clean the wire
3. place about 1 to 2 mL of the solution on a table spoon which has been rinsed with distilled water
4. place a wire loop into the Bunsen burner flame (top of the blue cone is the hottest portion of the flame) until the wire loop is a bright "cherry red"
5. holding the spoon near the air intake of the Bunsen burner (rest the spoon on the fuel supply nipple near the air intake) place the glowing wire into the ionic solution slowly "rolling it" until the heat has been transferred. Best results are achieved when the wire is slowly immersed into the solution
6. record the color of the Bunsen burner flame using the unaided (naked) eye, the spectroscope, and a cobalt filter. (make sure to indicate wavelength observed with spectroscope)

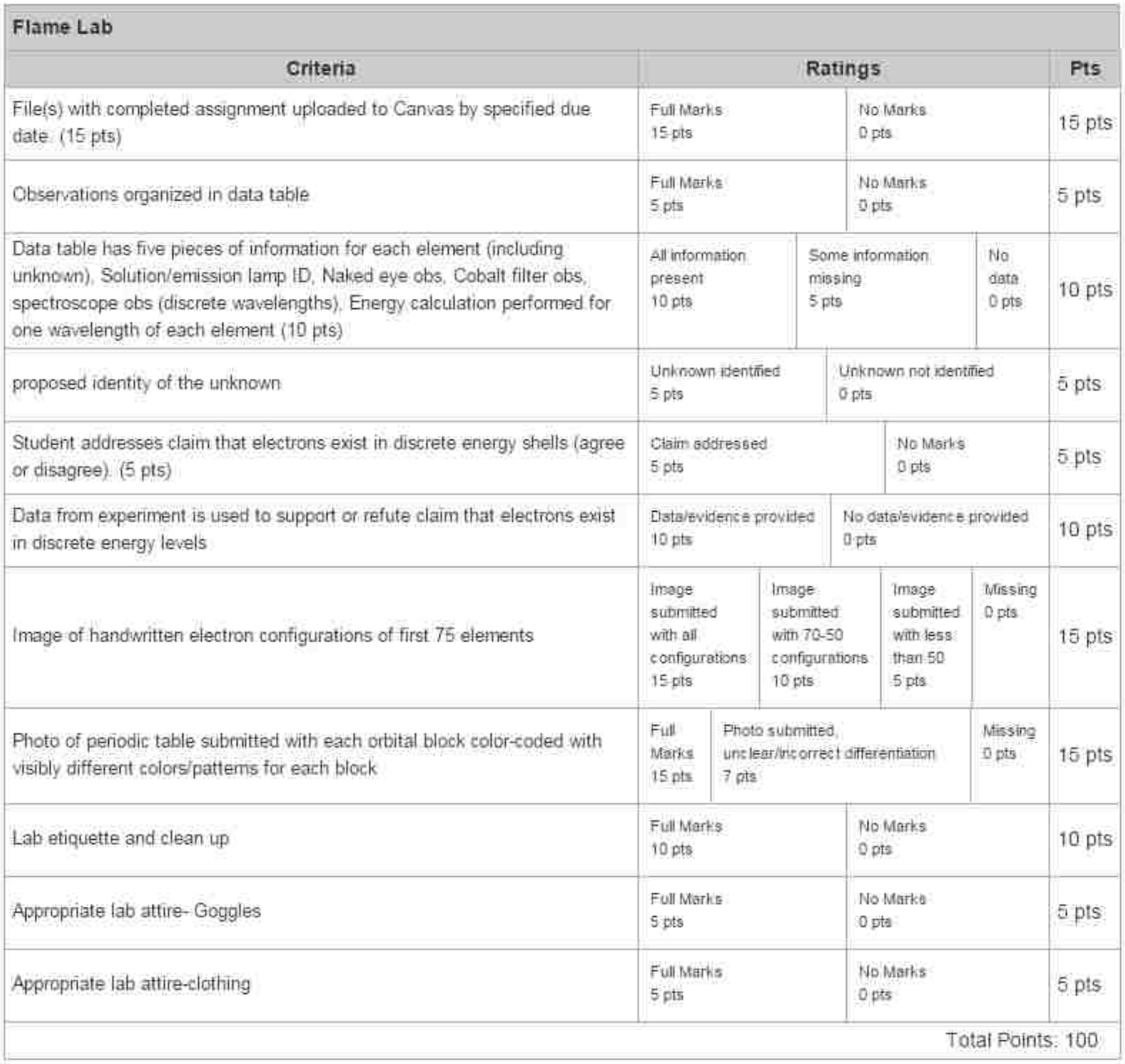
7. repeat with each solution provided; for simplicity's sake we will only be concerned with the element indicated

h = Planck's constant = 6.62606957 × 10-34 m2 kg / s

Submission:

For this assignment, please upload a single document that contains the following elements

1. Data table
    a. ID of all elements observed (flame tests and emission lamps)
    b. Observed using unaided eye, cobalt lens and spectroscope (include discrete wavelengths with spectroscope observations) for all ions/elements. Make sure that you indicate the excitation method.
    c. Proposed ID of unknown and justification
    d. One energy calculation per element
2. Discussion about how the data collected does or does not support the claim that electrons exist in discrete energy shells (should cite sources as appropriate)
3. Provide an image of your own hand-written electron configuration of the first 75 elements of the periodic table (each student must write their own in the lab.
4. Provide an image of periodic table provided in class color coded for s-,p-,d-, and f- blocks



Flame Lab

Criteria	Ratings	Pts
File(s) with completed assignment uploaded to Canvas by specified due date. (15 pts)	Full Marks 15 pts No Marks 0 pts	15 pts
Observations organized in data table	Full Marks 5 pts No Marks 0 pts	5 pts
Data table has five pieces of information for each element (including unknown), Solution/emission lamp ID, Naked eye obs, Cobalt filter obs, spectroscope obs (discrete wavelengths), Energy calculation performed for one wavelength of each element (10 pts)	All information present 10 pts Some information missing 5 pts No data 0 pts	10 pts
proposed identity of the unknown	Unknown identified 5 pts Unknown not identified 0 pts	5 pts
Student addresses claim that electrons exist in discrete energy shells (agree or disagree). (5 pts)	Claim addressed 5 pts No Marks 0 pts	5 pts
Data from experiment is used to support or refute claim that electrons exist in discrete energy levels	Data/evidence provided 10 pts No data/evidence provided 0 pts	10 pts
Image of handwritten electron configurations of first 75 elements	Image submitted with all configurations 15 pts Image submitted with 70-50 configurations 10 pts Image submitted with less than 50 5 pts Missing 0 pts	15 pts
Photo of periodic table submitted with each orbital block color-coded with visibly different colors/patterns for each block	Full Marks 15 pts Photo submitted, unclear/incorrect differentiation 7 pts Missing 0 pts	15 pts
Lab etiquette and clean up	Full Marks 10 pts No Marks 0 pts	10 pts
Appropriate lab attire- Goggles	Full Marks 5 pts No Marks 0 pts	5 pts
Appropriate lab attire-clothing	Full Marks 5 pts No Marks 0 pts	5 pts
		Total Points: 100

APPENDIX E.

ORGANIC STRUCTURES ASSIGNMENT AND RUBRIC

Organic Structures

You do not have to use the table present; the table is available to help you organize your work.

On a single sheet of paper (or other writing surface), write

1. the name of the molecule.
2. the molecular formula for the molecule.
3. the molecule line drawing for the molecule.

Use the molecular model kit to make the indicated molecule. When making the molecules using the molecular modeling kit, the short bonds should be used for single bonds and the longer flexible bonds should be used for double and triple bonds (2 long bonds for a double bond and three long bonds for a triple bond). The black atoms are carbon, red are oxygen, white are hydrogen, and blue are nitrogen.

Take a picture of the paper with the information present, the molecular model kit model of the molecule, and your nametag. If you are submitting the same image as your lab partner, make sure that both nametags are present in the image. No more than two individuals may submit the same image.

Name	Molecular formula	Molecule kit model image	Molecule line drawing
methane			
ethane			
propane			
butane			
pentane			
hexane			

heptane			
octane			
nonane			
decane			
ethene			
propene			
butene			
pentene			
hexene			
heptene			
octene			
nonene			
decene			
ethyne			
propyne			
butyne			
pentyne			
hexyne			
heptyne			
octyne			
nonyne			
decyne			

methanol			
ethanol			
propanol			
butanol			
pentanol			
hexanol			
heptanol			
octanol			
nonanol			
decanol			
methylamine			
ethylamine			
propylamine			
butylamine			
pentylamine			
hexylamine			
heptylamine			
octylamine			
nonylamine			
decylamine			
methanoic acid			

ethanoic acid			
propanoic acid			
butanoic acid			
pentanoic acid			
hexanoic acid			
heptanoic acid			
octanoic acid			
nonanoic acid			
decanoic acid			

For each molecule assembled in this lab activity, provide a compressed image, structural formula, and IUPAC name. Images should be inserted in a singular document, compressed, and uploaded. Remember your name card in your images.

This may be accomplished with a PowerPoint presentation:

1 molecule per slide, include
  - a photo of the model with your name cards
  - The structural formula and name may be clearly written and featured in the photo, or they can be added to the slide separately.

Define aromatic hydrocarbons, resonance structures, alkynes, alcohols, aldehydes, ketones, ethers, carboxylic acids, and amines.

Some Rubric (3)

Criteria	Ratings		Pts
Image of assembled molecules	Full Marks 25 pts	No Marks 0 pts	25 pts
structural formula of assembled molecules	Full Marks 20 pts	No Marks 0 pts	20 pts
IUPAC name of assembled molecules	Full Marks 20 pts	No Marks 0 pts	20 pts
Definition of aromatic hydrocarbons, resonance structures, alkynes, alcohols, aldehydes, ketones, ethers, carboxylic acids, and amines.	Full Marks 20 pts	No Marks 0 pts	20 pts
Submitted on time	Full Marks 15 pts	No Marks 0 pts	15 pts
			Total Points: 100

APPENDIX F.

ESTERIFICATION ASSIGNMENT AND RUBRIC

Introduction

This lab focuses on making esters through a process called Fischer Esterification. In this method, you will add a carboxylic acid to an alcohol and then add sulfuric acid and heat to yield an ester and water.

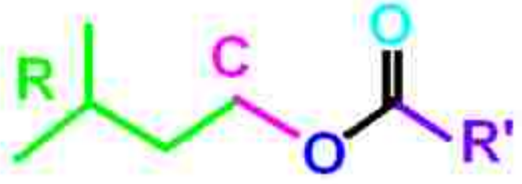
The sulfuric acid will be acting as a catalyst. In this reaction, the acid is regenerated in the reaction and therefore is present at the beginning and end of the process.

Isoamyl alcohol Acetic acid Isoamyl acetate Water

In the reaction above, the green hydrogen from the alcohol and the purple hydroxyl group (OH) from the carboxylic acid leave to form water while the oxygen left from the alcohol attaches to the acid. This leads us to the general structure of an ester.

To name the ester, take the alcohol (isoamyl in the example) and the name of the acid (acetic in the example) and combine them. You will replace the "ic" of the acid with an "ate" (acetic to acetate).

Structurally, an ester is written as RCOOR'. R and R' are the carbon backbones of the alcohol and carboxylic acid respectively. Here is the example of isoamyl acetate from above.



The image above shows the parts of the ester. While, R and R' will vary from ester to ester the structure RCOOR' remains consistent for all esters.

Instructions

The following instructions involve using concentrated sulfuric acid and heat. You need to make sure that you pay attention to what you are doing. Make sure to review the MSDS for these compounds so that you aware of all hazards, in particular this one has a flammable hazard and a heating element.

If you are pregnant, trying to get pregnant, or think that you may be pregnant, please inform your instructor before beginning this lab.

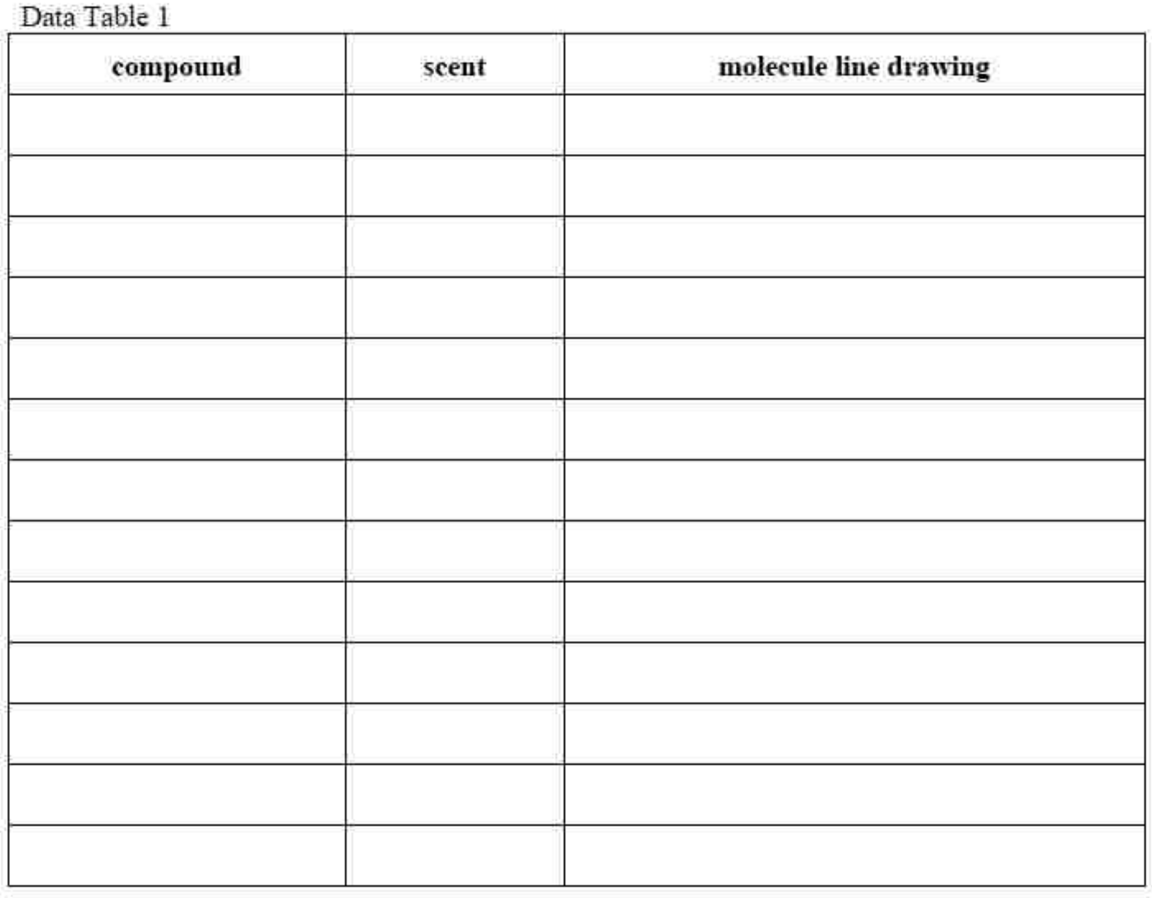
1. Note the scent for each compound that you will be using in this lab by gently wafting; do not smell the compounds directly. Record your observations in Data Table 1.
2. Label your test tubes with the names of your alcohols.
3. Add 20 drops of the alcohol indicated by the label on each test tube.
4. Add 10 drops (liquid) or 0.5 g (solid) of a carboxylic acid to each of the test tubes, and mix the contents.
5. Note the scent for each compound by gently wafting; do not smell the compounds directly. Record your observations in the Data Table 2.
6. Add 5 drops of sulfuric acid to each test tube and mix the contents.
7. Place the test tube in a hot water bath (250 mL beaker half filled with tap water heated to at least 50 degrees Celsius in a microwave or on a hot plate) for 5 minutes and let them “cook” for about 5 minutes.
8. While you are waiting for the compounds to cook, fill out the Data Table 2 with the alcohols, acids, and the scents for the esters that you are making.
9. Remove the test tubes from the hot water bath (you may use the test tube clamp) and place the test tubes in the test tube rack or an empty 100 mL beaker.
10. Note the scent for each compound by gently wafting; do not smell the compounds directly. Record your observations in the Ester Table.
11. Use an empty pipette to add 10 drops of distilled water to each test tube and mix the contents.

12. Note the scent for each compound by gently wafting; do not smell the compounds directly. Record your observations in your Data Table 1.
13. Empty and clean the test tubes (make sure that you remove all labels).
14. Draw the molecule line drawing for each of the starting compounds and each of the products formed.

Isopropyl alcohol and citric acid form the ester isopropyl citrate.

To name the ester, take the name of the alcohol (*isopropyl* for example) and the name of the acid (<u>citric</u> for example) and combine them. You will replace the “ic” of the acid with an “ate” (citric to citrate).

Therefore, *isopropyl* alcohol and <u>citric</u> acid form the ester *isopropyl* <u>citrate</u>.



Data Table 1

compound	**scent**	**molecule line drawing**

Sample Ester Table

Mixture sent before cooking	Ester name	Ester scent	Ester with water scent	Ester molecule line drawing

You should make the following esters: methyl salicylate, ethyl butyrate, isoamyl acetate, ethyl cinnamate, isopropyl acetate, and methyl benzoate

For Data Table 1, include

1. Name of each reagent (alcohols and carboxylic acids)
2. Scent of each reagent
3. Line drawing of each reagent

For Data Table 2, include

1. Scent of the mixture before heating
2. Name of ester formed
3. Scent of ester before adding water
4. Scent of ester after adding water
5. Line drawing of ester

Submit a single document with both data tables. (Clear photos of handwritten tables or typed tables are acceptable).

Esterification

Criteria	Ratings			Pts
File(s) with completed assignment uploaded to Canvas by specified due date.	Full Marks 15 pts	No Marks 0 pts		15 pts
Data Table 1-Name of each reagent (alcohols and carboxylic acids)	Full Marks 10 pts	Missing some names 5 pts	No Marks 0 pts	10 pts
Data Table 1-Scent of each reagent	Scent recorded for all reagents 10 pts	Missing some scents 5 pts	No Marks 0 pts	10 pts
Data Table 1-Line drawing of each reagent	Line drawing for all reagents 10 pts	Missing some drawings 5 pts	No marks 0 pts	10 pts
Data Table 2 Scent of the mixture before heating, before adding water, and after adding water	All three scent observations recorded for all esters 10 pts	> 50% of scent observations 5 pts	<50 % of observations 0 pts	10 pts
Data Table 2 Name of ester formed	Name for all esters 10 pts	3-5 names 5 pts	<3 names 5 pts	10 pts
Data Table 2 Line drawing of ester	Line structure for all esters 10 pts	3-5 line structures 5 pts	<3 line structures 0 pts	10 pts
Reagents match products	All esters in Data Table 2 are constructed from reagents in Data Table 1 5 pts	Esters in Data Table 2 do not match reagents 0 pts		5 pts
Appropriate lab attire-goggle	Goggles worn while performing the experiment 5 pts	No Marks 0 pts		5 pts
Appropriate lab attire-clothing	Appropriate lab attire was worn/obtained before starting the experiment 5 pts	No Marks 0 pts		5 pts
Lab etiquette and clean up	Waste disposed of properly and lab bench space clean before leaving 10 pts	No Marks 0 pts		10 pts

Total Points: 100

APPENDIX G.

LEWIS STRUCTURES ASSIGNMENT AND RUBRIC

You will need to use both your kit and your partner's kit to complete this activity.

It is suggested that you read about valence electrons, Lewis structures, resonance structures, and formal charge before completing this activity. Your chemistry textbook and Internet sources like chemeddl.org are good places to look.

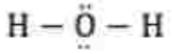
For Lewis structures:
Bonding electrons are shown as lines between atoms. Each line represents 2 electrons.
Non-bonding electrons are shown as dots around an atom. Each dot represents 1 electron.

To draw a Lewis structure:

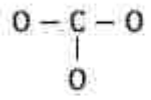
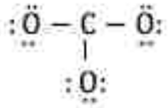
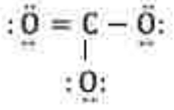
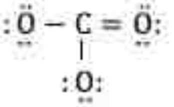
1. count valence electrons of all atoms present in formula and add them together (note: pay attention to charge when determining available electrons)
2. draw the basic structure using first atom in the formula as the central atom with the other atoms bonded to the central atom (exception: H is never a central atom)
3. give all outer atoms an octet except hydrogen
4. count electrons used and subtract from the number determined in step 1. Place any remaining electrons on the central atom.
5. if central atom does not have an octet, try to give it one using double or triple bonds. H & F will not get more than one bond in this course. If you cannot give the central atom an octet, elements from the second period will get less than an octet, while elements from the 3rd period and higher will have more than an octet.

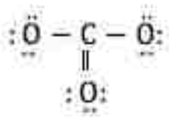
Example: H_2O

1. valence electrons for
    a. H: 1, because there are 2 H's, 1(2) = 2
    b. O: 6
    c. 2 + 6 = 8
2. first atom is H but since H is never a central atom, so O is the central atom
    a. H – O – H
3. all outer atoms are H, so do not give them octets.

4. two bonds are in the structure; each bond represents 2 electrons. 2(2) = 4 electrons used.
    a. 8 - 4 = 4
    b. 4 electrons go onto central atom; O
    c. 
5. central atom has an octet
    a. two single bonds; 2(2) = 4, and 4 nonbonding electrons, 4 + 4 = 8

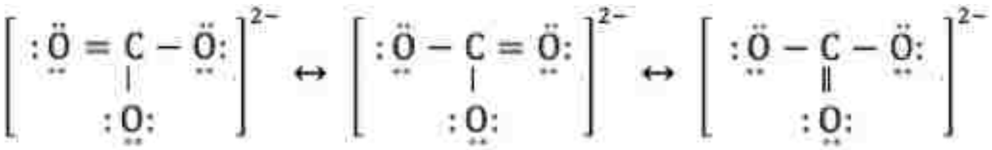
Example: CO_3^{2-}

1. valence electrons for
    a. C: 4
    b. O: 6, because there are 3 O's, 6(3) = 18
    c. the negative 2 charge indicates that there are an additional 2 electrons
    d. 4 + 18 + 2 = 24
2. first atom is C, so C is the central atom
    a. 
3. all outer atoms are O, so they each need octets.
    a. 
4. three bonds and 18 non-bonding electrons are in the structure; each bond represents 2 electrons. 2(3) = 6 +18 = 24 electrons used.
    a. 24 - 24 = 0
    b. there are no additional electrons to place on the central atom
5. central atom does not have an octet, so double or triple bonds must be used.
    a. 
    b. 

c. 

d. the multiple possible structures indicate a resonance.

e. because of the charge on the molecule, brackets must be used to indicate the charge (often called the “I do too know how to count” brackets because they indicate that the drawer intended to have additional or missing electrons than the neutral molecule would have).



For molecular modeling:

- single bonds are short sticks (31 in kit)
- double bonds are long sticks (8 in kit)
- non-bonding electron pairs are beige paddles (30 in kit)
- hydrogen is the white ball with 1 hole (23 in kit)
- boron is the trigonal planar beige ball (1 in kit)
- oxygen is the tetrahedral red ball (6 in kit)
- carbon is the tetrahedral black ball (10 in kit)
- fluorine is the tetrahedral green balls (6 in kit)
- nitrogen is the tetrahedral light blue ball (1 in kit)
- sulfur is the tetrahedral yellow ball (1 in kit)
- phosphorous is the trigonal bipyramidal purple ball (1 in kit)
- sulfur is the octahedral yellow ball (1 in kit)

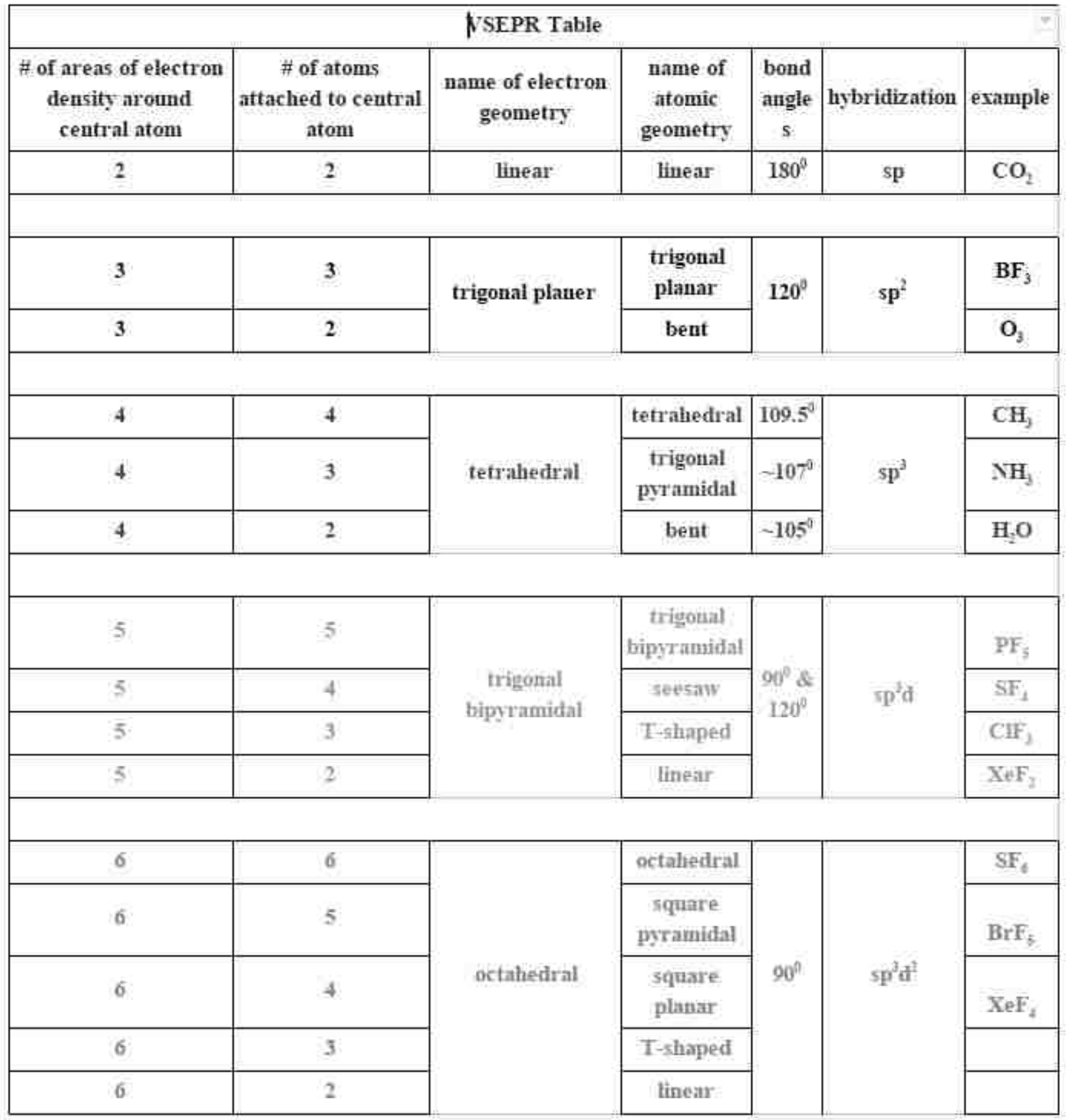
To use the VSEPR Table, determine how many areas of electron density are around the central atom; each pair of non-bonding electrons is one area, each single bond is one area, each double bond is one area, and each triple bond is one area. Then, determine how many atoms are connected to the central atom. Use the chart to determine the name of the electron geometry, atomic geometry, bond angle, and hybridization. It is important to note that lone pairs take up more space than bonding pairs, so the bond angles of molecules with non-bonding electrons are less than molecules with the same electron geometry and less or no non-bonding electrons.

In the example of H2O

- There are 4 areas of electron density; 2 non-bonding pairs and 2 single bonds (2 + 2 = 4).
- There are 2 atoms attached to the central atom (2 H's).
- According to the VSEPR table, H_2O has
- tetrahedral electron geometry
- bent atomic geometry
- bond angles of approximately 105^0
- hybridization of sp^3.

In the example of CO_3^{2-}

- There are 3 areas of electron density; 1 double bond and 2 single bonds (1 + 2 = 3).
- There are 3 atoms attached to the central atom (3 O's).
- According to the VSEPR table, CO_3^{2-} has
- trigonal planar electron geometry
- trigonal planar atomic geometry
- bond angles of 120^0
- hybridization of sp^2



VSEPR Table						
# of areas of electron density around central atom	# of atoms attached to central atom	name of electron geometry	name of atomic geometry	bond angles	hybridization	example
2	2	linear	linear	180^0	sp	CO_2
3	3	trigonal planer	trigonal planar	120^0	sp^2	BF_3
3	2		bent			O_3
4	4	tetrahedral	tetrahedral	109.5^0	sp^3	CH_3
4	3		trigonal pyramidal	$\sim 107^0$		NH_3
4	2		bent	$\sim 105^0$		H_2O
5	5	trigonal bipyramidal	trigonal bipyramidal	90^0 & 120^0	sp^3d	PF_5
5	4		seesaw			SF_4
5	3		T-shaped			ClF_3
5	2		linear			XeF_2
6	6	octahedral	octahedral	90^0	sp^3d^2	SF_6
6	5		square pyramidal			BrF_5
6	4		square planar			XeF_4
6	3		T-shaped			
6	2		linear			

To find formal charge (FC) on an atom (not on a molecule), take the number of valence electrons and subtract the sum of the number of bonds and the number of nonbonding electrons.

FC = # of valence electrons - (# of bonds + # of nonbonding electrons)

Example of H_2O: $FC_H = 1 - (1 + 0) = 0$

$FC_O = 6 - (2 + 4) = 0$

The sum of the formal charges must be the total charge; since both of the formal charges are “0”, the sum of the formal charges is 0, which is equal to the total charge.

Example of CO32-: $FC_C = 4 - (4 + 0) = 0$

FC_O double bond = $6 - (2 - 4) = 0$

FC_O single bond = $6 - (1 + 6) = -1$

The sum of the formal charges must be the total charge; since the formal charge of C and the double bonded O are both “0” and the two single bonded O are both -1, the sum of the formal charges is -2 (-1 + -1 = -2) which is equal to the total charge.

For each of the molecules listed

1. draw the Lewis structure(s) and include resonance structures as appropriate
2. create a VSEPR model using the provided molecular modeling kit
3. provide the electron geometry
4. provide the bond angles
5. provide the hybridization
6. provide the molecular geometry
7. provide the formal charge for each atom

Record the hand drawn the Lewis structure(s), an image or drawing of the molecular modeling kit molecule, electron geometry, bond angles, hybridization, molecular geometry, and formal charges in your lab log.

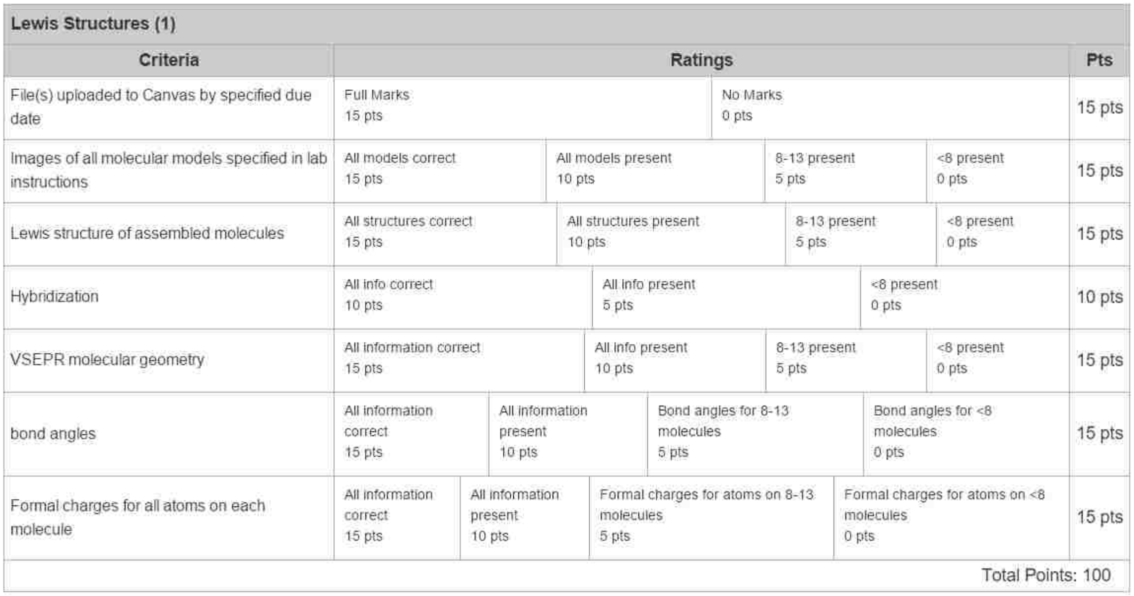
- CO_2
- NH_4^+
- BF_3
- CH_3F
- CNS^-

- NH_3
- H_3O^+
- PF_5
- CNO^-
- BH_2^-
- SF_5^-
- PF_4^-
- N_2O
- ethanol
- butyric acid
- ethyl butyrate

For each molecule modeled, provide

1. an image of the molecular model (constructed using the MolyMod kit)
2. Hand-drawn Lewis structure
3. Electron pair geometry (VSEPR shape classification such as linear, trigonal planar, tetrahedral, trigonal bipyramidal, or octahedral).
4. Molecular geometry (VSEPR shape classification such as linear, trigonal planar, tetrahedral, trigonal bipyramidal, or octahedral)
5. Hybridization
6. Bond angle
7. Formal charges for each atom

This may be best accomplished with a PowerPoint presentation, 1 slide/molecule OR you may choose to put #2-7 in a table. Just be clear about which information applies to which molecule. Please compress photos before submitting.



Lewis Structures (1)

Criteria	Ratings				Pts
File(s) uploaded to Canvas by specified due date	Full Marks 15 pts	No Marks 0 pts			15 pts
Images of all molecular models specified in lab instructions	All models correct 15 pts	All models present 10 pts	8-13 present 5 pts	<8 present 0 pts	15 pts
Lewis structure of assembled molecules	All structures correct 15 pts	All structures present 10 pts	8-13 present 5 pts	<8 present 0 pts	15 pts
Hybridization	All info correct 10 pts	All info present 5 pts	<8 present 0 pts		10 pts
VSEPR molecular geometry	All information correct 15 pts	All info present 10 pts	8-13 present 5 pts	<8 present 0 pts	15 pts
bond angles	All information correct 15 pts	All information present 10 pts	Bond angles for 8-13 molecules 5 pts	Bond angles for <8 molecules 0 pts	15 pts
Formal charges for all atoms on each molecule	All information correct 15 pts	All information present 10 pts	Formal charges for atoms on 8-13 molecules 5 pts	Formal charges for atoms on <8 molecules 0 pts	15 pts
					Total Points: 100

APPENDIX H.

COPPER CYCLE ASSIGNMENT AND RUBRIC

Reaction 1- Formation of copper II nitrate

One teammate should collect a sample of 0.6 g-0.8 g of copper and place it in the bottom of a 600 mL glass beaker.

The other teammate should collect about 9 mL of concentrated nitric acid from the snorkel.

Warning: concentrated nitric acid is caustic and can cause permanent tissue damage. If you get nitric acid on your skin, it will turn your skin yellow and you should rinse the area with copious amounts of cold water.

Caution: poisonous gas will be evolved- this step should be conducted under a snorkel or in a fume hood.

Place the copper into the 600 mL beaker and place the beaker under the snorkel. Tilt the beaker so that the copper is collected in a corner of the beaker. Pour about 9 mL of nitric acid into the 600 mL beaker while it is tilted so that the copper wire is in contact with the nitric acid.

Record your observations; an example data table has been provided to you at the end of this document. While monitoring the reaction progress, prepare a 1 M solution of sodium hydroxide (6 g NaOH in 150 mL of distilled H_2O).

Do not remove the solution from the snorkel until you have observed that the reaction is complete (make sure that you swirl the beaker in front of a white background). If you think that your reaction is complete, you may not remove your beaker from the snorkel until your TA agrees that there is no more poisonous gas evolving from the beaker.

Quenching Reaction 1

Add distilled water until there is approximately 200 mL of solution into the 600 mL beaker.

Reaction 2- Formation of copper II hydroxide

Slowly add 1 M sodium hydroxide to the solution in the 600 mL beaker by pouring down a stir rod until the reaction is complete or the pH is above 8. You should pour down a stir rod as demonstrated by your TA. You may need to make multiple batches of sodium hydroxide. If you add an excess of sodium hydroxide, you will make it difficult for reaction 3 to run to completion. If you have excess sodium hydroxide, you should share with another group. ***Caution: sodium hydroxide is a caustic substance and can cause tissue damage. If you get sodium hydroxide on your skin, rinse with copious amounts of cold water until your skin no longer feels slimy.***

Record your observations.

Reaction 3- Formation of copper II oxide (copper black)

While ***gently*** stirring (just enough movement to prevent the bottom from burning), ***slowly*** heat your solution with a hot plate. Do not allow the solution to boil. Continue to simmer and stir until the reaction is complete. When the reaction is complete, (all of the blue is gone), remove the beaker from the heat onto a hot pad and let the mixture settle.

If you have not added too much acid or too much sodium hydroxide, this step can occur fairly quickly; the reaction should still take several minutes but no more than 30. If this step is done too quickly, the product is formed in smaller crystals, which can complicate the next step.

Record your observations.

Washing the product

Decant the supernatant; remember to be careful not to lose product. The supernatant should be added to the waste container.

Reaction 4- formation of copper II chloride

Add about 50 mL of hydrochloric acid to the product that remains in the 600 mL beaker. Initially, do not stir the solution; after the reaction has progressed if there is a ring of unreacted copper II oxide, swirl or stir the solution to complete the reaction.

Record your observations.

Reaction 5- formation of solid copper

Obtain 1 piece of about 30 cm of aluminum wire and coil them as you did with the copper wire in Reaction 1. You should leave a tail of aluminum wire up to the top of the beaker so that you can stir with the aluminum wire. Under a snorkel, submerge the aluminum wire in the solution. The gas generated is noxious but not toxic.

When the rate of reaction slows, grasp the aluminum wire sticking out of the solution and gently tap the coil against the side of the beaker to expose unreacted wire for the reaction to continue. If gentle tapping is inadequate, slowly increase the vigor of the tapping. You may also use a stir rod if the "tail" becomes submerged. Once the copper ions are gone (the solution has no blue remaining), gently tap the aluminum wire against the side of the beaker to remove the solid copper and remove the excess aluminum wire.

Record your observations.

Collecting product

Decant the supernatant. The supernatant should be added to the waste container. Using filter paper and a funnel, collect the solid copper.

Record your observations.

You should dispose of all liquids from this lab in the liquid waste container and all solids should be disposed of in the solid waste container.

Make sure that you wash your work area well with a sponge.

For your Canvas submission, please submit the following:

List all of the compounds used in this activity. Provide chemical formula and IUPAC name for each compound.

Communicate your observations. Maximum points are given for organized observations. Tables and graphs should be used when appropriate.

For each set of observations, provide a chemical equation. You may provide an image of handwritten equations or use an equation editor. Make sure that you include states of matter, coefficients, and subscripts.

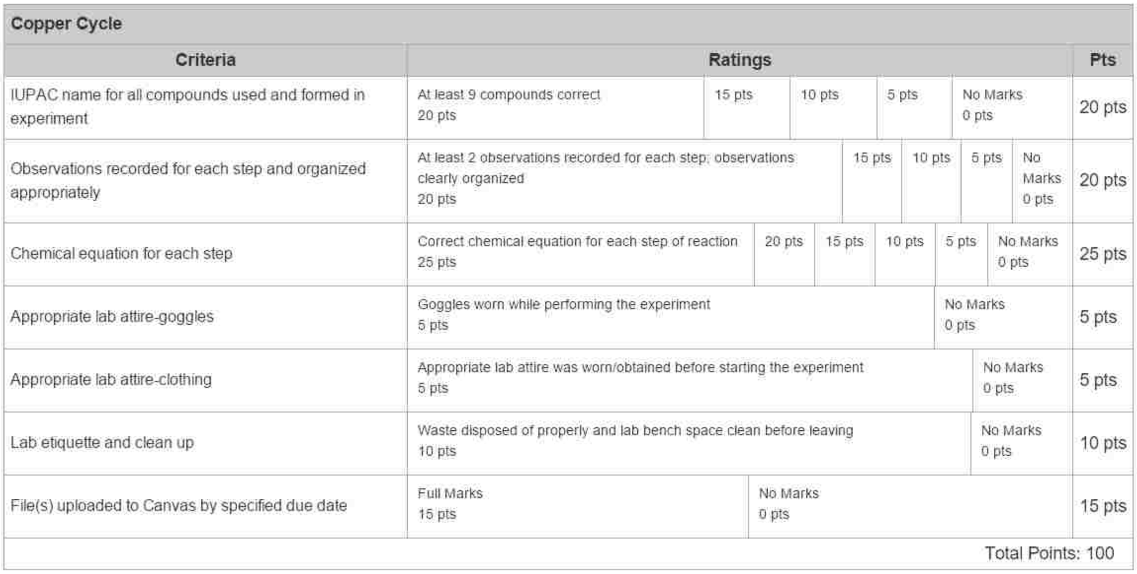
Data Table 1

Reaction	Observation

For submission, provide

1. A list of all compounds (reagents and products) used in this activity
    a. Include chemical formula and IUPAC name for each compound.
2. Communicate your observations for each reaction.
    a. Maximum points are given for organized observations. Tables and graphs should be used when appropriate.
3. For each reaction, provide a chemical equation.
    a. You may provide an image of handwritten equations or use an equation editor. Make sure that you include states of matter, coefficients, and subscripts.

Submit a single document with the information above. (Clear photos of handwritten tables and equations or typed tables and equations are both acceptable). Please compress your photos before submitting.



Copper Cycle

Criteria	Ratings						Pts
IUPAC name for all compounds used and formed in experiment	At least 9 compounds correct 20 pts	15 pts	10 pts	5 pts	No Marks 0 pts		20 pts
Observations recorded for each step and organized appropriately	At least 2 observations recorded for each step; observations clearly organized 20 pts	15 pts	10 pts	5 pts	No Marks 0 pts		20 pts
Chemical equation for each step	Correct chemical equation for each step of reaction 25 pts	20 pts	15 pts	10 pts	5 pts	No Marks 0 pts	25 pts
Appropriate lab attire-goggles	Goggles worn while performing the experiment 5 pts	No Marks 0 pts					5 pts
Appropriate lab attire-clothing	Appropriate lab attire was worn/obtained before starting the experiment 5 pts	No Marks 0 pts					5 pts
Lab etiquette and clean up	Waste disposed of properly and lab bench space clean before leaving 10 pts	No Marks 0 pts					10 pts
File(s) uploaded to Canvas by specified due date	Full Marks 15 pts	No Marks 0 pts					15 pts

Total Points: 100

APPENDIX I.

PAPER CHROMATOGRAPHY ASSIGNMENT AND RUBRIC

Materials:

- FD&C dyes (7)
- Chromatography sheets (2)
- 10 mL syringe
- Ruler
- Eluting chamber
- Warm tap water
- Salt
- Spoon
- Pencil
- Stapler

You may also conduct the activity using store bought food coloring; if you choose to experiment with food coloring, it is suggested that you use green and or black for optimal understanding of this lab. Optionally, any other consumable item with food coloring you would like to test (you can use M&M's®, but they don't tend to turn out well every time). If it is a solid, you will need to use water to dissolve the coloring. You should preferably use something that says what type of dye it has in it (for example Blue #1 in the ingredients list)

Introduction:

In this exercise, we will separate food dyes from a variety of sources. The separation is based on polarity. Polarity means that a molecule has an unequal dispersion of electrons. Electrons are negatively charged particles, so when there are more electrons on one side, that side is said to be negative.

For example:

In water, the electrons would rather stay closer to the oxygen than the hydrogen. Therefore, there is an unequal dispersion of electrons with hydrogen having less and oxygen having more. So, water has a positive end (hydrogen) and a negative end (oxygen). This means that the water molecule is polar. Think about a magnet, it has two poles, a north and south or negative and positive. If a molecule has an equal dispersion of electrons, it is non-polar.

Molecules can have varied degrees of polarity. The more separated that the electrons are, the more polar the molecule is. Water is just about the most polar molecule because there is a large amount of separation. Another way to think of this is as a seesaw. If two 5 year olds of identical weight sit opposite from each other, they are balanced (non-polar). If an average 9 year old sits on one side opposite from an average 1 year old, they will be very unbalanced (very polar). If an average 6 year old sits on one side opposite from an average 4 year old, the difference will be less, but they will still be off balance (polar, but not as polar as the 9 year old-1 year old).

Most dyes are polar and will be soluble in water (polar is soluble in polar, non-polar is soluble in non-polar). We will absorb the dyes on paper, which is less polar. Then we will use slightly salted water as our solvent to move the dyes on the paper. Since some of the dyes are more polar than others, they are absorbed more tightly to the paper and are moved more slowly by the salt water.

In paper chromatography, there is a mobile phase (the water), and a stationary phase (the paper). The distance that the dye will travel depends upon how attracted the dye is to the mobile phase vs. the stationary phase. You can picture it like this. You and I are going to cross a crowded room. You like most of the people in the room, and I am less social. While it won't take me long to cross the room, you may stop and shake hands with many of the people you come into contact with, so you will take longer. I am the dye that is more attracted to the mobile phase, and you are the dye that is attracted to the stationary phase. The more that you like the people (the stationary phase), the longer it will take for you to cross the room (move up the paper). If you like the stationary phase enough, you may not move at all.

FD&C dyes refer to specific dyes approved for human consumption under the US government's Food, Drugs, and Cosmetics Act. Food coloring typically found in grocery stores may vary from brand to brand. One brand of food coloring- like the colors used for different food products- may consist of only one FD&C dye, while another brand may be a mixture of two or more dyes. This experiment will show you qualitatively the various color constituents of Kool-Aid® (brand name or generic, depending upon which you were provided with make sure to save some of the grape for the next lab if you only have one grape), your grocery store’s brand of food coloring, plus any other food items you would like to test.

Method:

Add a pinch of salt to the bottom of your eluting chamber. Add warm water until the bottom of the chamber is just covered with salt water. Swirl the water to dissolve the salt, place something over the top of your chamber, and set the chamber aside.

Obtain your two chromatography sheets. On each piece;

1. Draw a thin horizontal line with a pencil (NOT a pen!) across the paper 20 mm (2 cm) from the bottom. The line should just barely be visible.
2. Draw small cross lines along the horizontal line about 2 cm apart, as shown (example shown may not be the exact number of columns you have).
3. In each column, make a small tick on the horizontal line roughly centered in the column. The illustration below is a table, which does not allow for me to easily put the tick mark in, sorry.

1. On Sheet 1, from left to right **skipping the first column**, lightly label in pencil the *top of each section* between the cross lines with the abbreviation for the seven FD&C food colors from your lab kit that will be tested, i.e., B1, B2, R3, R40, Y5, Y6, G3, and “all”.

2. Also on Sheet 1, in the columns right after the FD&C dyes, place labels for any additional solutions to be tested
3. Repeat steps 1 through 3 on Sheet 2.
4. For each dye on the sheet to be tested:
    a. Add a drop of dy in the CENTER (the tick mark that you made in step c above the image) of the appropriately marked section on the horizontal line (along the bottom of the paper) on the filter paper (spotting). In the column labeled “all”, you should have a drop of every FD&C color. Be patient and let the paper dry between dots.
    b. Let the dye dry completely and repeat 5a to produce a more vivid color. This can be done multiple times until you have no more than 5 layers of dye.
        i. Note 1: A small drop of water on a little bit of Kool-Aid® powder will be sufficient to make a sample to spot the paper.
        ii. Note 2: Apply only a small drop of each dye on the paper. Big drops often spread over a greater area and overlap other dyes. This is called band broadening. Although a larger dot will produce a more vivid color, a smaller dot will show the most distinct break between colors.
    c. Once the paper is spotted with all the dyes, allow the spots to dry for a few minutes.
5. Now form the paper into a cylinder with the edges touching, but NOT overlapped, and staple ⅓ from the bottom of the paper and ⅓ from the top of the paper. (You may want to use small pieces of tape on the outside to lightly hold the cylinder together while you securely staple it. This is where partners come in handy. If you use tape, remove the tape after stapling.)
6. Carefully drop the dye cylinder into the eluting chamber, making sure not to touch the chamber sides. The solvent-front will travel up the paper rapidly at first and then will slow down. Let the solvent-front rise for a few minutes, but immediately remove the cylinder if the solvent line gets within 2 cm of the top of the paper. If

all the solvent is soaked up before the front has time to move toward the top of the paper carefully add a little more solvent to the chamber.

7. When complete, remove the cylinder from the chamber and open the cylinder by tearing the staples so that it will lay flat on a clean paper towel. Then immediately (carefully) mark the top of each solvent-front (the line created by the moisture) with a pencil. Allow the paper to dry for several minutes.
8. Repeat steps 5 through 10 for Sheet 2. You should end up with all of the dyes on both sheets.
9. Measure to the nearest millimeter the height of the dye and the solvent::
   a. Start from the original horizontal pencil line and measure to the top center of where the dye stops in each column on the paper. Record in millimeters, mm.
   b. Measure the height of the solvent-front for each column from the original horizontal pencil line to the lines drawn in Step 10. Record in millimeters, mm.
10. Calculate and record the Rf value for each spot:
    a. $Rf = \frac{dye\ distance}{solvent\ distance} = \frac{distance\ in\ 12a}{distance\ in\ 12b}$
       i. Example: If the dye traveled 5 mm and the solvent traveled 10 mm, my equation should look like this.
       ii. $Rf = \frac{5}{10} = 0.5$
11. Repeat Steps 9 through 10 for the items listed on Sheet 2.

Results

1. By comparing the Rf of the color columns of the unknown samples if used (store bought dyes, misc. food products, Kool Aids, etc.) with those of the FD&C food dyes it is possible to determine which dyes are used in those products. Identify the following:

  a. The FD&C color(s) making up the grocery store food colorings (if tested). Don't forget to indicate the brand name; e.g., Kroger®, McCormick®, etc.
  b. The FD&C color(s) making up drinks (if tested).
  c. The FD&C color(s) making up other items containing food dye (if tested).

If you wish to repeat the experiment the filter paper we sent you (round circles) will work; coffee filters will also work but not as well.

For submission, provide

1. Background information about chromatography including references (at least 6 sentences, no more than 3 paragraphs)
    a. Include what has been done before (how has it been used in the past)
    b. how it is relevant to you (be creative about how it affects your life)
    c. how it is relevant to society
2. Image of your chromatography paper
3. Calculate the Rf for each compound
4. Identify the unknown compound
    a. Be sure to provide evidence for your claim (explain why you are claiming what you are claiming)

Submit a single document with the above information. Please compress photos before submitting.

Chromatography

Criteria	Ratings							Pts
Background with references	Full Marks 25 pts	Rating Description 20 pts	Rating Description 15 pts	Rating Description 10 pts	Rating Description 5 pts	No Marks 0 pts		25 pts
Image of paper	Full Marks 20 pts	Rating Description 15 pts	Rating Description 10 pts	Rating Description 5 pts	No Marks 0 pts			20 pts
Rf for each	Full Marks 20 pts	Rating Description 17 pts	Rating Description 14 pts	Rating Description 13 pts	Rating Description 10 pts	Rating Description 7 pts	No Marks 0 pts	20 pts
ID unknown	Full Marks 20 pts	Rating Description 15 pts	Rating Description 10 pts	Rating Description 5 pts	No Marks 0 pts			20 pts
On time	Full Marks 15 pts	No Marks 0 pts						15 pts

Total Points: 100

APPENDIX J.

IONIC PRECIPITATION ASSIGNMENT AND RUBRIC

Ionic Precipitation

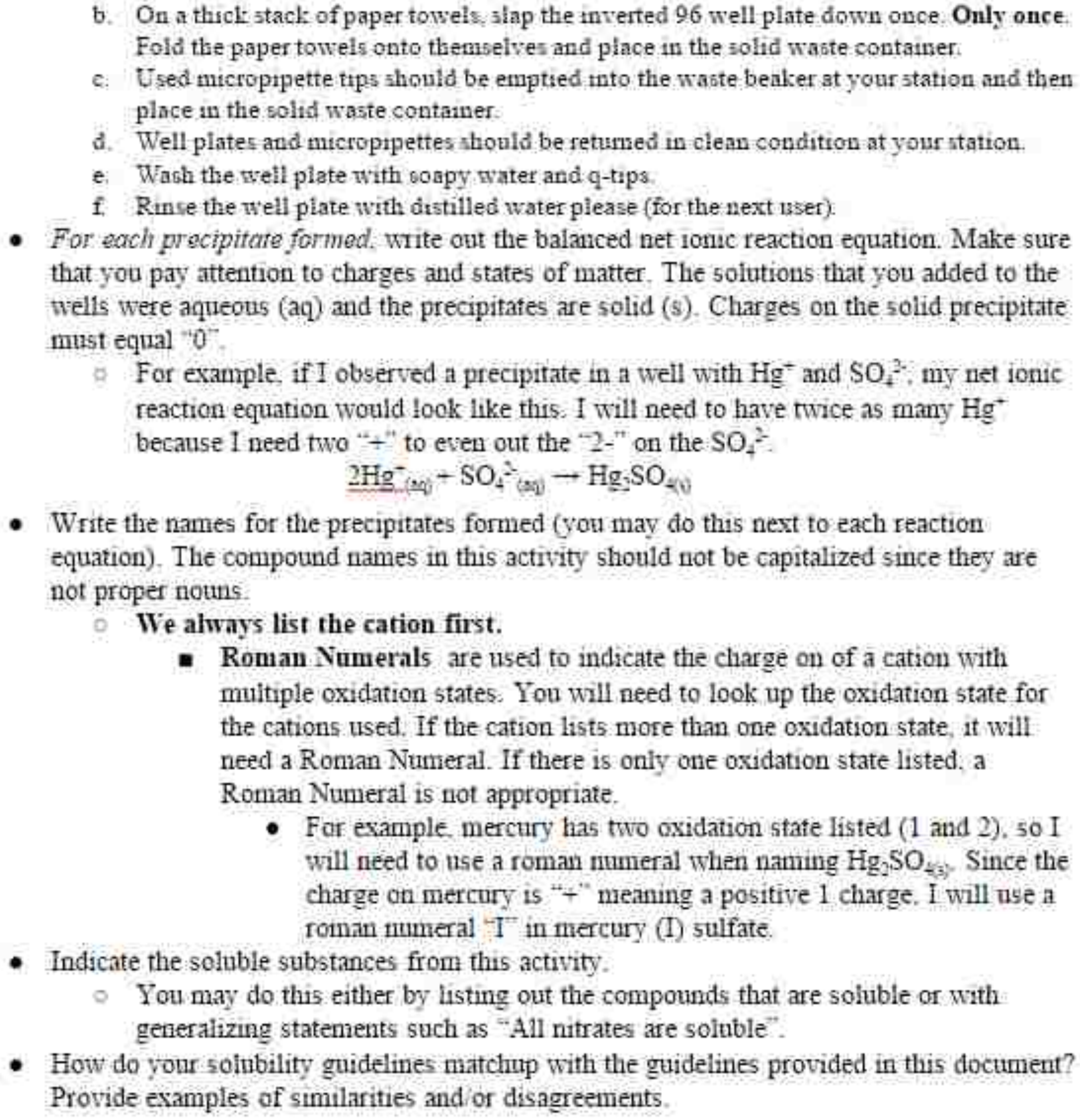
Learning Goals- After this lab, you will have experienced the ionic precipitation reactions and balancing and writing net ionic equations for precipitation reactions. You should also be able to compare your results to the solubility guidelines presented.

CAUTION!
Rinse any spills well with copious amounts of water.
Most of these chemicals are toxic by ingestion. Wash your hands as soon as you are done with the lab. After washing yourself, make sure that you wash all surfaces used; good soapy water will neutralize the hazard.

You should use the 24-well plate to obtain stock solutions. You will only need to fill the wells ⅓ of the way full. This should be plenty of material to complete the activity.
The 96-well plate should be used for the solubility tests.

Procedure

1. Solubility tests-
    a. Cations
        i. Place 75 microliters a cation in each of the wells in a row (for example, place 75 microliters of Mg^{2+} (magnesium) in each of the wells of row A, place 75 microliters of Ca^{2+} (calcium) in each of the first 10 wells of row B, etc.)
        ii. Repeat until all cations have been deposited.
    b. Anions
        i. Place 75 microliters of an anion in each well in a column (for example, place 75 microliters of CO_3^{2-} (carbonate) in the each well in column 1, place 75 microliters of OH^- (hydroxide) in each well in column 2, etc.). You may add the solutions in any order *except for sulfide;* sulfide should be added last as it will contaminate across to other columns. |
        ii. Once you complete a column, record your results for that column.
    c. Record your observations for each well with two compounds (where an anion and cation were both placed) paying particular attention to the formation of a cloudy solution or other indications of a solid (precipitate) being formed. You should create a data table to organize your results.
    d. Remember to check on light and dark surfaces
    e. Compare your results to the results of the other team at your table. You may need to reconduct some of the combinations to come to an agreement.
    f. Compare the combined results of your table to the results of the table directly across from you (east and west). Again, you may need to reconduct some of the combinations to come to an agreement.
2. Clean up
    a. Pour the remaining contents of your 24 well plate directly into the waste beaker at your station and rinse the plate with distilled water.



b. On a thick stack of paper towels, slap the inverted 96 well plate down once. **Only once.** Fold the paper towels onto themselves and place in the solid waste container.
c. Used micropipette tips should be emptied into the waste beaker at your station and then place in the solid waste container.
d. Well plates and micropipettes should be returned in clean condition at your station.
e. Wash the well plate with soapy water and q-tips.
f. Rinse the well plate with distilled water please (for the next user).

- *For each precipitate formed,* write out the balanced net ionic reaction equation. Make sure that you pay attention to charges and states of matter. The solutions that you added to the wells were aqueous (aq) and the precipitates are solid (s). Charges on the solid precipitate must equal "0".
  - For example, if I observed a precipitate in a well with Hg^+ and SO_4^{2-}; my net ionic reaction equation would look like this. I will need to have twice as many Hg^+ because I need two "+" to even out the "2-" on the SO_4^{2-}.

$$2Hg^+_{(aq)} + SO_4^{2-}_{(aq)} \rightarrow Hg_2SO_{4(s)}$$

- Write the names for the precipitates formed (you may do this next to each reaction equation). The compound names in this activity should not be capitalized since they are not proper nouns.
  - **We always list the cation first.**
    - **Roman Numerals** are used to indicate the charge on of a cation with multiple oxidation states. You will need to look up the oxidation state for the cations used. If the cation lists more than one oxidation state, it will need a Roman Numeral. If there is only one oxidation state listed, a Roman Numeral is not appropriate.
      - For example, mercury has two oxidation state listed (1 and 2), so I will need to use a roman numeral when naming $Hg_2SO_{4(s)}$. Since the charge on mercury is "+" meaning a positive 1 charge, I will use a roman numeral "I" in mercury (I) sulfate.
- Indicate the soluble substances from this activity.
  - You may do this either by listing out the compounds that are soluble or with generalizing statements such as "All nitrates are soluble".
- How do your solubility guidelines matchup with the guidelines provided in this document? Provide examples of similarities and/or disagreements.

For submission provide

1. a data table of your observations (the data table provided in the activity instructions is appropriate). Use abbreviations when necessary.
   a. Indicate appearance (color, opacity) of precipitates formed
   b. Indicate where no reaction occurred
2. a list of all of the insoluble substances (solids formed) from this activity. Use IUPAC nomenclature to name the compounds formed
   a. Write the net ionic equation for the formation of each

3. a list of general trends that you notice based upon your observations (all ____ are soluble except for _____).
4. a comparison of your solubility guidelines (#3) to guidelines provided in the instructions
    a. Provide examples of similarities and/or disagreements.

Submit a single document with the above information. Please compress photos before submitting.

Ionic Precipitation (1)

Criteria	Ratings	Pts
Submitted on time	File(s) with completed assignment uploaded to Canvas by specified due date 15 pts No Marks 0 pts	15 pts
Data Table-observations from experiment organized in data table, all solubility tests included	Full Marks 15 pts Rating Description 10 pts Rating Description 5 pts No Marks 0 pts	15 pts
IUPAC name for ALL insoluble substances formed in experiment	Full Marks 15 pts Rating Description 10 pts Rating Description 5 pts No Marks 0 pts	15 pts
Correct net ionic equations for ALL insoluble substances formed in experiment	Full Marks 15 pts Rating Description 10 pts Rating Description 5 pts No Marks 0 pts	15 pts
Comparison of Data (Observations from at least two other lab groups, comparison with solubility table, and general solubility rules based experimental results included)	Full Marks 20 pts Rating Description 15 pts Rating Description 10 pts Rating Description 5 pts No Marks 0 pts	20 pts
Appropriate lab attire-clothing	Appropriate lab attire was worn/obtained before starting the experiment 5 pts No Marks 0 pts	5 pts
Appropriate lab attire-goggles	Goggles were worn while performing the experiment 5 pts No Marks 0 pts	5 pts
Lab etiquette and clean up-Waste disposed of properly and lab bench space clean before leaving, verified by TA before exiting lab	Full Marks 10 pts No Marks 0 pts	10 pts
		Total Points: 100

APPENDIX K.

GAS LAWS ASSIGNMENT AND RUBRIC

The gas laws is an activity designed to provide students with an opportunity to experience the relationships of volume, pressure, and temperature in gases. Students are provided with a syringe with cap, a thermometer, and a portable electronic balance. Students submit organized observations, graphical representations of the relationships between volume, pressure, and temperature of gas, and a typed procedure.

Gather numerical observations about your choice of two relationships between the three variables in gas laws:

- volume
- pressure
- temperature

You should try to change one variable at a time while leaving one constant and observing the effect on the third.

Write notes as you explore the activity. Make sure that you record all of your observations. After completing the activity, type up a procedure so that someone else can repeat your experiment and successfully gather supporting data.

Organize your data into tables and then graph the relationship between volume and pressure, volume and temperature, and pressure and temperature. Make sure that you show all calculations.

The following criterions are used to assess the student submissions.

- Observations are consistent with graphs and are organized in list or table format (20 pts)
    - Observations are included (5 pts)
    - Observations provided for data in Graph 1 (5 pts)
    - Observations provided for date in Graph 2 (5 pts)
    - Observations organized in list/table format (5 pts)
- Graph 1 includes title, axis labels with units, at least 3 data points, and trend line with equation and R-squared value (20 pts)

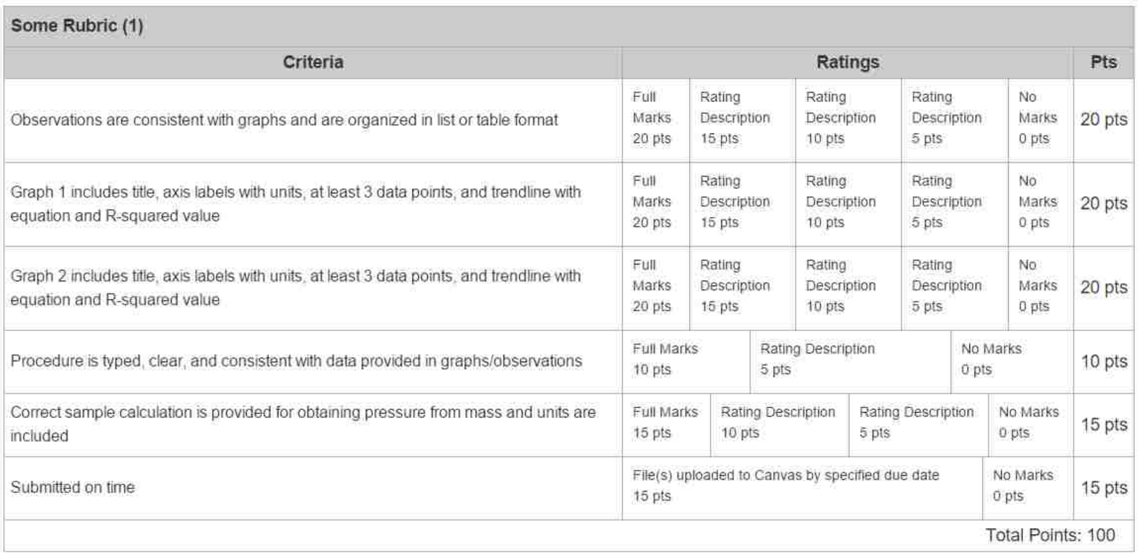
    - Appropriate title (5 pts)
    - Labels for x and y axes with units (5 pts)
    - 3 data points from experiment (5 pts)
    - Trend line with equation and R2 provided (5 pts)
- Graph 2 includes title, axis labels with units, at least 3 data points, and trend line with equation and R-squared value (20 pts)
    - Appropriate title (5 pts)
    - Labels for x and y axes with units (5 pts)
    - 3 data points from experiment (5 pts)
    - Trend line with equation and R2 provided (5 pts)
- Procedure is typed, clear, and consistent with data provided in graphs/observations (10 pts)
    - Procedure is typed (5 pts)
    - Procedure discusses how to obtain data provided in graphs and observations (5 pts)
- Correct sample calculation is provided for obtaining pressure from mass and units are included (15 pts)
    - Sample calculation is provided (5 pts)
    - Sample calculation includes units (5 pts)
    - Sample calculation is correct (5 pts)
- Submitted on time
    - File(s) uploaded to Canvas by specified due date (15 pts)

For submission provide

1. Observations organized in list form
2. Typed procedure
3. Example calculation for determination of pressure from mass
4. Scatter plots (must be created using spreadsheet program like Excel) for 2 of the following
    a. P vs T
    b. P vs V

  c. V vs T
5. Scatterplots should include
   a. Title
   b. Axis labels with units
   c. Data points
   d. Trend line with equation and R2 value

Please submit two files: (1) a document with the observations (can be clear photo of handwritten list), typed procedure, and sample calculation (can be clear photo of handwritten calculation) AND (2) file with graphs listed above.
Please compress photos before submitting.



Some Rubric (1)

Criteria	Ratings					Pts
Observations are consistent with graphs and are organized in list or table format	Full Marks 20 pts	Rating Description 15 pts	Rating Description 10 pts	Rating Description 5 pts	No Marks 0 pts	20 pts
Graph 1 includes title, axis labels with units, at least 3 data points, and trendline with equation and R-squared value	Full Marks 20 pts	Rating Description 15 pts	Rating Description 10 pts	Rating Description 5 pts	No Marks 0 pts	20 pts
Graph 2 includes title, axis labels with units, at least 3 data points, and trendline with equation and R-squared value	Full Marks 20 pts	Rating Description 15 pts	Rating Description 10 pts	Rating Description 5 pts	No Marks 0 pts	20 pts
Procedure is typed, clear, and consistent with data provided in graphs/observations	Full Marks 10 pts	Rating Description 5 pts	No Marks 0 pts			10 pts
Correct sample calculation is provided for obtaining pressure from mass and units are included	Full Marks 15 pts	Rating Description 10 pts	Rating Description 5 pts	No Marks 0 pts		15 pts
Submitted on time	File(s) uploaded to Canvas by specified due date 15 pts	No Marks 0 pts				15 pts
						Total Points: 100

APPENDIX L.

TYPES OF COMPOUNDS ASSIGNMENT AND RUBRIC

Types of Compounds
Calorimetry, Conductivity and pH

Lab-Quest Mini

1. Turn on computer
2. connect the Lab-Quest Mini
3. connect the temperature probe

Logger Pro temperature

1. Locate and run the Logger Pro program.
2. Select "Experiment" on the toolbar
3. Select "Data Collection"
4. Ensure that the mode is "Time Based"
5. Select "Sample at Time Zero"
6. Set the duration to 8 minutes
7. Set the sampling rate to 5 samples per minute
8. Choose "Done"
9. When ready to collect data, click on the green "Collect" button at the top of the window.
10. After the data has been collected, save the data by selecting, copying, and pasting the data into an Excel spreadsheet (or other fashions as desired).

Excel Workbook

1. Open an excel workbook; save the workbook with your name and date ie yournameMMDDYY.xls
2. Change each worksheet's name from "sheet one" to the compound's name ie "calcium chloride" for each of the enthalpy investigations
3. Place all of the conductivity investigations on a worksheet labeled "conductivity"
4. Place all of the pH investigations on a worksheet labeled "pH"

Enthalpy

1. Place a 250 mL beaker on a ring stand with a ring around the beaker (the ring should be near the top of the beaker).
2. Place 100.0 mL of distilled water into the beaker
3. Start data collection while simultaneously adding 10.0 g of $CaCl_2$; stir briskly with the temperature probe for the first 90 seconds.
4. After the container has cooled for 8 minutes and the Logger Pro has stopped collecting data, remove the probe, and empty the beaker into the designated waste container.
5. Repeat steps 1-4 for
    a. $CaCl_2$ repeat 2X so that you have 3 trials
    b. copper II sulfate anhydrous; add 1.50 grams and increase stir time to 3 minutes
    c. ammonium nitrate; add 3 grams

   d. urea; add 5 grams.

6. Calculate the molarity (M) of each solution prepared; record your work and the molarity on the appropriate excel worksheet.

Conductivity

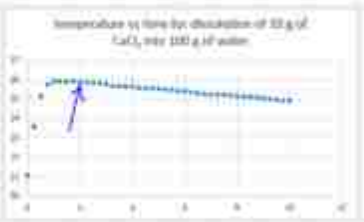
1. Use the Lab Quest 2 connected to the conductivity probe.
2. Measure the conductivity of 10.0 mL of distilled water in a 18 x 150 test tube
3. Record the conductivity in your excel workbook on a worksheet labeled "conductivity"
4. Determine how many grams of urea are required to make a 0.15M solution
5. Record your calculation on the worksheet (show at least one example calculation)
6. Add the urea and when dissolved
7. Measure the conductivity of the solution
8. Record the conductivity in your excel workbook on a worksheet labeled "conductivity"
9. Dispose of the solution in the proper container.
10. Repeat steps 2-9 for sodium chloride, sucrose, and magnesium sulfate

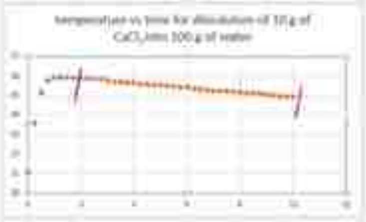
pH

1. Use the Lab Quest 2 connected to the pH probe
2. Measure the pH of 10.0 mL of distilled water in a 18 x 150 test tube
3. Record the pH in your excel workbook on a worksheet labeled "pH"
4. Determine how many grams of sodium sulfate are required to make a 0.15M solution
5. Record your calculation on the worksheet
6. Add the sodium sulfate and when dissolved
7. Measure the pH of the solution
8. Record the pH in your excel workbook on a worksheet labeled "pH"
9. Dispose of the solution in the proper container.
10. Repeat steps 2-9 for succinic acid, dextrose, and potassium hydrogen phthalate

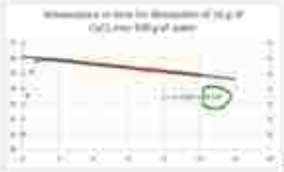
Finding the final temperature T_f

1) Make a scatter plot of temperature versus time.
2) Locate a data point on the curve after the temperature has begun to cool and add a second scatter plot from that point to the end of the data.





3) Generate a trend line (make sure to select "display equation for the line") for the shortened data set and note the **y-intercept**, this is the **final temperature** as if the



reaction had occurred instantaneously. The initial temperature is your first data point (t=0).

Calculating molar heat of dissociation.

1. Solve for *q* $q=mc\Delta T$
2. Where *c* is the specific heat of water
3. Where m is the mass of the water and the mass of the reagent; therefore it is the mass of the system.
4. Use $T_f - T_i = \Delta T$
5. Where the **y-intercept** from the cooling trend line is the final temperature for the reaction.
6. Where the temperature of the water from before the reaction is the initial temperature.
7. Take negative *q* and divide by the moles of the salt to find the molar heat of dissociation in J/mol ($\Delta H_{sol}=-q/mol$)

What to turn in:

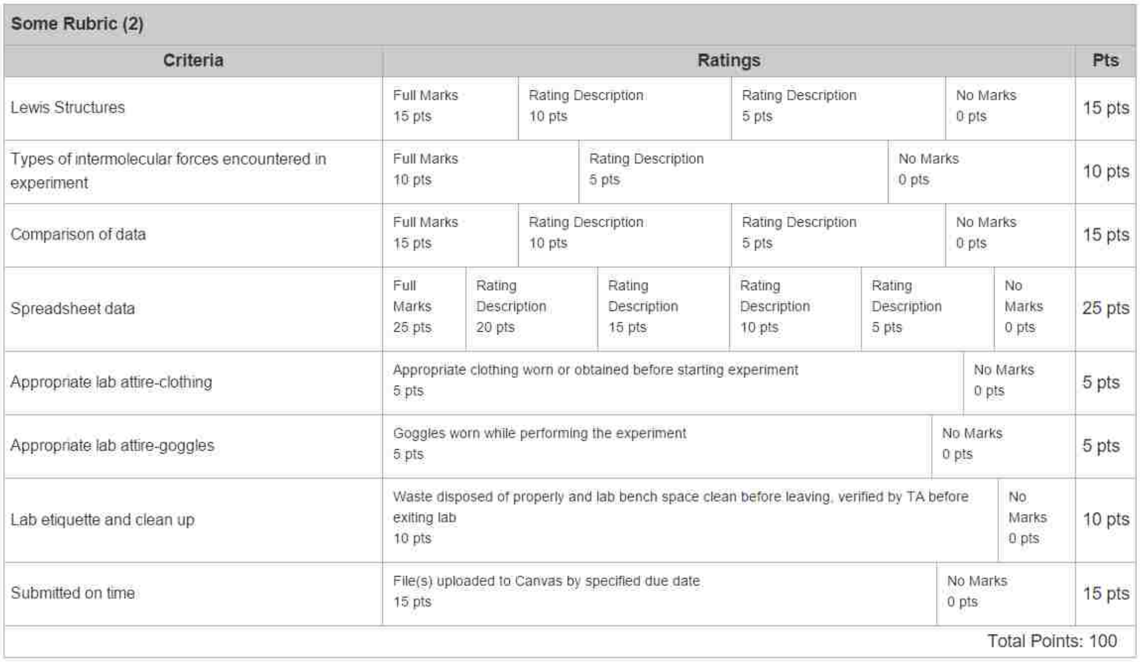
1. your excel spreadsheet with
    a. the plots for determining the final temperature (each tab named for the compound being investigated)
    b. the molar heat of dissociation for calcium chloride, include the standard deviation and provide the percent difference from the accepted literature value (which you must look up and cite)
    c. the molar heat of dissociation for urea, ammonium nitrate, and sucrose.
    d. the molarity of the calcium chloride, copper II sulfate anhydrous, ammonium nitrate and urea solutions; remember you must show one example calculation
    e. the conductivity table which has before and after conductivity measurements for each reagent assigned to the conductivity section
    f. show the example calculation and list in a table the number of grams used for each conductivity reagent
    g. the pH table with before and after pH readings for each reagent assigned to pH
    h. show the example calculation and list the number of grams for each pH reagent in a table
    i. provide at least a one paragraph description of the trends observed for each type of compound

A simple formula for finding the desired mass when preparing a solution is:
(FW)(M)(volume) = ___g of . . . to add to volume

$$sd=\sqrt{\frac{\Sigma(x_i-\bar{x})^2}{(n-1)}}$$

In your submission, provide

- your Excel spreadsheet.
- an image of the hand-drawn Lewis structures for each of the molecules used in the activity.
- a description of the types of intermolecular bonds present in the compounds used in the activity.
- a comparison of the data collected with the types of intermolecular bonds present.



Some Rubric (2)

Criteria	Ratings						Pts
Lewis Structures	Full Marks 15 pts	Rating Description 10 pts	Rating Description 5 pts	No Marks 0 pts			15 pts
Types of intermolecular forces encountered in experiment	Full Marks 10 pts	Rating Description 5 pts	No Marks 0 pts				10 pts
Comparison of data	Full Marks 15 pts	Rating Description 10 pts	Rating Description 5 pts	No Marks 0 pts			15 pts
Spreadsheet data	Full Marks 25 pts	Rating Description 20 pts	Rating Description 15 pts	Rating Description 10 pts	Rating Description 5 pts	No Marks 0 pts	25 pts
Appropriate lab attire-clothing	Appropriate clothing worn or obtained before starting experiment 5 pts	No Marks 0 pts					5 pts
Appropriate lab attire-goggles	Goggles worn while performing the experiment 5 pts	No Marks 0 pts					5 pts
Lab etiquette and clean up	Waste disposed of properly and lab bench space clean before leaving, verified by TA before exiting lab 10 pts	No Marks 0 pts					10 pts
Submitted on time	File(s) uploaded to Canvas by specified due date 15 pts	No Marks 0 pts					15 pts
							Total Points: 100

APPENDIX M.

STOICHIOMETRY OF CHALK ASSIGNMENT AND RUBRIC

Write the reaction equation to describe the reaction between aqueous sodium hydrogen carbonate and aqueous calcium chloride. Then, identify and define the parts of a chemical reaction including the reactants and products. Write the net ionic reaction equation, the complete reaction equation and identify the spectator ions.

Conduct the indicated reaction; do not make more than 100 mL of any solution. Suggested concentration is 0.10 M for all solutions; do not worry about making it exactly 0.10 M but do ensure you know its concentration to at least 2 significant digits. Suggested volumes would be around 30 mL per attempt so that you can collect 3 trials or pool data with another lab team. If you make too large of a batch it will be difficult to get it dry before you need to submit your results.

Did a precipitate form? Provide your observations that indicated a precipitation reactions (what did you see that supports the claim that you had a precipitate form?). Was your filter paper dry? Provide your observations that support your claim that the filter paper is dry (research drying or heating to a constant mass).

Provide the following information in a data table in your lab log for at least 3 trials:

- Initial mass: $CaCl_2$.
- Initial moles: $CaCl_2$.
- Initial mass: $NaHCO_3$
- Initial moles: $NaHCO_3$
- Theoretical mass: $CaCO_3$
- Mass of Filter paper
- Mass of Filter Paper + $CaCO_3$
- Actual mass : $CaCO_3$
- % Yield:
- average % Yield:
- standard deviation to one significant digit:

For submission, include

1. A list or table with the following
    a. reactants
    b. products
    c. net ionic equation
    d. spectator ions
    e. complete reaction equation (balanced, with states of matter)
2. Observations that indicated a precipitation reaction occurred (what did you see that supports the claim that you had a precipitate form?)
3. A photo of your precipitate (remember your name card).
4. A data table with the following information
    a. Initial mass of CaCl2
    b. Initial moles of CaCl2
    c. Initial mass of NaHCO3
    d. Initial moles of NaHCO3
    e. Theoretical mass of CaCO3
    f. Mass of Filter paper
    g. Mass of Filter Paper + CaCO3
    h. Actual mass of CaCO3
    i. % Yield:
    j. Average % yield
    k. Standard deviation of percent yield of at least 3 trials (If you were unable to complete 3 trials with your supplies, you can obtain data for the other trials from another group or groups)

To submit, upload a single document with the information above. Please compress photos before submitting.

Stoichiometry of a Precipitation Reaction

Criteria	Ratings								Pts
Identification and definition of reactants and products, net ionic equation, spectator ions, and full reaction equation provided	Full Marks 25 pts	Rating Description 20 pts	Rating Description 15 pts	Rating Description 10 pts	Rating Description 5 pts	No Marks 0 pts			25 pts
Observations indicating a precipitation reaction occurred	Full Marks 15 pts	Rating Description 10 pts	Rating Description 5 pts	No Marks 0 pts					15 pts
Image of precipitate provided	Full Marks 10 pts	No Marks 0 pts							10 pts
Information in Data Table (measured and calculated data with correct units)	Full Marks 35 pts	Rating Description 30 pts	Rating Description 25 pts	Rating Description 20 pts	Rating Description 15 pts	Rating Description 10 pts	Rating Description 5 pts	No Marks 0 pts	35 pts
Submitted on time	Full Marks 15 pts	No Marks 0 pts							15 pts

Total Points: 100

APPENDIX N.

HARD WATER TITRATION ASSIGNMENT AND RUBRIC

Water Hardness Titration

Collecting your samples:

<u>This activity is designed to test a sample of water direct from a local water supply (faucet, drinking fountain, hose, etc.). About 50 mL of the water sample will be required.</u>

Preparing the buret:

1. Rinse the buret with distilled water by adding distilled water and rolling the buret to rinse the sides. You do not need to fill the buret with distilled water, just add enough that you can rinse the buret. *Note: make sure that the buret tip is closed when adding liquid.*
2. Repeat step 1 for a total of three rinses.
3. Rinse your buret with a small amount of EDTA solution as described in step 1.
4. Fill your buret with EDTA solution. Make sure that you record the starting volume of EDTA for each trial in Data Table 1 (the buret does not have to be filled to the top each time).

Testing the Indicator:

This test verifies that the indicator is working correctly and it shows the blue color that should be expected at completion of the titration experiment.

1. Add 8-10 drops of distilled water into a test tube.
2. Add a few grains of calcium chloride to the distilled water in the test tube and stir.
3. Add 2-4 drops of buffer solution to the solution in the test tube.
4. If using liquid indicator, add 5 drops to your solution. If using powder, add a few grains of EBT indicator powder to the solution and stir with a toothpick. The solution should become pink.
5. Add 1 drop of EDTA to the solution and stir.
6. The solution should be a bright clear blue. IF NOT, add 1 drop of EDTA at a time until you observe a blue color.
7. Wash the content of the test tube into the waste container.

Performing a Titration of a Water Sample of Unknown Hardness:

1. Rinse your 125 mL Erlenmeyer well with distilled water. Place a small piece of white paper under the flask to help in the observation of color changes.
2. Use a graduated cylinder to measure exactly 10 ml of the water to be tested and pour it into a 125 mL Erlenmeyer flask.
3. Add 10-20 drops of buffer solution to the water sample in the flask.

4. If using liquid indicator, add 5 drops to your solution. If using powder, add a few grains of EBT indicator powder to the solution and stir with a toothpick. Use the toothpick to stir the water sample. The indicator will dissolve in the water and should produce a required pale burgundy pink color.
5. Gently swish and swirl the flask to agitate the water sample for at least 30 to 60 seconds to ensure that all the indicator powder dissolves.
6. Use the buret to add the EDTA solution to the water sample dropwise to the solution in the flask.
7. Gently swirl the sample in the flask after each drop and observe the color for five seconds.
8. Continue adding only 100 uL of EDTA solution at a time until the color changes to and remain blue in color.
9. Record how much EDTA was required to complete the titration.
10. Wash the contents of the flask into the waste container. Well rinse the flask with distilled water and dry it thoroughly with a paper towel before reusing.
11. Repeat the titration process until you have three consistent trials (± 10%) with water from the same sample source.

Calculate the Hardness of the Water Sample:

The concentration of the EDTA has been adjusted so that the mL amount of EDTA used for each titration represents hardness in mg/10 mL water sample of hardness. Since the water hardness is usually expressed as mg/L (or ppm), use the conversion factor for mL to L (1000mL/L) to obtain appropriate units. Most of the math has been done for you and is shown below.

$$\frac{x\ \cancel{mL\ EDTA}}{1}\times\frac{0.01\ \cancel{mol\ EDTA}}{1000\ \cancel{mL\ EDTA}}\times\frac{1\ \cancel{mol\ Ca^{2+}}}{1\ \cancel{mol\ EDTA}}\times\frac{1\ \cancel{mol\ CaCO_3}}{1\ \cancel{mol\ Ca^{2+}}}\times\frac{100\ \cancel{g}\ CaCO_3}{1\ \cancel{mol\ CaCO_3}}\times\frac{1000\ mg}{1\ \cancel{g}}\times\frac{1}{10\ \cancel{mL}}\times\frac{1000\ \cancel{mL}}{1\ L}$$

$$= x\frac{0.01\times1\times1\times100\times1000\times1000}{1\times1000\times1\times1\times1\times1\times10\times1}\frac{mg\ CaCO_3}{L}$$

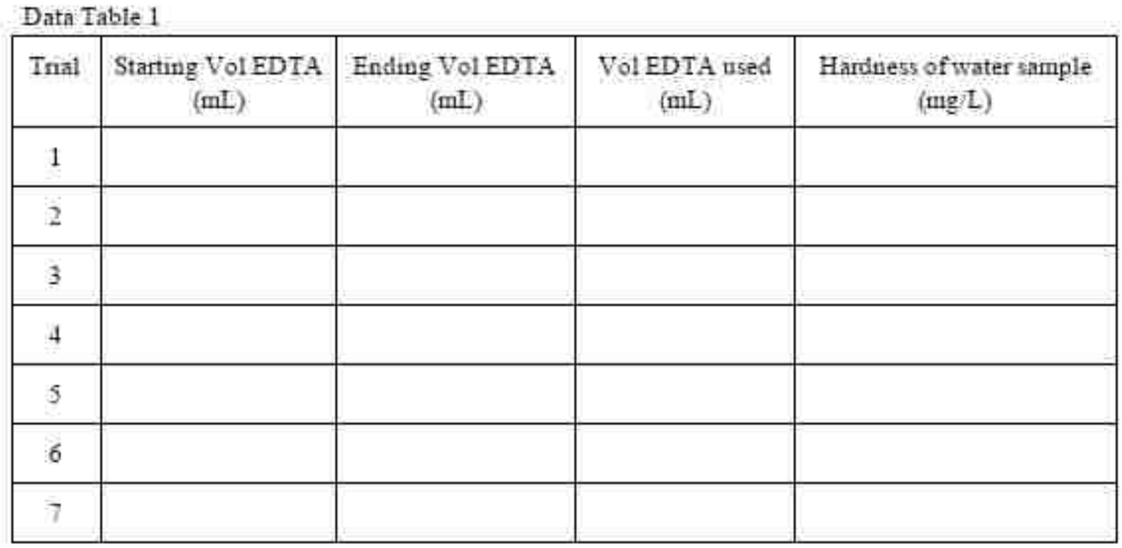
$$= x\frac{100\cancel{0000}}{1\cancel{0000}}\frac{mg\ CaCO_3}{L}$$

$$= x(100)\,\frac{mg\ CaCO_3}{L}$$

This means that to find the hardness of the water sample, the volume of EDTA used in mL (x) should be multiplied by 100.

For example, if it takes 1.6 mL of EDTA to titrate 10 mL of water sample, then the hardness is recorded as 1.6 x 100 or 160 mg/L hardness as $CaCO_3$.

Cleanup: If any solutions are left over, rinse them into the waste container. Rinse all equipment with water and then dry and store.



Data Table 1

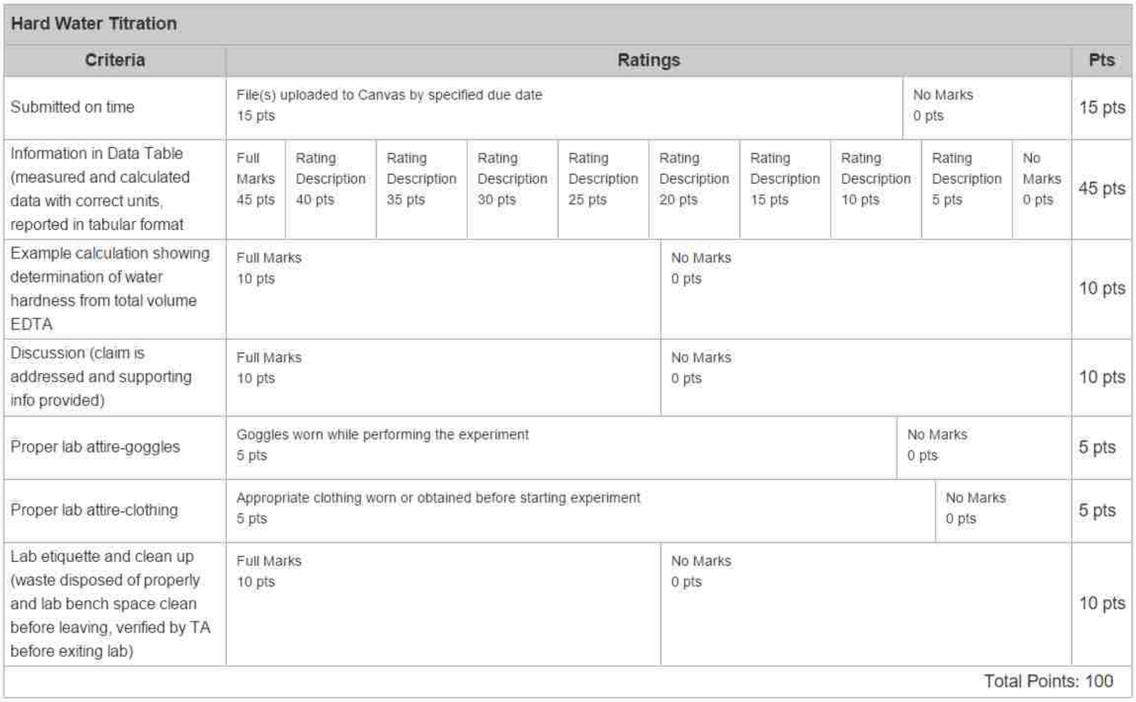
Trial	Starting Vol EDTA (mL)	Ending Vol EDTA (mL)	Vol EDTA used (mL)	Hardness of water sample (mg/L)
1				
2				
3				
4				
5				
6				
7				

Maximum points will be given for a tabular representation of experimental data!

For submission include

1. Data table with the following information for each trial for both samples (at least six trials)
    a. Initial volume EDTA (to nearest 0.01 mL)
    b. Final volume EDTA (to nearest 0.01 mL)
    c. Total volume EDTA (to nearest 0.01 mL)
    d. Hardness of water in ppm
2. Example calculation showing determination of water hardness from total volume volume EDTA used. Must include units! Can be clear photo of handwritten work or typed.
3. Brief discussion of experimental results (3-5 sentences)
    a. You should discuss whether hard water is advantageous or detrimental and provide data from your experiment or other reputable source to explain why you think so.
    b. If you use an outside source, be sure to cite it.

To submit, upload a single document with the information above (data table and example calculation). Please compress photos before submitting.



Hard Water Titration

Criteria	Ratings										Pts
Submitted on time	File(s) uploaded to Canvas by specified due date 15 pts	No Marks 0 pts									15 pts
Information in Data Table (measured and calculated data with correct units, reported in tabular format	Full Marks 45 pts	Rating Description 40 pts	Rating Description 35 pts	Rating Description 30 pts	Rating Description 25 pts	Rating Description 20 pts	Rating Description 15 pts	Rating Description 10 pts	Rating Description 5 pts	No Marks 0 pts	45 pts
Example calculation showing determination of water hardness from total volume EDTA	Full Marks 10 pts	No Marks 0 pts									10 pts
Discussion (claim is addressed and supporting info provided)	Full Marks 10 pts	No Marks 0 pts									10 pts
Proper lab attire-goggles	Goggles worn while performing the experiment 5 pts	No Marks 0 pts									5 pts
Proper lab attire-clothing	Appropriate clothing worn or obtained before starting experiment 5 pts	No Marks 0 pts									5 pts
Lab etiquette and clean up (waste disposed of properly and lab bench space clean before leaving, verified by TA before exiting lab)	Full Marks 10 pts	No Marks 0 pts									10 pts
											Total Points: 100

APPENDIX O.

SPECTROSCOPE AND NATURE OF LIGHT ASSIGNMENT AND RUBRIC

For this activity, you will be constructing a spectroscope. This document includes some links that describe the process. As you can see, there are many methods that you can choose from. If you find a different source that you like better, please use it. You can also find videos of the activity, but try to avoid letting them govern what you see and learn. There is not a "wrong" way to complete this lab except not trying to do something.

Once you construct your spectroscope, continue on to the activity on the final page in this document

For bonus points, try to find instructions with a scale and calibrate your spectroscope. You will need additional images to support a claim that you deserve the bonus points.

One of the objectives for this lab is to locate, evaluate, and complete instructions for constructing a spectroscope. This means that you will need to search for instructions until you find some that fit with what you have available to you and then successfully follow them.

The first set of links below contain ideas on how to build a spectroscope, you can seek other directions if you wish. I think I like the box versions better than the tube ones but you can build either or both.

http://www.swpc.noaa.gov/Curric_7-12/Activity_1.pdf
http://www.ccmr.cornell.edu/education/modules/documents/BuildingaSpectroscope.pdf
http://esamultimedia.esa.int/docs/scienceonstage/IT_Turricchia_Spectroscope.pdf
http://www.euhou.net/docupload/files/Exercises/measuring%20the%20world%20around%20us/how_to_build_spectroscope.pdf
https://pantherfile.uwm.edu/awschwab/www/specweb.htm
http://www.spectrohelioscope.org/net/spectro.pdf
http://www.phy.ohiou.edu/~stinaff/index_files/Spectrometer.pdf
http://sci-toys.com/scitoys/scitoys/light/cd_spectroscope/spectroscope.html
http://www.iucaa.ernet.in/~scipop/Obsetion/spectro/pizza_box_sp.htm
http://solar-center.stanford.edu/scope1.html

These links are reading/research about portions of the EM spectrum, if you are going into a allied health field a later professor or test may expect you to have memorized the EM spectrum.
You should do an internet search for EM spectrum images.

http://www.harmsy.freeuk.com/fraunhofer.html
(this site discusses some application of spectroscope applications)

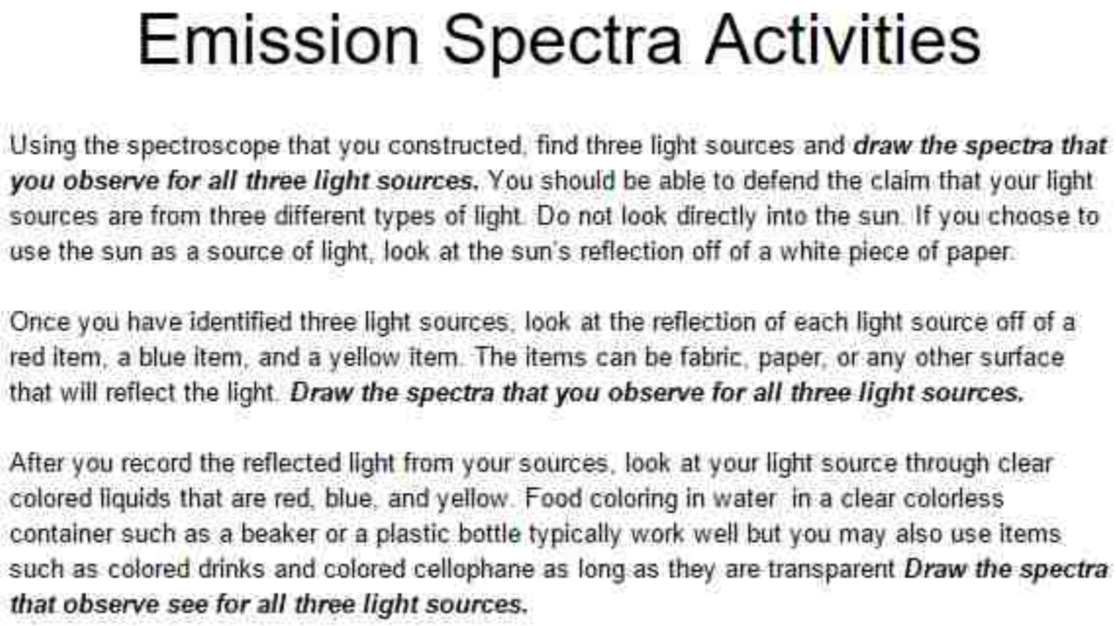
http://chemistry.bd.psu.edu/jircitano/periodic4.html
(this sight has the spectra of all the elements)

http://csep10.phys.utk.edu/astr162/lect/light/absorption.html
(the first part has useful information but it does get technical quickly)

http://webmineral.com/help/FlameTest.shtml
(these spectra are what you might see in your own flame lab but often the lab does not give such clear results)

http://ioannis.virtualcomposer2000.com/spectroscope/elements.html
(let the site load before navigating it; very indepth)

I also use Wikipedia to get background information on a topic, for specific details visit the references at the end of the page.
http://en.wikipedia.org/wiki/Spectrometer



Emission Spectra Activities

Using the spectroscope that you constructed, find three light sources and ***draw the spectra that you observe for all three light sources.*** You should be able to defend the claim that your light sources are from three different types of light. Do not look directly into the sun. If you choose to use the sun as a source of light, look at the sun's reflection off of a white piece of paper.

Once you have identified three light sources, look at the reflection of each light source off of a red item, a blue item, and a yellow item. The items can be fabric, paper, or any other surface that will reflect the light. ***Draw the spectra that you observe for all three light sources.***

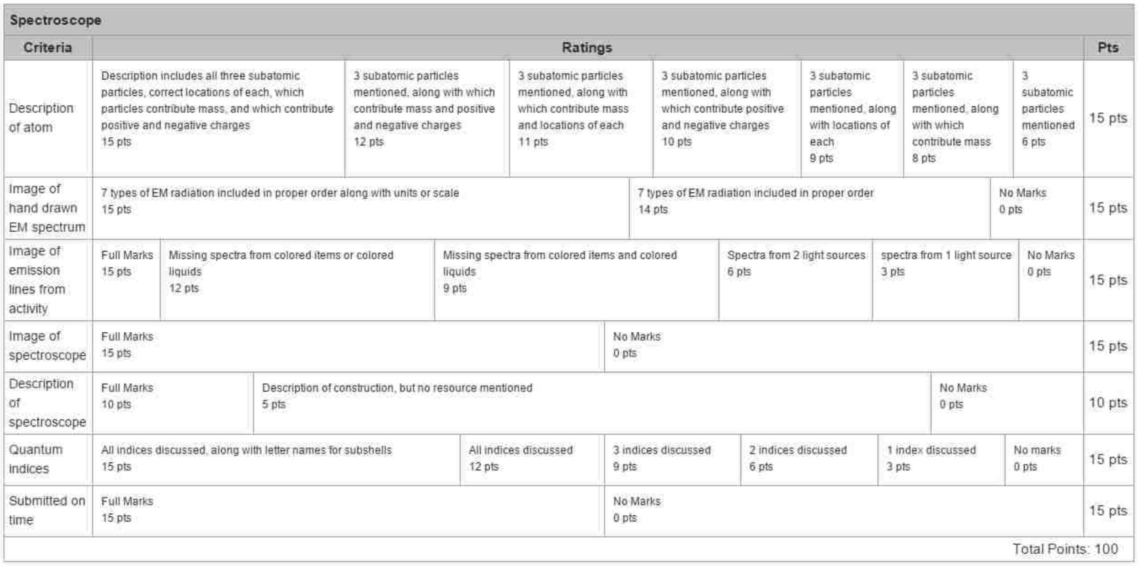
After you record the reflected light from your sources, look at your light source through clear colored liquids that are red, blue, and yellow. Food coloring in water in a clear colorless container such as a beaker or a plastic bottle typically work well but you may also use items such as colored drinks and colored cellophane as long as they are transparent ***Draw the spectra that observe see for all three light sources.***

For this assignment, please upload a single document that contains the following elements

- Description of an atom- please provide your description of an atom: what is it made of, where do the parts live, what is responsible for mass, what is responsible for volume, and what is responsible for charge? You are welcome to use references, but please cite your sources.
- Upload an image of a hand drawing of the EM spectrum from radio to gamma

- Upload an image of the hand drawn emission lines for spectra observed in the activity
- Upload an image of your spectroscope
- Describe the construction of your spectroscope (brief description, just a few sentences of how you put it together) and indicate the source that you used for your instructions
- Go to chemwiki page for quantum indices (Links to an external site.) (quantum numbers) and provide a brief summary of the information found. Make sure that you include information about n, l, ml, and ms

If you submit a Google document, please make sure to check for your instructor to request access so that the submission can be graded.
You should practice compressing images in documents when submitted online (Google if you aren't sure).



Spectroscope

Criteria	Ratings							Pts
Description of atom	Description includes all three subatomic particles, correct locations of each, which particles contribute mass, and which contribute positive and negative charges 15 pts	3 subatomic particles mentioned, along with which contribute mass and positive and negative charges 12 pts	3 subatomic particles mentioned, along with which contribute mass and locations of each 11 pts	3 subatomic particles mentioned, along with which contribute positive and negative charges 10 pts	3 subatomic particles mentioned, along with locations of each 9 pts	3 subatomic particles mentioned, along with which contribute mass 8 pts	3 subatomic particles mentioned 6 pts	15 pts
Image of hand drawn EM spectrum	7 types of EM radiation included in proper order along with units or scale 15 pts	7 types of EM radiation included in proper order 14 pts	No Marks 0 pts					15 pts
Image of emission lines from activity	Full Marks 15 pts	Missing spectra from colored items or colored liquids 12 pts	Missing spectra from colored items and colored liquids 9 pts	Spectra from 2 light sources 6 pts	spectra from 1 light source 3 pts	No Marks 0 pts		15 pts
Image of spectroscope	Full Marks 15 pts	No Marks 0 pts						15 pts
Description of spectroscope	Full Marks 10 pts	Description of construction, but no resource mentioned 5 pts	No Marks 0 pts					10 pts
Quantum indices	All indices discussed, along with letter names for subshells 15 pts	All indices discussed 12 pts	3 indices discussed 9 pts	2 indices discussed 6 pts	1 index discussed 3 pts	No marks 0 pts		15 pts
Submitted on time	Full Marks 15 pts	No Marks 0 pts						15 pts
								Total Points: 100

APPENDIX P.

SILVER BOTTLE FINAL ASSIGNMENT AND RUBRIC

This activity will be completed in class and will require no online submission or quiz.

Final lab practical

Criteria	Ratings							Pts
Student arrived to lab on time	Full Marks 50 pts	Rating Description 40 pts	Rating Description 30 pts	Rating Description 20 pts	Rating Description 10 pts	No Marks 0 pts		50 pts
Appropriate clothing and goggles worn or obtained before starting experiment	Full Marks 50 pts	No Marks 0 pts						50 pts
Waste disposed of properly and lab bench space clean before leaving, verified by TA before exiting lab	Full Marks 100 pts	No Marks 0 pts						100 pts
Good attitude	Full Marks 100 pts	No Marks 0 pts						100 pts
Lab sheet: work is shown in pen, volume calculations correct, volumes recorded using appropriate significant figures	Full Marks 50 pts	Rating Description 45 pts	Rating Description 35 pts	Rating Description 30 pts	Rating Description 20 pts	Rating Description 15 pts	No Marks 0 pts	50 pts
Glassware check-in	Full Marks 50 pts	No Marks 0 pts						50 pts
Lab Skills	Full Marks 50 pts	No Marks 0 pts						50 pts
Product (bottle)	Full Marks 50 pts	No Marks 0 pts						50 pts
								Total Points: 500

APPENDIX Q.

TITRATION FINAL ASSIGNMENT AND RUBRIC

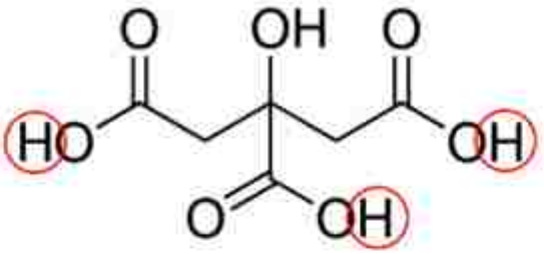
Titration Final

The final In-the-Commons titration lab is an activity designed to provide an opportunity to write a full lab report including reaction equations, calculations, an introduction, a discussion, and a conclusion. Students take a kit including

- a 100 mL beaker
- 30 mL syringe with plunger
- 10 mL syringe with stopcock (buret)
- a test tube holder/clamp **(you should obtain this from your lab drawer)**
- 100 mL 0.5 M citric acid
- 100 mL sudsy ammonia (unknown concentration)
- 3 indicators (2 mL methyl orange, 2 mL bromothymol blue, and 5 mL turmeric solution)

Students submit a full lab report of the activity including a claim and references to their own data supporting their claim.

Note: citric acid is a triprotic weak acid. Some simplifying assumptions have been made to ensure the calculations required to complete this lab are within the scope of the material covered in Chem 1310.



1. Use the test tube holder and textbooks to set up a stand for the syringe with stopcock (called the buret for the remainder of the lab), you will want the stopcock to be high enough that the 100 mL beaker will fit beneath it.
2. With the stopcock in the closed position, add 10 mL of tap water to the buret.
3. Open and close the stopcock to practice allowing for drops to flow into an empty beaker below the buret. Once you are comfortable with the operation of the stopcock, pour out the water from the beaker and from the buret.
4. Use the syringe (with plunger) to add 10.0 mL of sudsy ammonia to the 100 mL beaker.
5. Add 5 drops turmeric solution to the sudsy ammonia in the beaker.
6. With the stopcock in the closed position, add about 10 mL of 0.5 M citric acid to the buret. The amount does not need to be exactly 10 mL; be sure to record the exact starting

volume. You may refill the buret as often as needed; make sure that you always record the volume before and after you refill the buret.

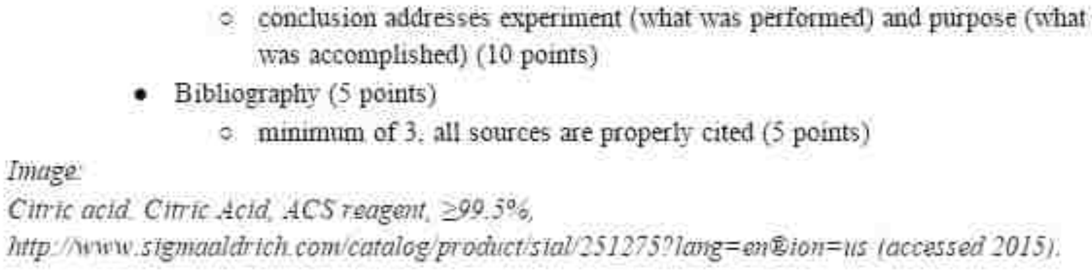
7. Add the 0.5 M citric acid to the sudsy ammonia in the beaker until you reach the end point. ***(You may need to look up the endpoint of a turmeric indicator solution.)***
8. Record the ending volume of the citric acid in the buret once you reach the end point.
9. Empty the beaker into the liquid waste container.
10. Repeat steps 4 through 9 until you have completed three trials with the unknown concentration sudsy ammonia.
11. Take pictures or make sketches as appropriate for steps for the lab report, experiment set up, etc.
12. Using the following reaction equation
    $C_6H_8O_7\ (aq) + \mathbf{3}\ NH_4OH\ (aq) \rightarrow \mathbf{3}\ H_2O\ (l) + (NH_4)_3C_6H_5O_7\ (aq)$
    Calculate the concentration of ammonia in the sudsy ammonia using the average of your three trials. *(Assume **all 3** acidic hydrogens react with ammonia.)*
13. Repeat steps 4-9, using methyl orange instead of turmeric solution.
14. Calculate the concentration of ammonia in the sudsy ammonia based on the volume of citric acid used to titrate to the methyl orange endpoint.
    a. Use the following reaction equation
       $C_6H_8O_7\ (aq) + NH_4OH\ (aq) \rightarrow H_2O\ (l) + NH_4C_6H_7O_7\ (aq)$
       *(Assume only **one** of the acidic hydrogens reacts with the ammonia.)*
15. Calculate the percent difference between this value and the average concentration of ammonia from the turmeric indicator trials
16. Repeat steps 4-9, using bromothymol blue instead of turmeric solution.
17. Calculate the concentration of ammonia in the sudsy ammonia based on the volume of citric acid used to titrate to the bromothymol blue endpoint.
    a. Using the following reaction equation
       $C_6H_8O_7\ (aq) + \mathbf{2}\ NH_4OH\ (aq) \rightarrow \mathbf{2}\ H_2O\ (l) + (NH_4)_2C_6H_6O_7\ (aq)$
       *(Assume only **two** of the acidic hydrogens react with the ammonia.)*
18. Calculate the percent difference between this value and the average concentration of ammonia from the turmeric indicator trials
19. Write an introduction including
    a. What has been done in the past (how have titrations been used?)
    b. What you have done for this experiment (brief overview)
       i. Define titration, titrant, analyte, and equivalence (stoichiometric) point.
       ii. Discuss equipment and reagents used
          1. Be sure to include information about the indicators used, especially endpoints)
    c. Why you performed the experiment (what were you trying to find out?)
20. Write a discussion of your results and what they indicate. Be sure to

   a. Compare and contrast your results using the different indicators. Propose an explanation for differences in the calculated ammonia concentration between each indicator.
   b. Include which indicator you would use if performing this experiment in the future and why.

21. Write a conclusion summarizing your work and providing evidence that you have or have not done what you set out to do.
22. Write a bibliography including all sources (you should include a minimum of three citations. Any commonly accepted citation format is appropriate).

The following criterion are used to assess the student submissions.

- Submitted on time (15 points)
  - first submission is on time (15 points)
- Introduction (15 points)
  - What has been done in the past (5 points)
  - What you have done for this experiment (5 points)
    - Indicator endpoints discussed
  - Why you performed the experiment (5 points)
- Data table (25 points)
  - organized in a tabular format (5 points)
  - volume measurements are recorded to 0.1 mL (5 points)
  - data is complete (10 points) with
    - three turmeric indicator trials
    - at least one bromothymol blue trial.
    - at least one methyl orange trial
  - average volume for turmeric indicator trials is shown (5 points)
- Calculations (20 points)
  - molarity of ammonia (5 points)
  - work shown for molarity of ammonia (5 points)
    - If you use a spreadsheet, be sure to include the formula you used
  - percent difference of ammonia concentration obtained using methyl orange as an indicator from concentration obtained using turmeric indicator (5 points)
  - percent difference of ammonia concentration obtained using bromothymol blue as an indicator from concentration obtained using turmeric indicator (5 points)
- Discussion and conclusion (20 points)
  - discussion addresses student's results and what they indicate (10 points)



  - conclusion addresses experiment (what was performed) and purpose (what was accomplished) (10 points)
- Bibliography (5 points)
  - minimum of 3, all sources are properly cited (5 points)

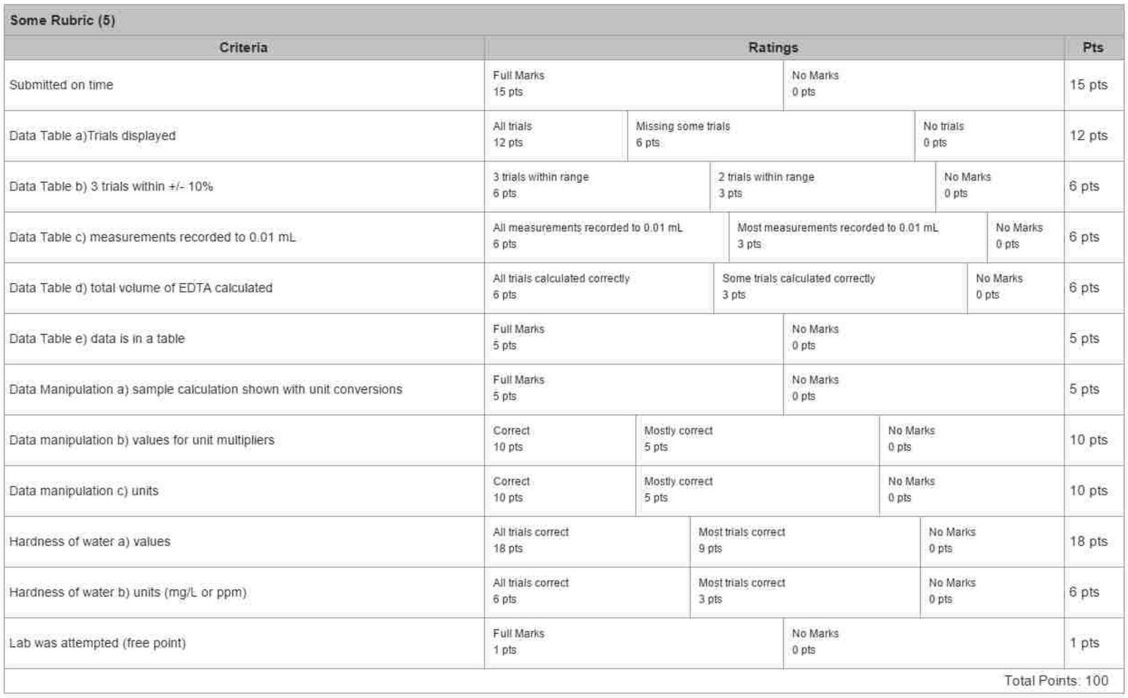
Image:

Citric acid. Citric Acid, ACS reagent, ≥99.5%, http://www.sigmaaldrich.com/catalog/product/sial/251275?lang=en®ion=us (accessed 2015).

Provide data from the Titration of Hard Water. Maximum points will be given for a tabular representation of data and for volume measurements with two decimal places.

Submit your data manipulation to calculate the hardness of the water. Points will only be awarded for the work shown.

Show the hardness of the water tested.



Some Rubric (5)

Criteria	Ratings			Pts
Submitted on time	Full Marks 15 pts	No Marks 0 pts		15 pts
Data Table a)Trials displayed	All trials 12 pts	Missing some trials 6 pts	No trials 0 pts	12 pts
Data Table b) 3 trials within +/- 10%	3 trials within range 6 pts	2 trials within range 3 pts	No Marks 0 pts	6 pts
Data Table c) measurements recorded to 0.01 mL	All measurements recorded to 0.01 mL 6 pts	Most measurements recorded to 0.01 mL 3 pts	No Marks 0 pts	6 pts
Data Table d) total volume of EDTA calculated	All trials calculated correctly 6 pts	Some trials calculated correctly 3 pts	No Marks 0 pts	6 pts
Data Table e) data is in a table	Full Marks 5 pts	No Marks 0 pts		5 pts
Data Manipulation a) sample calculation shown with unit conversions	Full Marks 5 pts	No Marks 0 pts		5 pts
Data manipulation b) values for unit multipliers	Correct 10 pts	Mostly correct 5 pts	No Marks 0 pts	10 pts
Data manipulation c) units	Correct 10 pts	Mostly correct 5 pts	No Marks 0 pts	10 pts
Hardness of water a) values	All trials correct 18 pts	Most trials correct 9 pts	No Marks 0 pts	18 pts
Hardness of water b) units (mg/L or ppm)	All trials correct 6 pts	Most trials correct 3 pts	No Marks 0 pts	6 pts
Lab was attempted (free point)	Full Marks 1 pts	No Marks 0 pts		1 pts
				Total Points: 100

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VITA

Shayna Brianne Burchett received her Associate of Arts with an emphasis in Chemistry with honors from State Fair Community College (SFCC), Sedalia, Missouri in May, 2011. In 2010, she began work as a Laboratory Technician for all of the science courses at SFCC. Her duties included chemical hygiene plan development, curriculum development, laboratory activity design, and blended/online course development for Chemistry, Biology, Physics, Anatomy, Physiology, and Microbiology. She continued to work as a laboratory technician as she went on to receive a Bachelor's of Science in Chemistry with a minor in Mathematics from Central Methodist University, Fayette, Missouri in May 2013 where she was a member of Gamma Sigma Epsilon. Upon graduation in 2013, she began to work at SFCC as an adjunct in the Chemistry department. She became a lead Chemistry instructor at SFCC in 2014 and also began to teach a dual credit Chemistry course at Sacred Heart High School in Sedalia, Missouri. In May 2016, she received her Ph.D. in Chemistry from the Missouri University of Science and Technology, Rolla, Missouri.

She has published thirty conference papers and was awarded a 2015 S&T Provost's eFellows Program grant and a 2015 Tier 1 eFellow grant under her advisor, Dr. Klaus Woelk. She was selected to receive the Council of Graduate Students Fall 2013 Travel Grant and the Outstanding Graduate Teaching award in 2015.

Shayna Burchett has been a member of the American Chemical Society since 2013. She was inducted in Phi Theta Kappa and Gamma Sigma Epsilon in 2010 and 2011, respectively.