INCORPORATING SPECTROSCOPY AND MEASUREMENT TECHNOLOGY
INTO THE HIGH SCHOOL CHEMISTRY LABORATORY

A Dissertation
Presented to the Faculty of the Graduate School
at the University of Missouri – Columbia

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

By
EMILY ANN HARBERT
Dr. Renee JiJi, Dissertation Supervisor

JULY 2014
The undersigned, appointed by the dean of the Graduate School, have examined the dissertation entitled

INCORPORATING SPECTROSCOPY AND MEASUREMENT TECHNOLOGY INTO THE HIGH SCHOOL CHEMISTRY LABORATORY

presented by Emily A. Harbert,

a candidate for the degree of doctor of philosophy,

and hereby certify that, in their opinion, it is worthy of acceptance.

__________________________________________________________________
Professor Renee D. JiJi

__________________________________________________________________
Professor Carol A. Deakyne

__________________________________________________________________
Professor Steven W. Keller

__________________________________________________________________
Professor Peter V. Cornish
I want to thank all of my family, especially Mom and Dad, for encouraging me to chase my dreams and never, ever give up. And to all of my dearest friends, for your unwavering support and encouragement, thank you. I would never have been able to achieve this without each and every one of you!
ACKNOWLEDGEMENTS

First I would like to thank my advisor, Dr. Renee JiJi for her patience and invaluable insights throughout my graduate program. In addition to Dr. JiJi, I want to acknowledge the rest of the members of the CHIP team: Dr. Peter Cornish, Dr. Deanna Lankford, and Anahita Zare as well as Stephanie Harman for their help in making the program a success. I would also like to thank my group members for their support. Finally, I would like to acknowledge the University of Missouri and the National Science Foundation (CHE-1151533) for funding.
# TABLE OF CONTENTS

**ACKNOWLEDGEMENTS** .......................................................................................................................... ii

**LIST OF FIGURES** ................................................................................................................................. vi

**LIST OF TABLES** ................................................................................................................................... vii

**ABSTRACT** .............................................................................................................................................. viii

**INTRODUCTION** .................................................................................................................................... 1

**CHAPTER 1: Barriers to Education and Implementation of Laboratory Measurement Technology in the Science Classroom: Assessing Current Needs of Science Teachers**

Introduction .................................................................................................................................................. 6

Educational Technology and Measurement Technology ................................................................. 7

Incorporating Laboratory Technology into Instruction .............................................................. 9

Professional Development and Teacher Training on Equipment ........................................ 9

The Needs-Assessment Survey .............................................................................................................. 10

Methods .............................................................................................................................................. 10

Survey Questionnaire ......................................................................................................................... 10

Participants ......................................................................................................................................... 11

Results and Discussion ......................................................................................................................... 12

Professional Development Preferences ......................................................................................... 12

Barriers to Effective Science Teaching ......................................................................................... 13

Measurement Technology in the High School Chemistry Laboratory ........................................ 14

Inciting and Maintaining Student Interest in Science and Chemistry ........................................ 16

Summary ............................................................................................................................................. 18
CHAPTER 2: The Chemistry Immersion Program

Introduction............................................................................................................21

Program Overview .................................................................................................22

  Selection Criteria ..................................................................................................23

  Participants..........................................................................................................23

Program Design and Implementation ....................................................................24

Results and Discussion ..........................................................................................27

  Pre and Post Exams...............................................................................................27

    Stoichiometry ......................................................................................................29

    Chemical Bonding ...............................................................................................30

    Thermochemistry ................................................................................................31

    Ideal Gas Law .....................................................................................................31

  Focus Group Interview .........................................................................................32

  Post-Program Evaluation ......................................................................................35

Summary ..................................................................................................................39

References..............................................................................................................41

CHAPTER 3: Spectroscopy and the Next Generation Science Standards: Incorporating Spectroscopy into the High School Science Classroom

Introduction............................................................................................................42

Experimental Design..............................................................................................43
LIST OF FIGURES

1.1 All respondents (n=180) were asked to choose how they prefer to receive professional development from among the options listed. They could choose more than one option.................................................................12

1.2 All respondents (High School, n=109; Middle School, n=32; Elementary, n=39) were asked to indicate which obstacles they faced when teaching science. They were allowed to choose more than one of the options, or none at all................14

1.3 Technology availability and usage as a function of class size. Teachers were asked to indicate how many students were in their typical science class and then asked whether they had laboratory technology available and if so, how often the students used that technology during lab.................................................................16

1.4 Teachers ranked the four options presented for increasing student interest in science from the first choice being most effective to the fourth choice being the least effective. Cumulative rankings are shown with the greatest weight (x4) given to the first choice (shown in red) and the lowest weight (x1) given to the fourth choice (shown in yellow).................................................................17

2.1 Student responses were scored individually and averaged for each question from the four sections. The averages for the pre- and post-tests were then compared. Percent increases in correct responses are illustrated in green to the right of the zero line; percent decreases in correct responses are illustrated in red to the left of the zero line............................................................................................................29

3.1 The reaction of acetylsalicylic acid (aspirin) with methanol to form methyl salicylate (wintergreen), methyl acetate, and water.................................................45

3.2 Comparison of Raman spectra for aspirin and methanol versus wintergreen. The peak at 812 cm-1 was chosen for analysis because it is present only in the wintergreen with no contribution from the reactants. The peak at 777 cm-1 in aspirin was used as a reference for calculating approximate concentrations of wintergreen product. .........................................................................................47

3.3 Representative sample of student spectra collected. The relative peak heights at 777 cm-1 and 812 cm-1 were used to identify the approximate concentration of wintergreen in the sample by comparing the ratio of the aspirin peak at 777 cm-1 and the wintergreen peak at 812 cm-1. The “good” student sample had 65% wintergreen; the “poor” student sample had 57% wintergreen. ............................50

3.4 Two TLC plates showing students’ samples #1 (“good”) and #2 (“poor”). “A” is acetylsalicylic acid; “M” is the mixture; and “W” is the pure wintergreen. The approximate concentrations of wintergreen in the mixtures as determined by spot areas were 70% and 55% wintergreen respectively.................................................51
LIST OF TABLES

2.1 Student program evaluation completed at the close of CHIP. Score assignments could range from 1 (completely disagree) through 5 (completely agree). The average response for each statement is listed; the average overall was a score of 4.8. ...........................................................................................................................37
ABSTRACT

Science and technology are becoming increasingly important in maintaining a healthy economy at home and a competitive edge on the world stage, though that is just one facet affected by inadequate science education in the United States. Engaging students in the pursuit of knowledge and giving them the skills to think critically are paramount. One small way to assist in achieving these goals is to increase the quality and variety of technology-rich activities conducted in high school classrooms. Incorporating more laboratory measurement technology into high schools may incite more student interest in the processes and practices of science and may allow students to learn to think more critically about their data and what it represents.

The first objective of the work described herein was to determine what measurement technology is being used in schools and to what extent, as well as to determine other teacher needs and preferences. Second, the objective was to develop a new program to provide incoming freshmen (or rising seniors) with measurement technology training they did not receive in high school, and expose them to new research and career opportunities in science. The final objective was to create a technology-rich classroom laboratory activity for use in high schools.
INTRODUCTION

A search in the Scopus database for articles published in 2013 featuring the keyword “spectroscopy” produced over 71,000 results. When the terms “high school” and “student” were added, only 15 scholarly articles—out of over 71,000—were published in 2013. To put that in perspective, when just “high school” and “student” were used, over 2800 articles were published in 2013 as listed in Scopus. Spectroscopy and other types of simple yet sophisticated measurement technologies are an integral part in nearly every scientific laboratory whether in an academic or industrial setting.

Students need to be introduced to measurement technology earlier in their academic careers, in order to potentially incite interest in pursuing degrees or careers in science, technology, engineering or math (STEM) fields. Though there is little evidence of whether increased exposure to using measurement technology in high schools increases that interest, it is a likely possibility. Another reason to increase student exposure to technology in the laboratory is to better prepare them for college and beyond. Either way, students should have the opportunity to learn to use the measurement technology that is quite likely already available in their classrooms.

In Chapter 1, the “Needs Assessment Survey” is described in detail. The survey was created in conjunction with the MU Office of Science Outreach and with contributions from local high school teachers and myself. I promoted the survey among teachers across the United States through a variety of approaches which are detailed in Chapter 1, and performed the data analysis on the subsequent survey responses.
The survey was designed to assess science teachers’ needs and technology usage in the high school classroom, most of the chemistry teachers that responded indicated they had many types of laboratory measurement technology available, yet far fewer actually used it regularly in their instruction. This survey focused on determining what teachers think they need to be effective in teaching science, what kinds of measurement technology are available to them, and how often they actually use that technology in their instruction.

In addition to determining needs, available technology, and usage, the teachers were asked to indicate their preferences on receiving professional development. This was done primarily to establish the best way to provide teachers with training in incorporating technology into high school chemistry laboratories, in a format teachers are more likely to attend. There is growing consensus in education literature regarding what best-practice in professional development looks like. For example, several studies suggest that mentoring is one of the best ways for teachers to develop their skill sets. Yet according to the survey respondents, mentoring is one of the least favored modes for receiving professional development, particularly among the high school teachers who responded.

It is perhaps obvious that to prepare students for the future by increasing their comfort level with measurement technology, researchers must first determine what professional development, technology training, and support teachers need to effectively and regularly incorporate measurement technology into their instruction. And though there is a growing body of research on what constitutes effective professional development, if teachers do not want to participate in those types of professional development, ultimately students will not benefit. Possible ways to address this issue is to better promote the newer modes
of professional development, or to improve the existing, preferred methods of professional development.

Chapter 2 describes the development of and results from the inaugural year of the Chemistry Immersion Program (CHIP). For this program, I designed a comprehensive program that covered the four main topic areas in high school chemistry (stoichiometry, Ideal Gas Law, thermochemistry, and chemical bonding) while exposing the students to a variety of measurement technologies. In addition to designing and implementing the program materials and content assessments, I aided in the development and implementation of the program assessments. In order to highlight the use of spectroscopy, I implemented a novel twist on the traditional stoichiometry lab and introduced spectroscopy to have students determine relative concentrations of the product.

This program was offered to incoming college students or rising seniors in high school with a grade of “B” or better in chemistry, a 3.0 GPA or better, and a score in the 80th percentile on the SAT (1700) or ACT (25). The program was held in July 2013. The first cohort of students comprised eight students. The primary purpose for Year 1 of this program was to provide students with an opportunity to learn to properly operate the measurement technology and to perform appropriate analytical techniques that students are expected to use during the first two semesters of general chemistry in college. In addition to the training students received in the laboratory, students refreshed or enhanced their knowledge of four key chemical concepts: stoichiometry, the Ideal Gas Law, thermochemistry, and chemical bonding. The third aspect of the program was to introduce students to different career opportunities in STEM disciplines. Finally, students learned about the many undergraduate research opportunities available at the University
of Missouri and were encouraged to participate in a research program as undergraduates regardless of which institution they attend.

Pre- and post-program exams indicated an overall increase in student content knowledge. A focus group interview with the participants revealed an expanded awareness of career opportunities and of the importance of pursuing research opportunities early in their college careers. Additionally, students felt better prepared for college laboratories. Post-program evaluation indicated students were very satisfied with their overall experience.

In Chapter 3, the focus shifts to the design and implementation of a laboratory investigation meant to introduce high school students to spectroscopy, more specifically to Raman spectroscopy. I created this unique laboratory activity using the well-known synthesis of wintergreen from aspirin, which has been implemented in a high school experiments in combination with Raman spectroscopy, which was used as the detection method. I created a video introduction to spectroscopy to go along with the laboratory activity. In the course of the experiment, I guided the students during the synthesis and subsequent analysis of their samples. To determine the overall effectiveness of the activity, I created an evaluation survey for the students, and then assessed their responses.

The laboratory activity was conducted at a local high school over two school days on a block schedule for a total of three hours of contact time. Seventy-six students from three different chemistry classes participated in the activity. The laboratory activity itself was divided into three sections. The first section required students to synthesize oil of wintergreen from commercially available aspirin tablets. For the second section, students watched a video introduction to spectroscopy created specifically for this lab. The final
section involved the students in using Raman spectroscopy to analyze known samples and then use that data to determine the relative amount of wintergreen in their synthesized samples.

Results from the activity were positive. Prior to participating in the laboratory activity, 72% of the students reported no knowledge of spectroscopy. After participation, 72% were able to completely or partially define spectroscopy, and 59% could describe at least partially how spectroscopy works. Most students were engaged throughout the activity and enjoyed the hands-on nature of the lab and working with the spectrometer. Although the students were unable to collect spectra at the time of the laboratory, their samples yielded excellent spectra after allowing sufficient time for the suspended particles to settle.
CHAPTER 1

Barriers to Education and Implementation of Laboratory Measurement Technology in the Science Classroom: Assessing Current Needs of Science Teachers

Students are increasingly unprepared for the rigors of college classes and in the use of measurement technology used in college laboratories.¹⁻³ It remains to be seen whether the implementation of the Next Generation Science Standards (NGSS) and Common Core curricula will better prepare students for college, particularly science courses with labs. However, much of that turnaround in student performance depends upon the elementary, middle, and high school teachers who must not only cover what is required in the new standards, but make that material interesting and accessible to their students as well.

INTRODUCTION

For many years, researchers have known that teachers face several obstacles that may prevent them from teaching science effectively. Henderson and Darcy (2008) found that the barriers common to the instructors interviewed included:

… large class sizes, broad content coverage expectations, classroom infrastructure, scheduling constraints, poor student preparation/motivation, and the institutional reward system [that] all appear to favor traditional instruction.⁴

An important subset of generalized instructional barriers relates specifically to instructional technologies. A study conducted by Bauer and Kenton (2000) found that inadequate equipment and lack of preparation time were significant obstacles for teachers to overcome in integrating instructional technologies into their classrooms.⁵ Providing reliable and accessible instructional technology, professional development that provides
teachers enough time to learn to use the technology, and the ability to modify the
provided materials and/or technology to fit into their curriculum is essential.\textsuperscript{4,6-7}
Furthermore, if teachers are to be expected to incorporate the technology into their
curriculum, their unique classroom setting and related circumstances must be
considered.\textsuperscript{4}

There is a growing awareness of the need for integrating not just instructional
technologies, but measurement technology in the laboratory as well. There are several
excellent examples of such technology being used in classrooms.\textsuperscript{8-11} However, many of
these activities neglect to consider the teachers’ time commitment required to fully
integrate these technologies into their curriculum. Also, researchers tend to neglect how
they intend to aid teachers in creating, adapting, and enriching activities with the
technology after the researchers are no longer actively participating in the classroom.

The incorporation of technology into a teacher’s curriculum is critically important to
developing students’ confidence with and understanding of measurement technologies
required for pursuing any STEM (science, technology, engineering, or math) degree or
career in the future. All of the challenges and barriers to instruction which teachers face
must be considered when developing technology-rich activities for teacher professional
development that will encourage teachers to implement technology into the classroom
and the laboratory.

\textit{Educational Technology and Measurement Laboratory Technology}

Educational technology is having more of an impact in classrooms than ever before,
and research on the effectiveness of educational technology is emerging.\textsuperscript{8-9,12-14} For
example, Apple iPads® are increasingly being used in science classrooms and laboratory settings.8-9 Educational technologies of this type hold promise in engaging and motivating students in science. Measurement technology is a subset of educational technology that is utilized primarily in a collegiate setting.10 One of the advantages to incorporating measurement technology into classrooms is tied to the ability to use sensors to collect real-time data.10 This allows students to focus more on the relationships of the variables being measured and the concepts behind those relationships, rather than focusing primarily on manually collecting the data. Real-time measurements may be more engaging than manual data acquisition. To enhance student interest in science, measurement technology should be incorporated regularly into high school laboratories. Integrating more measurement technology in high schools might inspire more interest in pursuing a STEM degree or career, and better prepare the students for using more sophisticated equipment later in college and beyond.15

One example of the integration of measurement technology into a high school setting was a project conducted by Iskander and Kapila (2012) entitled, “Revitalizing Achievement by Using Instrumentation in Science Education” or RAISE.15 The project involved pairing college students with high school science teachers and students to encourage incorporation of sensor-based technologies into the curriculum. Teachers were provided with ongoing technical and content knowledge support, which is generally considered one of the criteria for successful professional development.16-17
Incorporating Laboratory Technology into Instruction

The Next Generation Science Standards (NGSS) were designed with an emphasis on developing cross-cutting relationships among science concepts, as well as incorporating more science and engineering practices and technology into the science curriculum.\textsuperscript{18} Two of the standards outlined under the high school physical sciences section explicitly deal with the important place of technology within the NGSS.

The first of these two examples states that students will (NGSS, 2013, p. 88):

\begin{quote}
\ldots communicate technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy.
\end{quote}

The second example standard states that students will “evaluate questions about the advantages of using a digital transmission and storage of information.” How can students be expected to develop an understanding around these and other standards without using laboratory technology appropriately and consistently in their high school classrooms?

Professional Development and Teacher Training on Laboratory Equipment

Most teachers undoubtedly understand the importance of incorporating technology and engineering practices into their curriculum, yet there is ample evidence of hesitation or resistance in putting new educational technologies into practice.\textsuperscript{5-6, 19} A gap in published research exists regarding the effective implementation of laboratory technology (such as temperature probes, O\textsubscript{2} sensors, handheld spectrometers) into high school classrooms, or on what teachers need in order to be successful in adopting the new or already available technology.\textsuperscript{15} Some researchers have sought to answer why there is some resistance to change within high school settings.\textsuperscript{20} In reference to incorporating new
technology into a mathematics classroom, Shafer (2008) also indicated that some resistance was due in part to teachers’ perceived loss of control over the classroom environment. Several studies noted that teachers are more likely to include new technologies in their instruction when they understand how to use it and troubleshoot when failures occur.  

Teacher perceptions and comfort levels with laboratory technology are important considerations when addressing the incorporation of technology into teachers’ regular classroom instruction and when designing effective professional development for teachers. Assessing teacher perceptions of and comfort level with laboratory technology is critical in developing meaningful professional development involving measurement technology that could aid teachers in engaging students in science and chemistry.

THE NEEDS-ASSESSMENT SURVEY

The purpose of the survey was to ask teachers directly about the aforementioned issues in order to design more targeted professional development and ultimately to create an opportunity for improved education for students.

Methods

Survey Questionnaire

This online survey consisted of 22 questions ranging from simple demographic information to more detailed questions about professional needs. The first six questions consisted of personal information, such as name, school name, and school address. Questions 7 – 12 dealt with teaching demographic information: certification levels, class
size, years of teaching experience, etc. For questions 13 and 14, all teachers were asked what obstacles to effective teaching they face and what types of professional development they prefer. The remaining questions, 15 – 22, were asked solely of the teachers who indicated they teach chemistry. These questions focused on lab conditions, available lab technologies, how often that lab technology was implemented, and what activities would increase interest in science and chemistry. The final question asked the chemistry teachers if they would be interested in partnering with a university for the purpose of offering labs to their students.

Participants

The survey, although targeted towards science (particularly chemistry) teachers, was open to all teachers regardless of grade level taught. The link to the Qualtrics survey was presented directly through school district mailing lists, passed by word-of-mouth, or offered via a national listserv for teachers through the National Science Teachers Association. The teachers who completed the survey represent 38 states and Puerto Rico. Of the 180 respondents who completed the survey, 109 were high school teachers, 32 were middle school teachers, and 39 were elementary school teachers. Of the 109 high school teachers, 30 were from urban schools, 47 from suburban schools, and 32 from rural schools. The suburban designation was defined as a city being adjacent to an urban area, or if not adjacent to an urban area, a city having a population between 40,000 and 100,000 people. The urban areas in this study had populations greater than 100,000, typically with adjacent suburban areas. Rural was defined as less than 40,000 with no nearby larger urban or “suburban” areas. Most participants (43%) reported having high
school class sizes with 20-25 students. On average, the high school teachers spent about 1100 minutes (18.5 hours) per week teaching science. This does not take into consideration other classes taught, preparation time, or block-scheduling.

RESULTS AND DISCUSSION

Professional Development Preferences

All of the respondents to the survey were asked to choose their preferred method(s) of participating in professional development. Respondents were allowed to choose more than one of the options listed. The results are reported in Figure 1.1.

Figure 1.1. All respondents (n=180) were asked to choose how they prefer to receive professional development from among the options listed. They could choose more than one option.

As a group, the survey respondents preferred one- to two-week summer institutes (63%) and one-day (Saturday) workshops (52%) for their professional development. More science coursework was third at 36%. High school teachers’ responses all followed this generalized trend at 63%, 41%, and 37% respectively. Middle school teachers’ responses were slightly different, with 72% preferring one-day workshops and 59% preferring summer institutes, followed by 44% for more science coursework. The top
choice for elementary teachers was split between one-day workshops (67%) and summer institutes (64%). Additionally, their third choice was not more science coursework but “job-embedded staff development with a mentor” at 38%. (Science coursework came in fourth at 26%.)

It is interesting to note that the choices of “job-embedded staff development with a mentor” was much less popular with the middle and high school teachers, and that “research at a college or university” was even less popular with all respondents, despite research that suggests that these are good ways to inform teacher instruction.22-24 The teachers surveyed at the middle and high school levels do not view either of these avenues as desirable opportunities for professional development. This small detail may imply that more needs to be done to promote mentorship and research opportunities to teachers, or that efforts must focus on improving the existing avenues of professional development that are generally more popular with teachers.

Barriers to Effective Science Teaching

All respondents were asked to indicate what obstacles might prevent them from teaching effectively (Figure 1.2). Not surprisingly, the foremost obstacle that teachers face is lack of adequate preparation time. Of the respondents, 61% of the high school, 56% of the middle school and 79% of elementary teachers indicated that lack of preparation time was their number-one perceived obstacle. The next barrier faced by these teachers was split between lack of in-class time and the lack of physical materials. High school teachers were evenly split between the two at 36% each. Middle school teachers chose inadequate course materials (53%) over insufficient class time (44%),
whereas elementary teachers chose insufficient class time (59%) over inadequate materials (49%). Additionally, most teachers indicated that they receive some form of professional development, with much smaller percentages receiving no professional development. In this case, professional development includes both “in-house” school- or district-level programs as well as outside speakers and programs.

Figure 1.2. All respondents (High School, n=109; Middle School, n=32; Elementary, n=39) were asked to indicate which obstacles they faced when teaching science. They were allowed to choose more than one of the options, or none at all.

Measurement Technology in the High School Chemistry Laboratory

Laboratory measurement technology can serve as a means to both engage students and make the process of science and inquiry more accessible as well as potentially more exciting and relevant. The use of measurement technology is much more common in university lab settings and in the workplace, therefore students might be better served if
they were more prepared for the use of such technologies. Students who have already used those types of tools in high school would likely have an advantage in college settings because they would not have to learn how to use the technology while at the same time learning new concepts. Instead they could focus on learning and understanding the new material.

Of the 85 chemistry teachers who responded to the survey, 70% reported having access to laboratory technology (defined in the survey as “equipment such as temperature probes, pressure or O₂ sensors, portable or hand-held spectrometers or full-size absorption spectrometers”), but only about 20% reported using the technology in more than 25% of their labs throughout the course. This implies that laboratory measurement technology is widely available, but not widely implemented on a regular basis.

Analysis suggested a possible relationship between class size and increased usage of laboratory technology (Figure 1.3). Of the respondents, 25% had class sizes with 1 to 19 students and 86% of those teachers have technology available. Even more interesting, 50% of those with technology use it on a regular basis (more than 25% of the time). Contrast that with teachers who have 30 or more students (n=11); of those teachers with very large classes, only five reported having technology available, and only one teacher used it more than 25% of the time. Even when the class size is only moderately larger with 20 to 25 students, the use of laboratory measurement technology declines. In this group, only 15% of those teachers actually use it regularly.
Figure 1.3. Technology availability and usage as a function of class size. Teachers were asked to indicate how many students were in their typical science class and then asked whether they had laboratory technology available and if so, how often the students used that technology during lab.

*Inciting and Maintaining Student Interest in Science and Chemistry*

Chemistry teachers were also asked what they believe would lead to the greatest gains in student interest in science and chemistry. In Figure 1.4, they were asked to rank four available options from most likely to least likely to increase student interest in chemistry and science. The choices included: more classroom activities; more technology-based activities; student workshops or field trips to regional colleges or universities; and teacher workshops or research opportunities at regional colleges or universities. The highest ranked choice was offering more classroom activities, followed by offering more technology-based activities.
Figure 1.4. Teachers ranked the four options presented for increasing student interest in science from the first choice being most effective to the fourth choice being the least effective. Cumulative rankings are shown with the greatest weight (x4) given to the first choice (shown in red) and the lowest weight (x1) given to the fourth choice (shown in yellow).

Offering more classroom activities or technology-based activities were the top two choices for most of the chemistry teachers, with approximately 70% of the teachers choosing one of those two options as their first or second choice. This implies that more needs to be done to offer teachers tools such as classroom activities or technology-based activities to use throughout their curriculum. These would not solely serve as a one-time push for peaking student interest as in a workshop or field trip, but would serve as a continued series of “nudges” that ultimately increase student interest in science and chemistry. Although student workshops or field trips and professional development teacher workshops might be offered, it is interesting that those activities are not what these particular chemistry teachers believe will be most effective at igniting students’ interest in chemistry and science.

Furthermore, these rankings indicate the perceptions these teachers have of the critical importance of providing student-centered learning opportunities. According to the
chemistry teachers surveyed, fully two-thirds offer more than 15 labs per course, including the 38% who offer more than 20 per course. The implication is that out-of-classroom learning opportunities (e.g., field trips, after-school science clubs) should not be the sole means of exciting students about science, but instead be used as a supplement for the curriculum that is already in place. Indeed, 86% of the chemistry teachers responded that they would like to partner with local colleges and universities to increase the number and types of lab activities in which the students get to participate.

**SUMMARY**

Teachers have limited time to learn new technologies and prepare lessons using those technologies. They want more classroom-based, technology-rich activities for their students. One way to address these issues is to create more activities that are easily adaptable and require minimal investment of time and materials. Another way to address some of these issues is to train teachers on the use of the laboratory technology they already have available in their classrooms. Offering teachers more professional development in formats they prefer that are rich in science content and technology training is an avenue worth pursuing.


CHAPTER 2
The Chemistry Immersion Program

The inaugural session (July 2013) of the Chemistry Immersion Program was a one-week outreach program for high school students. This multi-faceted program was designed to provide high school students with an opportunity to increase their familiarity with measurement technology used during the first two semesters of collegiate chemistry, to refresh content knowledge in general chemistry concepts, to introduce spectroscopy and spectroscopic technology, and to expose students to careers and undergraduate research opportunities in science, technology, engineering and math. Initial results indicate students’ content knowledge improved after participating in the program, and the students felt that they had a positive experience in the program overall.

INTRODUCTION

There are a number of supplemental learning opportunities currently available to high school students interested in science, technology, engineering or math (STEM) fields. These programs range from local to national in scope. Local-level programs include: science clubs, mobile laboratories such as the Virginia Tech Chemistry Outreach Program; student research partnerships between high schools and universities; summer camps or institutes; and in-class training or workshops. National-level opportunities for students include the American Chemical Society’s Project SEED or the Chemistry Olympiad.
Of these opportunities, almost all involve time spent away from the classroom or commitments over the summer. Few involve the students’ teachers, and inevitably some students will get left out of these programs due to limited resources. Ideally, all science teachers would be able to provide students with equally enriching, challenging, and technology-based research opportunities during the course of a regular school year. Until that ideal is achieved, however, other steps must be taken to mitigate the differences in science instruction and laboratory experiences that students face. The Chemistry Immersion Program (CHIP) is concentrated on improving just one small part of a much larger picture which will need to be addressed.

PROGRAM OVERVIEW

CHIP is a multi-faceted program designed to provide science outreach to students, teachers, and the community. The first phase of this program focused solely on students who would be entering college as freshmen or finishing their last year of high school as seniors. Subsequent phases will include teachers and the community. The remainder of this document refers solely to this initial phase of CHIP.

The program was designed to address a need shared by students who may not have the best grades or scores on standardized exams, but who demonstrate consistent performance in class. Students with higher scores and grades have multiple enrichment opportunities available. Increasingly, students who are at greater risk also have more enrichment opportunities. However, students who are consistent “B level” performers in school may not have as many opportunities available. The CHIP program is primarily focused on providing those “B level” students the necessary preparation that they might
not otherwise get in order to enhance future success with collegiate chemistry course content and to foster successful use of laboratory technology. Although focused on those particular students, any students with similar or better credentials were also considered for attending CHIP 2013.

Selection Criteria

Students were selected in part based upon the following criteria:

1. GPA between 3.0 and 3.6 *later modified to include 3.0 to 4.0
2. Grade of “B” or better in high school chemistry
3. Scores in the 80th percentile or greater on the SAT or ACT
4. Recommendation from their high school science or math teacher

Participants

Eight participants were chosen for the inaugural year of CHIP. They were evenly divided by gender. Three were going to be seniors in high school and five were incoming college freshmen. Half of the students attended high schools in very large suburban areas with low free and reduced lunch student populations (8 – 19%). Two students attended high schools in remote, rural areas with very high free and reduced lunch student populations (44%, 61%). Five students identified themselves as Caucasian and three chose not to list their ethnicity.
PROGRAM DESIGN AND IMPLEMENTATION

The primary focus of CHIP is to introduce students to the measurement technology and techniques used in the first two semesters of general chemistry as well as to introduce the concept of spectroscopy. The intent is to increase the students’ comfort level with the technology and techniques without having them merely repeat the same labs that will be covered during the first two semesters of general chemistry. The next step was to combine the technology with topics to cover during CHIP.

For the first year of CHIP, four topics in chemistry were chosen for particular focus. The four topics chosen—stoichiometry, gas laws, thermochemistry, and chemical bonding—are topics that most general high school chemistry classes would have covered by the end of the year. Students could then reasonably be expected to be somewhat familiar with the topic material being covered, although they might need a brief review. Four experiments, one for each day of CHIP, were designed around the technology and content requirements.

The stoichiometry/spectroscopy experiment was the first laboratory investigation for CHIP. The experiment had students determine the stoichiometric ratio of iron(II) to phenanthroline in an iron(II)-phenanthroline complex based upon changes in the intensity of the reddish-orange color of the complex formed. The more intense or darker the color, the more complex formed. Students used absorption spectroscopy to measure the color intensity of samples with known stoichiometric ratios to determine the actual ratio of iron(II) and phenanthroline.

One of the reasons for choosing this laboratory activity as the first one students would complete was that they should be quite familiar with stoichiometry and calculating
stoichiometric ratios. That topic is usually heavily emphasized in high school classrooms. The aspect of the laboratory the students had not experienced before was the addition of the absorption spectroscopy technology component in determining those ratios.

The second day covered the Ideal Gas Law. Students experimentally determined the value of the gas constant, R. Although the value for this constant is known, students could still improve their lab skills by attempting to get as close as possible to the known value. Additionally, students learn the importance of accounting for water vapor pressure and of making precise measurements. For this experiment, students dissolved Alka-Seltzer tablets in hydrochloric acid which produced carbon dioxide. They then determined the volume and mass of CO₂ produced based on water displacement and mass change of the contents remaining in the test tube after the reaction was complete. Using the pressure of CO₂ (barometric pressure minus vapor pressure of H₂O), volume and moles of CO₂, students were able to calculate a value for R and then compare their value to the actual R value.

This laboratory activity was a verification exercise chosen primarily for its technique intensive procedure and the ease with which the data could be compiled and calculated in Excel. The main goals were to impress upon the students the need for careful laboratory technique, detailed notes, error, and reproducibility of results. Whether or not they verified the true value of R was irrelevant. The most important lesson to be gained in this activity was the importance of technique and reproducibility.

Thermochemistry was the third topic covered during CHIP. The goal for this experiment was to introduce students to using the temperature probes and other equipment used for specific heat laboratories conducted during the first semester of
general chemistry. For this experiment, students determined the heat capacities of copper, tin and a mixture of the two using a coffee cup calorimeter similar to the type used during general chemistry. Students also used temperature probes to measure the change in temperature. They first calculated the specific heat capacity of the calorimeter and then calculated the various specific heat capacities of the metals. From these values, students were able to determine the approximate percentage of copper and tin in their mixed sample.

The fourth and final laboratory engaged students with an exploration of chemical bonding. There were four parts to this laboratory. Part A was review of and practice drawing Lewis structures, both on paper and using software on the laboratory computers. Parts B and C examined the polarity of various liquids and solids, as evidenced by ease and amount dissolved. For Part D, students investigated miscibility of polar and non-polar liquids and then used conductivity probes to measure the resulting conductivity of pure liquids and mixtures of those liquids.

After each chemistry laboratory activity during the week, students participated in a debriefing session. During this session, students completed calculations and discussed the meaning of their results. Students seemed to appreciate this extra time made available to process their results and clarify their thinking.

A second facet of CHIP was to expose students to various STEM-related careers and undergraduate research opportunities, which occurred during evening seminars and tours. For one such evening seminar, students met with a sales professional who introduced them to the possibility of a career in sales of laboratory equipment. Other evening programs highlighted research opportunities in plant science at the university or further
introduced spectroscopy. On the final lab day, students learned about undergraduate research opportunities at the university and toured laboratory facilities and met with undergraduate and graduate researchers as well as professors.

Another component of CHIP placed special emphasis throughout the program on keeping accurate and legible laboratory notebooks. On the first evening of CHIP, students participated in a presentation and demonstration about the importance of notebooks. First, students listened to examples of how keeping very good or inadequate records changed significant outcomes primarily in determining rightful holders of patents or receiving recognition for major discoveries. Following the introduction, students were then tasked with recreating specific shapes that combined several differently shaped puzzle pieces. Each pair determined combinations for shapes different from the other groups and then wrote directions in their notebooks in such a way so that someone else could follow those directions and easily recreate the design. Then the notebooks were exchanged and groups attempted to recreate the designs. This helped reinforce the point of keeping easily interpreted records.

RESULTS AND DISCUSSION

Pre- and Post-Program Exams

The pre- and post-program evaluations (Appendix 1.1) were identical and designed to gauge knowledge of STEM careers and conceptual understanding of the aforementioned four topics covered during CHIP. At the beginning of the week, prior to participating in the program, students answered questions about STEM careers of which they were aware. Answers varied, but most students included doctors, engineers, pharmacists and
researchers, among others. After the program, students were again asked about careers of which they were aware, and responses were more varied than previously. At that time, responses included sales representatives, biotechnology researchers, and patent lawyers, in addition to the doctors, engineers, pharmacists and researchers mentioned previously. One student even remarked that she knew “...lots more than I knew about earlier. There’s a technology and industry side to science as well that I was completely surprised by.”

Conceptual understanding over the four topics (stoichiometry, gas laws, thermochemistry, chemical bonding) was also tested prior to and after participation in CHIP. All of the students’ overall scores on the pre- and post-program evaluations regarding conceptual knowledge improved after participation in CHIP. Improvements ranged from 2 to 10 additional points on the post-test out of 36 total points possible (Figure 2.1). The thermochemistry section had the greatest overall gains in scores, and the section with the most consistent improvement concerned chemical bonding. Stoichiometry saw modest improvement in scores. The only subject area where student scores decreased in any way was in the section concerning the Ideal Gas Law.
Figure 2.1. Student responses were scored individually and averaged for each question from the four sections. The averages for the pre- and post-tests were then compared. Percent increases in correct responses are illustrated in green to the right of the zero line; percent decreases in correct responses are illustrated in red to the left of the zero line.

**Stoichiometry**

Overall, the stoichiometry section had modest gains. Question 1.2 had no change in scores. Students were to draw the appearance of water in a graduated cylinder with a volume of 7.2 mL. Full points were awarded for correct placement and indication of the shape for the meniscus. All students correctly answered the question on both the pre- and post-test.

Questions 1.4 and 1.5 had more improvement. Question 1.4 had students calculate the mass of CuSO₄ required to make 200. mL of a 0.230 M CuSO₄ solution. Full points were awarded for setting up the problem correctly, with or without a calculated answer, since many of the students did not have access to calculators during the administration of the
exams. Half of the students improved their scores on the post-test and three were unchanged. One student had a one point decrease in their score.

For Question 1.5, students read a short description of a student making a solution and were asked to identify mistakes in the procedure. Three students had no change in their pre- and post-test scores having partially or entirely incorrect responses both times. Three students had great gains in their scores, some improving from an entirely incorrect response (0 points) to an entirely correct response (3 points). Only one student had a decrease in their score on this particular question.

Chemical Bonding

The section with consistent improvement, with small or moderate gains in all questions asked, was that dealing with chemical bonding. The questions required students to draw Lewis dot structures for three molecules, explain the reasons for the immiscibility of oil and vinegar, and to identify and explain conductivity differences for pure water versus water with dissolved ions.

In the pre-test, students demonstrated a moderate understanding of Lewis dot structures. Students were asked to draw three structures: one of all single bonds, one with a double bond, and one with a triple bond. Five students drew the correct structure for CCl₄ but only 2 students drew the correct structure for C₂H₂. Most students knew to use single bonds for CCl₄ but did not use multiple bonds for drawing C₂H₂ or the third molecule, CO₂. In the post-test, more students answered Questions 3.1 and 3.2 correctly (with single and double bonds, respectively), but only one additional student answered Question 3.3 correctly (with triple bonds).
The next greatest gains posted were for Questions 2.4 and 2.6. For Question 2.4, students had to explain why oil and vinegar will separate after being mixed together. Five additional students correctly explained this on the post-test but had only partially correct responses on the pre-test. On Question 2.6, students were asked to indicate whether water with dissolved salt would conduct electricity and then explain their answer. Three students improved their scores after CHIP, with two of them having no answer on the pre-test but fully correct responses on the post-test.

Thermochemistry

The greatest gains were within the thermochemistry section, with 63% increases in scores on Questions 3.1 and 3.3. Question 3.1 required students to identify the missing variable to be accounted for when determining the value of \( q \) (heat transferred). The correct response was “heat capacity of calorimeter”. Prior to CHIP, only two students correctly responded to the question; following CHIP, seven students correctly identified the missing variable. Question 3.3 asked students to write the requisite formula and solve for \( q \). Full points were awarded for the correct equation and correctly identified variables, since several students did not have calculators available at the time pre- and post-tests were administered. Prior to CHIP, no-one answered correctly; following CHIP, five students identified the correct variables and equation.

Ideal Gas Law

Two questions in the Ideal Gas Law section (4.2 and 4.4) presented decreases in scores. Question 4.2 asked students to consider a balloon filled with air that is heated and
explain what would happen to the molecules inside the balloon. Question 4.4 required students to identify variables necessary to solve for the volume of a gas when given the gas constant, R. Two students with incorrect responses on the pre-test answered the post-test correctly, but two students with correct responses on the pre-test omitted responses on the post-test. Because the scores of the omitted or incorrect responses were greater than those gained, a small decrease in the overall average score resulted. Whether these omissions and incorrect responses are reflective of a change in conceptual understanding rather than student fatigue or time constraints is unclear.

*Focus Group Interview*

The ten guiding questions for the focus group interview dealt with topics regarding STEM careers, internships and training, and laboratory and technology experiences in high school. The first five questions focused specifically on STEM careers, which included asking students about which STEM careers they were aware of and what training they thought those jobs would require. The sixth question asked students about internships. The last four questions concerned high school laboratory and technology experiences.

The first question during the interview asked students to identify what kind of training they thought would be necessary for those in STEM fields, other than math or science classes. Students responded that since scientists have to collaborate, classes that teach people how to work together would be quite useful. Additionally, students mentioned classes that help develop critical thinking skills would be beneficial.
The next topic covered questioned students about STEM careers and whether they knew anyone working in a STEM field. Students replied that their relatives (generally parents) worked in STEM-related fields, which included medicine, engineering, chemistry, accounting, and manufacturing. Students were then asked about “Career Days” held at their schools and whether or not that was helpful in learning more about STEM careers. One student said she found some of the speakers helpful, and others not as much. Another student mentioned that he focused on chemistry as a possible career path in large part because of two people he met during a career fair who discussed their work, which he found extremely interesting.

The last set of questions on the STEM careers topic asked students whether they had participated in an internship or whether they had considered doing so. This question was met with no response from the students. A further question asked students why they had not taken part in an internship and if the time commitment was a contributing factor. Students responded that time and minimum age requirements had prevented them from pursuing internships.

The topic for the final set of questions shifted to their experiences in high school laboratories and what kinds of technology they had used during those laboratories. First, students were asked whether they did laboratories and if they ever designed their own investigations. The first student spoke about advanced placement (AP) chemistry and said she was exposed to various types of equipment during those laboratories, which was helpful. The second student to respond indicated that most laboratory investigations were highly structured and “cookbook” format, but that a few experiments required students to create their own protocols. While these labs were considered difficult, the student
considered those laboratories to be very interesting and fun. This response led another student to speak about a final exam in the laboratory requiring her to develop her own protocols to determine the identity of an unknown cation and an anion. She found the challenge to be “really cool” and memorable. When the group was asked whether they enjoyed the structured laboratories that did not require them to develop their own protocols versus the investigations they developed, and which kind of laboratories they remembered best, the response was that the most exciting ones were the most likely to be remembered, whether they were structured “cookbook” laboratories or not. There was a general consensus however that while titrations were memorable, they were not thought to be interesting.

Laboratory investigations in high school, specifically data collection, recording, and equipment usage during those investigations, was the next subtopic considered. When asked how they were analyzing data and what experiences they had doing that, the question was met with silence. This was followed by questions regarding science notebooks. Students were asked about how they used their lab notebooks prior to attending CHIP. They mentioned being introduced to lab notebooks during advanced biology classes and AP chemistry classes. Some of the students related how they had very strict guidelines for their notebooks set by the instructor, but added that they continued to use that style in other classes because they found keeping notebooks to be a very useful tool.

The final topic centered on how students used technology in their high school laboratories and to what extent that technology played a role in their investigations. The
first student to respond mentioned that iPads and iPods were used to take measurements, record data and take pictures. She found this use of technology to be engaging.

The next question refocused the students to think about measurement technology, such as temperature probes. Student responses were mixed. One mentioned that he had never used such technology before. He also said that being able to see the data as they were recorded in real time was very appealing. Others said that they had prior experience with some of the technology used during CHIP, such as micropipettes, primarily in their biology courses.

Students were then asked whether they thought their exposure to equipment and techniques during CHIP had increased their comfort levels with the technology. Responses were positive. One student replied that he would have been “blindsided” by the laboratories in college had he not had the experience with CHIP.

When asked for their final thoughts regarding CHIP, students agreed that the entire experience had been worthwhile. They enjoyed learning about the variety of careers, the college-level feel of the laboratories completed during CHIP, and the entire program in general. They also enjoyed that the cohort was small, just eight students, because of the individualized attention they had received and the way that contributed to the “laid back feel” of the program overall.

*Post-Program Evaluation*

The program evaluations completed by the students were overwhelmingly positive. In the first part of the program evaluation, students were given twelve statements and asked to score them on a scale of one to five, where one was completely disagree and five was
completely agree (Table 2.1). The average score for the program was a 4.8 overall. The statements receiving the lowest scores (4.4 each) were concerning the pace of the laboratories and the evening career and research themed seminars. Most students selected “slightly agree” for the laboratories having a reasonable pace. The evening seminars received a mixed assessment, with a “neither agree nor disagree” ranking from one student, “completely agree” from four students and the remainder choosing “slightly agree” regarding the usefulness of the evening programs.
<table>
<thead>
<tr>
<th>Statement</th>
<th>Average Score</th>
<th>Statement</th>
<th>Average Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>The content of the CHIP program chemistry investigations was relevant to my interests in science.</td>
<td>4.9</td>
<td>I enjoyed working with other students during the activities and investigations.</td>
<td>5.0</td>
</tr>
<tr>
<td>I felt the pace of the laboratory investigations was just right. I did not feel rushed and I was not bored.</td>
<td>4.4</td>
<td>I would recommend the CHIP program to my friends as an interesting and fun way to learn chemistry.</td>
<td>4.9</td>
</tr>
<tr>
<td>The chemistry laboratory investigations planned and implemented by Dr. Jiji’s team for the morning CHIP session were interesting and well organized.</td>
<td>5.0</td>
<td>Student housing (Schurz Hall) was comfortable and supplied the materials needed to make my stay comfortable.</td>
<td>4.8</td>
</tr>
<tr>
<td>Ms. Harbert was very knowledgeable and she organized the morning laboratory sessions very well. She was always available and able to help everyone understand the protocol and also how to use the equipment.</td>
<td>5.0</td>
<td>The Plaza 900 Dining Hall offered a wide culinary diversity and the food was good.</td>
<td>5.0</td>
</tr>
<tr>
<td>Ms. Harman was very knowledgeable and explained key concepts in chemistry in a way which was easy to understand.</td>
<td>4.9</td>
<td>The meals in the Chemistry Building were always good and I was able to select what I wanted from a menu.</td>
<td>4.5</td>
</tr>
<tr>
<td>The biochemistry laboratory investigations planned and implemented by Dr. Cornish’s team for the afternoon CHIP session were interesting and well organized.</td>
<td>4.9</td>
<td>The evening seminars were interesting and engaging. I believe I expanded my understanding of chemistry and careers related to chemistry. The time was well spent.</td>
<td>4.4</td>
</tr>
</tbody>
</table>

Table 2.1. Student program evaluation completed by the eight participants at the close of CHIP. Score assignments could range from 1 (completely disagree) through 5 (completely agree). The average response for each statement is listed; the average overall was a score of 4.8.
The second half of the program evaluation asked for students’ opinions and comments for four questions. Responses were ranked with a numerical value from one to five, where one was a very negative comment, two was negative, three was neutral, four was positive and five was very positive. The first question asked students to describe what they most enjoyed about the program and the second question asked for the least liked aspect of the program. The third statement asked students for feedback regarding the evening career and research seminars. The final statement asked for any other feedback regarding their participation in CHIP.

The responses to the first question were positive regarding their favorite aspect of CHIP. The average assigned ranking for the comments on question one was a four (positive). Six students indicated that they most enjoyed the laboratory investigations. Two additional comments by the students indicated the career seminars and laboratory tours were also very enjoyable parts of the experience. One student mentioned that although they enjoyed the chance to participate in the laboratories, they would have appreciated having more time built into the schedule to “work/think things out”.

Some of the comments regarding the least favorite aspect of the CHIP program were positive. The average assigned ranking was three (neutral). Two said there was nothing they would improve, one student indicated they wished the program went longer, and two mentioned the only thing they would improve was adjusting the curfew to be later. There were some slightly less positive comments. Two did not get as much out of the evening seminars as they would have liked. The last comment mentioned referred to the biochemistry laboratory investigations (held in the afternoons in conjunction with CHIP) being too challenging and not holding their interest.
The evening seminars were not as useful according to the students. The average assigned score was a three (neutral). Only two students considered the seminars useful, the rest were slightly less positive in their assessments, though they did offer constructive criticism. Some of the students suggested offering more seminars with hard science content instead of career-oriented seminars. In conjunction with that, one student recommended offering a career fair event for introducing STEM careers instead of during the evening seminars.

Overall, students seemed very pleased with their experience. Students mentioned that they enjoyed participating in CHIP, and one student wished the program went even longer. Comments for improvement included offering more “down time” or fun activities, have more breaks during the day, and extending the curfew.

SUMMARY

The first year of CHIP was successful in that students enjoyed the experience and believed it to be helpful in preparing them for the laboratories to be completed during the first two semesters of college chemistry. In general, students’ knowledge of the four chemical concepts covered was improved. Awareness of the career options available to those with STEM degrees also increased.

The concerns and recommendations offered by the CHIP 2013 cohort will be addressed for CHIP 2014. First, more breaks will be scheduled throughout the day to allow more time for students to process the information gained during the investigations. The evening seminars may be adjusted to include more science content or eliminated to allow students more time to socialize and relax after the hectic pace held during the day.
Exposure to STEM careers will continue throughout the program through independent activities designed to provide students guidance in navigating the wealth of information about STEM careers that is available on the internet. Having the career exploration as an individual task will also permit students to work at their own pace, exploring further any careers that might be of interest to them. For CHIP 2014, there are currently 20 registered students.

The length of CHIP 2014 will be increased to two weeks long. The first week will include training four teachers on the equipment used in the college laboratories. This will be followed in the second week by supporting those teachers in their instruction of the CHIP students in the use of that equipment and on the conceptual topics covered. One reason for including teachers is to have a wider impact on the students who can be positively influenced by the program. The principle is that teachers will take what they have learned back to their classrooms and improve their teaching by having students use more technology during laboratory investigations at their respective high schools. In addition to the inclusion of teachers, the number of students accepted into CHIP will also be increased, again to broaden the general impact of the program.
REFERENCES


8. ACS High School Chemistry Student Programs and Resources. [http://www.acs.org/content/acs/en/education/students/highschool/seed/about.html](http://www.acs.org/content/acs/en/education/students/highschool/seed/about.html) (accessed 12/6/2013).
CHAPTER 3
Spectroscopy and the Next Generation Science Standards:
Incorporating Spectroscopy into the High School Science Classroom

INTRODUCTION

The Next Generation Science Standards (NGSS) resulted from a combined effort by K-12 science teachers, researchers, scientists and others to promote the processes and practices of science within K-12 classrooms. There are three components highlighted with the NGSS: 1) knowledge of concepts in life science, physical science, earth & space science, and science applications; 2) science and engineering practices; 3) cross-cutting concepts relating science and engineering. Central to these standards is a desire to impress upon students the processes of science—how science works in the “real world”—not just as abstract concepts and information.

At the high school level, there are two standards within the NGSS that are applicable to spectroscopy. First, the NGSS standard HS-PS4-4 states that students will be able to “evaluate the validity and reliability of claims in published materials of the effects that different frequencies of electromagnetic radiation have when absorbed by matter.” Second, HS-PS4-5 states that students should be able to “communicate technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy.” Further clarification provided within the NGSS indicates that waves in this case may include light.

Spectroscopy provides an excellent method for addressing those concepts while engaging students in a meaningful way. Spectroscopy involves measuring changes in
wavelengths or frequencies of light that arise due to absorption, emission, or scattering effects. Typically, if spectroscopy of any kind is used in high school laboratories, it is absorption spectroscopy. Techniques that involve the measurement of light scattering are rarely used in high school laboratories. The focus of this experiment was centered on exposing high school students to spectroscopy in general and, more specifically, to Raman spectroscopy, which features measurement based on light scattering. The student guide to the experiment is included in Appendix 3.1.

**EXPERIMENTAL DESIGN**

Seventy-six high school students participated in this laboratory experiment. The students attended a large high school in Columbia, Missouri, and were from three different chemistry classes at that school. The school operates on a block schedule, meaning class periods are approximately 1.5 hours in length and meet every other day. This experiment was conducted over two class periods for a total of approximately three contact hours.

In addition to exposing high school students to spectroscopic measurement techniques, the purpose of this experiment was to combine a fun, hands-on activity with spectroscopy in an effort to introduce and incorporate some of the processes of science so integral to research. This is a particularly emphasized facet within the NGSS. The experiment described here consisted of three distinct parts: the synthesis of oil of wintergreen from aspirin; an introduction to spectroscopy; and the analysis of the students’ wintergreen samples using Raman spectroscopy.
Part 1: Synthesizing Oil of Wintergreen

The synthesis of oil of wintergreen from aspirin was chosen for Part 1 because the procedure is easy to follow, and the distinct change in scent provides evidence of a successful reaction. This particular method for wintergreen synthesis has also been conducted successfully in a high school setting.\(^2\) In previous versions of this experiment, safety restrictions on the requisite chemicals and other steps necessary for purification prevented the estimation of the concentration of wintergreen produced in the final samples. Those experiments that utilized other modes of spectroscopy to determine concentration of wintergreen required the use of dichloromethane (no longer permitted in many high schools) in the final purification step.\(^3\) Since Raman spectroscopy is a technique that does not necessarily require a final purification step, it is ideally suited to use in conjunction with this simple wintergreen synthesis.

Method

For the synthesis, students pulverized two aspirin tablets and dissolved them in 5 mL of methanol. This allowed the salicylic acid to dissolve in the methanol and the residual components were left behind in the solids. The samples were then filtered and the solids discarded. A few drops of sulfuric acid were added to the filtrate and then the solution was heated to 70°C for 30 minutes. (See Figure 3.1) Following the synthesis, students tightly wrapped their wintergreen samples using Parafilm and allowed them to sit until the following class period. After the waiting period, in most cases students had to add a small amount of methanol to their sample to create enough volume for the sample to be measured using the Raman spectrometer.
Part 2: Video Introduction to Spectroscopy

Part 2 engaged students in learning about the basic premises of spectroscopy through watching a video introduction to spectroscopy (Appendix 3.3, DVD) that was developed using an interactive program available online at Prezi.com. The video was designed to take a potentially complex topic and present it in such a way that high school students would come away with a better understanding of spectroscopy and an appreciation of how it affects them in their own lives.

The video introduction included a very brief explanation on the nature of light and what may happen to molecules when they interact with light. Students were presented with three possibilities for these interactions, which were: radiation of heat; changes in vibrations; and emission of a scattered photon of the same or differing energy. The basic concept of Raman spectroscopy was then introduced through a Raman spectrum of Tylenol (acetaminophen) and the meaning behind the positions and intensities of the peaks was explained. Potential uses of spectroscopy, specifically Raman, were then mentioned. These uses included topics such as determining authenticity of art, forensic and pharmaceutical applications, and space exploration, among others.
Originally, the intent was to have students watch this video between the first and second class periods over which the lab was to be completed. However, after discussion with the partner high school teacher immediately prior to carrying out the laboratory experiment, a decision was made to show the video during class while the students waited for the completion of Part 1 of the experiment (synthesis of wintergreen). Watching the video during the first class period addressed one significant issue: not all students might have had access to the video after school.

**Part 3: Analysis of Wintergreen**

In Part 3 of the experiment, students were required to use a Raman spectrometer to collect several spectra. Students first measured the spectra for each of the individual components present in their reaction: aspirin powder, methanol, and wintergreen (pure). This allowed them to see that each component has a very distinct spectral response, which would enable them to identify the presence of wintergreen in their final product.

The next step in Part 3 was to have students measure the spectrum for their product and compare it to spectra of varied concentrations of wintergreen (0%, 5%, 20%, 50%, 75%, and 100%) and methanol collected for them prior to the experiment. The peak at 812 cm\(^{-1}\) was chosen for analysis because, within this sample set, it is easily identified as being unique to wintergreen (Figure 3.2). Students then compared the relative intensities for the peak near 812 cm\(^{-1}\) versus the concentration of the solution in each of the given spectra. Using these values, students constructed a standard curve and then estimated the concentration of wintergreen in their product based on a comparison of the intensity at 812 cm\(^{-1}\) of their product to the standard curve.
RESULTS AND DISCUSSION

Throughout Part 1 of the experiment (wintergreen synthesis), the majority of students were actively engaged in the task. Very few students remained uninterested, and overall levels of participation were excellent. Students indicated that they enjoyed the hands-on nature of the task and in some cases were genuinely surprised that “chemicals smell good”, referring to the scent of the wintergreen upon the completion of the synthesis.

Interestingly, although every group produced a sample that smelled of wintergreen, several groups produced samples that were dark purple in color, instead of an almost clear, pale yellow. This may have been due to a number of factors, such as students not cleansing the test tubes thoroughly enough prior to use.

During the requisite wait time for the synthesis, students watched the video introduction to spectroscopy together as a class through the overhead projector. While
watching the video, most of the class in any given period appeared to be engaged and interested in the information presented. After watching the video, students asked insightful and thought-provoking questions. For instance, one student asked why not all frequencies are represented throughout the spectrum and why some frequencies (peaks) are more intense than others. This led to another question about how peaks can be assigned to specific bonds, and eventually led to a discussion of the nature of bonds. For example, bonds are not made of “sticks” even though they are often represented as such.

In another class, students inquired about the possibility of more than one type of response when a photon interacts with a molecule. In essence, the student wanted to know whether vibrations, heat, and reemission of a photon could happen concurrently.

During the following class period students were permitted to work at the Raman spectrometer, one group at a time and under supervision. After a very brief introduction to the parts of the spectrometer and being given a general idea of how the spectrometer works, the students were able to analyze several samples of standards and their own wintergreen sample. Students again asked some insightful questions, one of which was whether molecules with the same chemical formula would have the same “fingerprint” or whether the structure had to be exactly the same. This led to an interesting discussion on whether or not it was possible to have two molecules with different structures but the same types and numbers of bonds and therefore the same chemical fingerprint.

The only difficulty experienced in the general execution of this experiment was that most students’ wintergreen samples did not provide good data at the time of the experiment. In almost all cases, the students’ samples had to be diluted with a small volume of additional methanol to aid in the analysis. Though the methanol itself will not
contribute significantly to the peak of interest at 812 cm$^{-1}$, many groups had samples with visibly suspended particles that made collecting good spectra impossible. Additionally, a few groups appeared to have a fluorescent component develop over the 48 hours between synthesis and analysis, and some of the students’ samples turned an unexpected purple color, most likely due to insufficient cleansing of the test tubes prior to synthesis. Few groups produced useable spectra with a measurable peak at 812 cm$^{-1}$.

Interestingly, upon reexamining student samples saved from the experiment, excellent spectra were collected showing a significant amount of wintergreen present in their samples as originally evidenced by the strong minty odor (Figure 3.3). Apparently after a few weeks, the samples had sufficient time to allow all suspended particles to settle, and the strong purple color faded, allowing for the collection of better spectra. By calculating the ratio of the two peaks at 777 cm$^{-1}$ (aspirin) and 812 cm$^{-1}$ (wintergreen), it is possible to estimate the concentration of wintergreen in the product. In Sample #1 (labeled “good” in Figure 3.3), the concentration was 65% wintergreen; in Sample #2 (labeled “poor” in Figure 3.3), the concentration was 57%.
Figure 3.3. Representative sample of student spectra collected. The relative peak heights at 777 cm\(^{-1}\) and 812 cm\(^{-1}\) were used to identify the approximate concentration of wintergreen in the sample by comparing the ratio of the aspirin peak at 777 cm\(^{-1}\) and the wintergreen peak at 812 cm\(^{-1}\). The “good” student sample had 65% wintergreen; the “poor” student sample had 57% wintergreen.

To use an alternate method to verify the concentrations of wintergreen, the samples were run through a thin-layer chromatography (TLC) plate in 50% methanol/water solvent, in order to determine the approximate concentrations of wintergreen versus other components. (See Figure 3.4) In Sample #1, the spot for wintergreen represented about 70% of the total volume of the spots in that sample; Sample #2 (labeled “poor” in Figure 3.3.) had approximately 55% wintergreen when comparing that volume to total volume of spots in the TLC. These values are in close agreement with those collected from analysis of the Raman spectra.
Figure 3.4. Two TLC plates showing students’ samples #1 (“good”) and #2 (“poor”). “A” is acetylsalicylic acid; “M” is the mixture; and “W” is the pure wintergreen. The approximate concentrations of wintergreen in the mixtures as determined by spot areas were 70% and 55% wintergreen respectively.

In future iterations of this experiment, it will be important to have more discussion with students about why there were variations in their percent yields and what constitutes a “good” value and why. Using the TLC plates with the students during the experiment would provide a quick verification of the presence of wintergreen and approximate concentration in their samples, which would provide additional, interesting data for discussion with the students. Additionally, eliminating the 48-hour waiting period between synthesis and analysis would be ideal, though not necessarily realistic given the imposed time constraints within the classroom. Increasing the volumes of solutions used to create the wintergreen might help prevent the sample from drying out and eliminate the need to add additional methanol to re-dissolve the dried sample for analysis. And finally, if students are encouraged to decant or extract only the liquid without resuspending any solids, they might produce better spectra at the time of the experiment.
Students’ Evaluation of Laboratory Activity

The student evaluation began with the question, “What is spectroscopy?” Of all the high school students (n=76), 43% gave a completely correct response with some variation on making measurements using light, and 29% had a partially correct response. Some examples of those partially correct responses include “looking at wavelengths an element gives off” and “a way to find concentration in solutions”. Approximately 28% of the students gave a completely incorrect response or indicated they did not know.

The second question asked students to describe, in their own words, how spectroscopy works. Of the students, 22% had a good grasp of how spectroscopy works. Their responses indicated a general understanding of the possible interactions of light with bonds in molecules and the resulting information that could be gained from those interactions. Additionally, 37% of the students had a moderate grasp of how spectroscopy works. Their responses suggested a very limited understanding of the mechanics behind spectroscopy. They understood that light passed through a substance can reveal something about the makeup of that substance, but did not indicate an understanding of how that information is obtained. For instance, one respondent wrote, “A substance is in a vial and then a laser is passed through it and then depending on what the laser does, a graph is created which gives the user an idea of what substance is being tested.” The remaining students either gave completely incorrect responses or indicated that they did not know the answer.

On the third question, students were asked to write what, if anything, they knew about spectroscopy prior to this activity. Fully 72% of the students indicated having no prior knowledge of spectroscopy, while 28% reported having either a good grasp of the
material or some exposure to the topic before participating in the activity. This is remarkable because the same percentage (72%) of students having had no exposure to spectroscopy prior to the experiment either had a completely or partially correct definition of spectroscopy after the experiment, and 59% had at least some partial understanding as to how spectroscopy works.

The fourth question asked students to identify the best aspect about the laboratory activity and to explain their response. In some cases students answered with more than one aspect as the “best”. Fully 58% of the students answered that the best part of the overall experience was the hands-on nature of the investigation and that they enjoyed the synthesis aspect. Approximately 45% responded that their favorite part of the experiment was using the laser or learning about the spectra and what they represent, and 7% mentioned some other aspect as their favorite part about the activity.

The fifth question had students identify the worst aspect of the laboratory activity and explain their response. Just over half of the students (51%) identified the waiting time to be their least favorite part of the activity. The students referred to one or more of the following waiting periods: the time required for filtering the aspirin and methanol mixture; the 30 minutes of waiting time required to complete the synthesis; the time spent waiting from the first day of the experiment to the second; and the time spent waiting to use the laser on the final day.

A very small percentage of students (14%) felt confused about why they were doing this activity or unsure about what they were supposed to understand about spectroscopy after completing the activity and just 5% found the data analysis and calculations to be tedious or confusing. Other students answered that they liked everything about the
laboratory activity, while the remaining students gave a response that was varied or unrelated to the experiment itself.

Question six referred to whether or not the activity had a “wow” factor, and if so, requested that students identify what it was. For 42%, that “wow” factor involved the hands-on nature of the synthesis. Many students stated that being able to smell the wintergreen to know that they had completed the reaction successfully was the most exciting aspect. Using the laser and watching the real-time collection of the different spectra for different samples was the most exciting for 29% of the students. Overall, 24% of the students responded that they thought the lab had no “wow” factor, and 8% gave some other response.

One interesting point about the 24% of all students who did not seem to enjoy the lab is that 16% of those students were in just one of the three sections (76 total students) who participated in the lab. The other two sections each had just 4% of the students not find the activity exciting. Due to the nature of the data collection, it is not known which class section had so many students not enjoy the lab, so reasons for this discrepancy remain unclear.

**SUMMARY**

Although there were some difficulties encountered during the laboratory, in general students demonstrated a better understanding of spectroscopy after completing the activity. Prior to this experiment, 72% had no knowledge of spectroscopy. After the experiment, the same percentage of students (72%) were able to correctly or somewhat correctly identify what spectroscopy is, and at least 59% could accurately describe at
least some aspect of how spectroscopy works. In addition to gaining a better understanding of spectroscopy, students enjoyed working with and learning about the laser and they particularly enjoyed the hands-on nature of the experiment.

In future iterations of this experiment, more should be done to address the issue of time. Perhaps the synthesis and analysis could be during the same class period if students were to watch the video introduction to spectroscopy first, and then work in groups at the laser examining other samples while the synthesis completes. Then, once all groups have their samples prepared, each group could then come one at a time to examine their sample. This would likely be difficult to accomplish in one 75-minute class period, but might produce better results. If the class period is only 50-minutes, the experiment would have to be conducted over two days.

In summary, this experiment in bringing spectroscopy to high school students yielded promising initial results. Students certainly learned more about spectroscopy and demonstrated a better understanding of how it works. This was evidenced by the large gains in percentages of students, with no prior knowledge, being able to afterwards define spectroscopy and give some indication of how it works. Overall, the majority of students was engaged during all aspects of this activity and appreciated the experience. Though a few modifications are needed to address the time and laboratory technique issues, this appears to be a good activity to help teachers incorporate the processes of science, which is at the heart of the NGSS.
REFERENCES


CONCLUSION

Measurement technology plays a vital role in all scientific pursuits, yet the incorporation of such technology into the high school chemistry laboratory has met with limited success. The teachers surveyed indicated that although they had access to measurement technology, they did not use it regularly in their instruction. Teachers have limited time to learn to use and prepare lessons with new measurement technology, which may explain why students seem to have such limited interaction with it.

Students participating in the Chemistry Immersion Program also mentioned either no use of technology in the laboratory or limited use of technology in advanced placement laboratories only. After only one week of intense exposure to the technology, students reported feeling more confident when using it and better prepared for the first semesters of chemistry in college. Whether one week of preparation before college is an adequate replacement for regular exposure during high school remains to be seen.

In order to help ensure more students a better foundation on the use of measurement technology, future CHIP programs will include training teachers on the appropriate equipment and allowing them to instruct the CHIP students in its use. One reason for including teachers in this program is to have a wider impact on the students that can be positively affected through the teachers’ participation. The premise is that teachers will take what they have learned and improve their teaching by encouraging students to use measurement technology during laboratory investigations.

The activity described in Chapter 3 is an example of introducing students to an alternate measurement technology that they likely would not have otherwise been exposed to during the normal high school science sequence. Though there were some
challenges to the implementation of this activity in the classroom, overall the response was positive and students improved their knowledge of spectroscopy and how it works. Prior to the activity, 72% of the students had no knowledge of spectroscopy. After the activity, a similar number of the students could either correctly (43%) or somewhat correctly (29%) identify what spectroscopy is, and at least 59% of the students could describe some aspect of how spectroscopy works. Many students enjoyed the opportunity to work with the Raman spectrometer, and most enjoyed the hands-on aspect of the experiment.

Once again, time played a factor in the implementation of measurement technology into the laboratory. Students participating in the high school spectroscopy activity also mentioned the time required as being a significant drawback to the experiment. Future iterations of the experiment may need to be modified to better address the use of time during the activity.

In order to better serve students in preparing them for college and beyond, more must be done to expose them to more sophisticated measurement technology while still in high school. Despite the importance technology plays in every aspect of modern life, it is given minimal attention during what should be the time that best highlights its importance: the high school chemistry laboratory. Regardless of whether the use of measurement technology in high schools increases interest in pursuing degrees or careers in STEM fields, students should still learn to use the measurement technology that is quite likely already available in their classrooms.
A.1.1: Needs-Assessment Survey Questions and Results

A.2.1: CHIP Student Laboratory Instructions

A.2.2: CHIP Pre- and Post-Test Assessment

A.2.3: CHIP Focus Group Interview Questions

A.2.4: CHIP Program Evaluation Data

A.3.1: Introductory Raman Spectroscopy Lab Protocol

A.3.2: Spectroscopy Lab Evaluation Questions

A.3.3: DVD of “Introduction to Spectroscopy” Prezi Video
Survey Questions and Results

7. At what levels are you certified to teach?
   a. Elementary: 36 of 182 (20%)
   b. Secondary: 128 of 182 (70%)
   c. Other: 18 of 182 (10%)

8. How many years have you been a teacher?
   a. 1-5 years: 35 of 182 (19%)
   b. 6-10 years: 42 of 182 (23%)
   c. 11-25 years: 70 of 182 (38%)
   d. 26+ years: 35 of 182 (19%)

9. Level you currently teach:
   a. Elementary: 39 of 181 (22%)
   b. Middle School: 33 of 181 (18%)
   c. High School: 109 of 181 (60%)

10. What subject(s) do you currently teach (click all that apply)?
    a. Biology: 39 (35%)
    b. Chemistry: 86 (78%)
    c. Physics: 32 (29%)
    d. Science Research: 6 (5%)
    e. Other: 42 (38%)
       i. Science investigations; forensics; environmental science; physical science; astronomy; ecology; ...

11. How large is your typical class?
    a. 1-19: 37 of 178 (21%)
    b. 20-25: 75 of 178 (42%)
    c. 26-30: 46 of 178 (26%)
    d. >30: 20 of 178 (11%)

12. How many classroom minutes (not including prep time) do you spend each week teaching science?
    a. Answers varied, but the average values were:
       i. 205 min/week for elementary; 808 min/week for middle school; 1028 min/week for high school
13. What challenges do you face in teaching science?
   a. Not enough time in the classroom: 72 (41%)
   b. Not enough prep time 111 (63%)
   c. Physical materials not available 71 (40%)
   d. Professional development not available 35 (20%)
   e. Other 33 (19%)
      i. Students with poor work ethic; not enough common prep time with other teachers; safety/overcrowding; behavior; absences; too much time spent on non-academics; ...

14. In what types of professional development experience(s) would you like to participate?
   a. Summer institutes (1-2 weeks): 109 (62%)
   b. Research experience at a college or university: 47 (27%)
   c. One-day workshop (e.g., on a Saturday): 90 (51%)
   d. Coursework in education: 21 (12%)
   e. Coursework in science: 62 (35%)
   f. Job embedded staff development with a mentor: 45 (26%)
   g. Other: 15 (9%)
      i. School-based staff development; conferences; 1-2 day workshops in summer; after school; ...

15. What grade level do students typically enroll in chemistry?
   a. 9th: 2 of 83 (2%)
   b. 10th: 26 of 83 (31%)
   c. 11th: 54 of 83 (65%)
   d. 12th: 1 of 83 (1%)

16. The Physics First Initiative typically results in students taking chemistry a year earlier, in 10th grade instead of 11th. What is the greatest challenge for you as a teacher in re-developing the curriculum?
   a. Students’ math skills (level): 63 of 82 (77%)
   b. Appropriateness of activities: 3 of 82 (4%)
   c. Time to develop new activities: 10 of 82 (12%)
   d. Resources to teach new activities: 6 of 82 (7%)

17. How many lab activities do the students perform in a year?
   a. 0-10: 12 of 83 (14%)
   b. 11-15: 17 of 83 (20%)
   c. 16-20: 23 of 83 (28%)
   d. >20: 31 of 83 (37%)
18. Which of the following do the lab activities include (check all that apply)?
   a. Non-toxic chemicals, salt, water, etc.: 82 of 83 (99%)
   b. Household products: 78 of 83 (94%)
   c. Chemicals: 81 of 83 (98%)
   d. Technology, temperature, pH or pressure meters, spectrometers, etc.: 61 of 83 (73%)
   e. Other: 6 (7%)
      i. Bunsen burners; simulations; inquiry materials; manipulatives

19. Please check all that are available in your classroom.
   a. Gas lines: 55 of 83 (66%)
   b. Lab benches: 49 of 83 (59%)
   c. Hoods: 39 of 83 (47%)
   d. Safety equipment: 56 of 83 (67%)
   e. Waste disposal (e.g., hazardous waste): 18 of 83 (22%)

20. Approximately what percentage of the student lab activities include the use of technology (such as temperature, pressure, O\textsubscript{2} sensors, portable or hand-held spectrometers or full-size absorption spectrometers)?
   a. 0-24%: 64 of 83 (77%)
   b. 25-50%: 14 of 83 (17%)
   c. 50-75%: 2 of 83 (2%)
   d. 75-100%: 3 of 83 (4%)

21. Please rate the following activities on a scale of 1-4 (1 being the highest) for what would increase student interest in both chemistry and the sciences.

<table>
<thead>
<tr>
<th>Answer</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>More classroom based activities</td>
<td>31</td>
<td>25</td>
<td>20</td>
<td>7</td>
</tr>
<tr>
<td>More technology based activities</td>
<td>21</td>
<td>38</td>
<td>13</td>
<td>11</td>
</tr>
<tr>
<td>Student participation in workshops and/or field trips at regional colleges or universities</td>
<td>21</td>
<td>17</td>
<td>27</td>
<td>18</td>
</tr>
<tr>
<td>Teacher participation in workshops and/or research experiences at regional colleges or universities</td>
<td>6</td>
<td>14</td>
<td>22</td>
<td>40</td>
</tr>
<tr>
<td>Total</td>
<td>79</td>
<td>94</td>
<td>82</td>
<td>76</td>
</tr>
</tbody>
</table>

22. Would you be interested in partnering with regional colleges and/or universities to increase the number of chemistry lab activities the students participate in during the year?
   a. Yes: 71 of 83 (86%)
   b. No: 12 of 83 (14%)
Stoichiometry & Spectroscopy Lab

Materials:
- 250-mL beaker
- 100-mL beakers (x2)
- 10-mL graduated cylinder
- 1 black cuvette (0% transmittance)
- 2 clear cuvettes
- 9 small test tubes
- small stoppers or Parafilm
- DI water
- 2.5 x 10^{-4} M Fe^{2+} solution (approx. 30 mL)
- 2.5 x 10^{-4} M 1, 10-phenanthroline solution (approx. 40 mL)

Procedure:
1. Obtain approximately 30-mL of 2.5 x 10^{-4} M Fe^{2+} solution and 40-mL of 2.5 x 10^{-4} M 1, 10-phenanthroline solution into two 100-mL beakers, respectively.
2. First add the appropriate amounts of iron(II) solution (See Table) to each of your 9 test tubes. Then add the appropriate amount of 1, 10-phenanthroline (See Table) to each of your 9 test tubes. Mix each solution well by stoppering the test tube and inverting several times. The red-orange color of the iron(II)-phenanthroline complex should fully develop after about 10 minutes.

<table>
<thead>
<tr>
<th>Tube</th>
<th>Iron(II)</th>
<th>Phen</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.50 mL</td>
<td>0.50 mL</td>
</tr>
<tr>
<td>2</td>
<td>4.00 mL</td>
<td>1.00 mL</td>
</tr>
<tr>
<td>3</td>
<td>3.50 mL</td>
<td>1.50 mL</td>
</tr>
<tr>
<td>4</td>
<td>3.00 mL</td>
<td>2.00 mL</td>
</tr>
<tr>
<td>5</td>
<td>2.50 mL</td>
<td>2.50 mL</td>
</tr>
<tr>
<td>6</td>
<td>2.00 mL</td>
<td>3.00 mL</td>
</tr>
<tr>
<td>7</td>
<td>1.50 mL</td>
<td>3.50 mL</td>
</tr>
<tr>
<td>8</td>
<td>1.00 mL</td>
<td>4.00 mL</td>
</tr>
<tr>
<td>9</td>
<td>0.50 mL</td>
<td>4.50 mL</td>
</tr>
</tbody>
</table>

3. Follow the instructor’s directions to properly set up the spectrometers, including taking a dark spectrum with the blacked-out cuvette. Then take a small amount of 1, 10-phenanthroline in a cuvette to use as the blank with 100% transmittance. Set the wavelength of the spectrometer to \( \lambda_{\text{max}} = 508 \text{ nm} \).
4. Measure the absorbance of each of the nine prepared mixtures.
   a. Fill the clean, empty cuvette ¾ full with the solution from test tube #1. Place it in the spectrometer and measure the % transmittance by pausing the collection. After recording the transmittance value, hit play for a second or two and then pause again. Take another reading. Repeat this three times.
   b. Return the solution mixture to its original test tube. Rinse the cuvette with DI water and carefully dry it.
   c. Repeat this process with all the other solution mixtures in tubes #2-9.
5. When completely finished, dispose of all your chemical solutions in the appropriate unwanted materials container as directed by the instructor.
Analysis:

1. Using Excel, convert your transmittance values to absorbance using the following equations:
   
   \[ T = \frac{\%T}{100} \quad \text{and} \quad A = \log \left(\frac{1}{T}\right) \]

2. Find the average of your three readings for each mixture.

3. Plot your data as two data sets, one with increasing values and one with decreasing values, with the x-axis as concentration and the y-axis as absorbance. Plot both on the same graph, then fit each with a line of best fit and obtain the equations for each of these trendlines. Find the point of intersection between the two lines.

4. From the point of intersection you can determine the volume mixture of reactants used to obtain the maximum absorbance (hence the maximum amount of complex formed). Finally, using this volume mixture, you can determine the simplest whole number ratio of Fe\(^{2+}\):Ph (identical to the mole ratio), which is the stoichiometric ratio for this reaction.
Ideal Gas Law Lab

Materials:
- 150-mL beaker
- 250-mL beaker
- Large test tube
- Alka-Seltzer tablets (x2)
- Mortar and pestle
- Gelatin capsules (x3)
- Magnetic stir bar
- 6M hydrochloric acid
- Water bottle

Procedure:
This experiment is technique intensive. None of the individual steps are difficult; however, if they are not performed in the proper order, spurious results will be obtained. As always, measure all temperatures to 0.1°C and all masses to 0.001g.

1. Carefully clean and dry a 150 mL beaker, a 250 mL beaker, and a large 155mm test tube.
2. Remove two Alka-Seltzer tablets from their hermetically sealed packet and weigh them.
3. Use a clean (use paper towels only, NO water) mortar and pestle to grind the tablets into a fine power.
4. Accurately weigh an empty gelatin capsule. Note: make sure your hands are dry and that you close the bottle containing the capsules IMMEDIATELY! Gelatin starts dissolving when it comes in contact with moisture.
5. Take the capsule apart and use your scoopula to fill the larger portion with your powdered Alka-Seltzer.
6. Put the two parts of the capsule back together, carefully blow off any powder than may be sticking to the outside and reweigh.
7. Add a magnetic stir bar to your test tube and place it upright in your 150 mL beaker. Use a pipet to add 10.0 mL of 6M HCl to the test tube.
8. Weigh the beaker, test tube, stir bar and HCl.
9. Fill your water bottle to about half an inch below the 'full line' with distilled water and place it on the magnetic stirrer motor.
10. Weigh your clean, dry 250 mL beaker.
11. Place it on your iron ring with the wire gauze, and position it so it can catch all of the water from the water bottle.
12. Remove the top from your water bottle and place the test tube/stir bar/HCl in the bottle; it should float.
13. Quickly drop the Alka-Seltzer filled gelatin capsule into the test tube and seal the water bottle. Be sure that the top is on tight or some of the carbon dioxide will escape. Make sure the spout of the water bottle is pointed into the 250 mL beaker.
14. Now adjust the magnetic stirrer motor to agitate the capsule and HCl. It may take a minute or two for the capsule to dissolve and the reaction to begin.
15. As the reaction proceeds you should see ‘foam’ produced. At the same time, water will be
displaced from the water bottle into the 250 mL beaker.
16. Keep adjusting the rate of the magnetic stirrer up and down for about 10 minutes or until all of
the ‘foam’ has disappeared and no more water is being generated.
17. After the reaction is complete, weigh the 250 mL beaker. By difference, you now have the mass
of water generated.
18. Open the water bottle and carefully remove the test tube/stirrer/HCl. Use a paper towel to
wipe off any water from the outside of the test tube.
19. Place the test tube upright in the same 150 mL beaker and reweigh. By difference, you now
have the mass of CO₂ generated.
20. Record the temperature of the water in the bottle (to 0.1°C). You can use a C.R.C. or a table of
water density to find the density of water at this temperature. You will use this to convert the
grams of water you obtained in Step #19 into mL. This is the volume of CO₂ generated.
21. Record the barometric pressure in the lab.
22. Clean the test tube thoroughly to remove any remnants of the gelatin capsule. Rinse with
distilled water and thoroughly dry with paper towels.
23. Repeat Step #4-22 until you have at least three GOOD trials. You can perform a simple
calculation to determine if a given trial is 'good' or not. Calculate the amount of water
generated by subtracting (c) from (f) and then divide by the mass of CO₂ generated, (n). This
value should be in the range of 500-600 and should not vary by more than 10-20 units from trial
to trial. If it does, you have made some mistakes and will have to run additional trial(s).

Results:
Use the attached table to guide your data collection and calculations.

Analysis/Calculations:
For EACH trial, calculate the following from your data (show all calculations):

- The mass, volume, and moles of carbon dioxide generated.
- The molecular weight of carbon dioxide.
- The ideal gas law constant, R.
- The molar volume of carbon dioxide at STP.
- The percentage of sodium bicarbonate in Alka-Seltzer.

Questions:
1. Include a table with the molecular weight, ideal gas law constant, molar volume, and percent
NaHCO₃ for each trial. Also include the percent error versus the accepted value.
2. How did your trials compare to each other?
3. How did your results compare to the accepted values? Calculate the percent error.
4. What do you think is the biggest source of error in this experiment?
<table>
<thead>
<tr>
<th>Useful Data</th>
<th>Trial #1</th>
<th>Trial #2</th>
<th>Trial #3</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) Weight of two Alka-Seltzer tablets (0.001g):</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(b) Weight of 150 mL beaker + test tube + stir bar + 10 mL HCl:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(c) Weight of empty 250 mL beaker:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(d) Weight of empty gelatin capsule:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(e) Weight of capsule + Alka-Seltzer powder:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(m) Mass of Alka-Seltzer, (e) - (d):</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(f) Weight of 250 mL beaker + water:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(g) Weight of 150 mL beaker + test tube + stir bar + HCl after:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&quot;Goodness&quot; of trial, [(f) - (c)] / (n):</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(h) Temperature of water in bottle (0.1°C):</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(i) Barometric pressure in the lab (0.1 mm Hg):</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(j) Vapor pressure of water:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(k) Density of water:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volume of water, [(f) - (c)] / (k):</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(n) Mass of CO₂ = (b) + (e) - (g):</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volume of CO₂ = Volume of water:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moles of CO₂ = Mass of CO₂ / 43.9898:</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Thermochemistry Lab

Materials:
- Styrofoam cups (x2)
- 400-mL beaker
- Temperature probe
- Thermometer
- 10-g copper
- 10-g tin
- 10-g copper-tin (bronze) mixture

Procedure:

***Calibrate the temperature probe according to the directions provided by the instructor.***

Heat Capacity of the Calorimeter
1. Nest two clean, dry Styrofoam cups one inside the other, and put them in a 400 mL beaker.
2. Cool some water to about 20°C, and put a mass of that water in your calorimeter. Use about 50 g of water, but record exactly how much you use.
3. With the software, make the following changes: Choose the “Experiment” menu and select “Data Collection”. In the “Data Collection” box, select the “Collection” tab. This will take you to the menu where you can change the way the software will collect the data. Extend the time in “Experiment Time” to 500 seconds. Click on “Done”.
4. Get a beaker with another 50 grams of DI water, record exactly how much you use, and heat it to about 60°C. The exact temperature doesn’t matter, but make sure to record how hot the water gets. Also make sure that the thermometer bulb does not touch the sides or bottom of the beaker.
5. Press the collect button on the top-center of the screen and allow the baseline of the cool water in the calorimeter to collect for about a minute. Read and record the temperature of the hot water. This value is $T_{ih}$ for the hot water. Remove the cover of the calorimeter and add the warm water to the cool water and re-cover it quickly while giving the calorimeter a swirl. Allow the computer to collect data for the next two minutes or so.
6. You may need to fit a straight line to the final linear part of your data. Click and drag the mouse over a linear segment of the data at the end of your run to have this section of the line to be measured for slope and intercept. With the line segment selected, click on “Analyze” and select “Linear Fit” or click the “Linear Fit” icon.
7. Calculate the apparent heat capacity of the calorimeter. Do your results make sense? Does your value for $C_C$ have legitimate units?

Specific Heat Capacity of Metals
1. Dry out your calorimeter.
2. Cool some water to about 20°C and put a mass of that water in your calorimeter. Use about 50 grams of water, but record exactly how much you use.
3. Obtain about 10 g of copper. Record the mass of the metal you actually obtain.
4. Put your metal in a large test tube, and put the test tube in a beaker of water. Heat the water to approximately 90°C. Be careful to place the test tube in the beaker in such a way that the water cannot splash into the test tube. Be certain that the metal sample is in the hot water bath for at least 5 minutes.
5. Press the collect button on the top-center of the screen and allow the baseline of cool water in the calorimeter to collect while your metal is heating up.

6. You are now ready to add the hot metal to the water in the calorimeter; first you need to record the temperature of the water bath. (This will be the $T_{\text{mf}}$ for the hot metal.) Pour the hot metal into the calorimeter and allow the system to equilibrate for at least 5-7 more minutes. Do not delay while transferring the metal to your calorimeter.

7. You may need to fit a straight line to the final linear part of your data. Click and drag the mouse over a linear segment of the data from the end of your run to allow this section of the line to be measured for slope and intercept. With the line segment selected, click on “Analyze” and select “Linear Fit” or click on the “Linear Fit” icon.

8. To print, click on “File” and then on “Print Graph”. Click on the “footer” box and add the names and other pertinent information. It is recommended that you add the experimental run (e.g., Run #4) and initials of yourself and your partner.

9. Repeat steps 1-8 for tin and your assigned bronze alloy of unknown composition. Run two trials for copper, two for tin, and two for bronze (if time allows).

**Analysis/Calculations:**

**Part 1**

1. You should have a graph of your data, with the calorimeter water temperature (°C) on the y-axis and the time (seconds) on the x-axis. The water is initially near room temperature. The calorimeter temperature will rise rapidly after the addition of the hot water. A maximum temperature will be reached after the mixing is complete. The temperature of the calorimeter water, now above room temperature, will then drop noticeably. Some heat is already lost through the calorimeter walls *before* the maximum temperature is reached. You can compensate for this loss by using the $T_f$ obtained from the extrapolation. The extrapolation yields $\Delta T_C$ which is the maximum temperature rise of the calorimeter water that would have been observed had the calorimeter walls been perfect heat barriers.

2. Use the extrapolated maximum temperature ($T_f$) to find the temperature changes ($\Delta T_{\text{mf}}$) of the hot water from the beaker. ($\Delta T_{\text{mf}} = T_f - T_i$)

3. The heat transfer due to cooling of the hot water ($q_H$) is calculated from its mass ($m_H$), specific heat capacity of water ($s_{H2O}$), and $\Delta T_H$. Note: $\Delta T_H$ will be negative and so the value of $q_H$ will be negative.

$$q_H = m_H \times s_{H2O} \times \Delta T_H$$

4. The amount of heat gained by the calorimeter ($q_C$) is exactly equal to that lost by the hot water ($q_H$), however since one “gains heat” and the other “loses heat”, the signs are opposite.

5. The heat transfer to the calorimeter and its contents may be expressed as the sum of two parts, where the first part represents the heat gained by the water in the calorimeter and the second part represents the heat gained by the cups and the temperature probe.

$$-q_H = q_C + q_{\text{cal}}$$

$$-m_H \times s_{H2O} \times \Delta T_H = (C_{\text{cal}} \times \Delta T_C) + (m_C \times s_{H2O} \times \Delta T_C)$$

The symbol $C_{\text{cal}}$ represents the heat capacity of the calorimeter. Use your experimental values and solve for $C_{\text{cal}}$.

**Part 2**

1. Analyze the calorimeter temperature versus time data as you did previously. Again extrapolate to find $T_i$ and obtain $\Delta T_C$, the temperature increase.

2. Use your value for $C_{\text{cal}}$ to calculate the heat transfer ($q_C$) to the calorimeter.

$$q_C = (m_C \times s_{H2O} \times \Delta T_C) + (C_{\text{cal}} \times \Delta T_C)$$
3. Remember that the heat that the metal lost is equal in magnitude to the heat the calorimeter gained, but opposite in sign.

4. Use T_f to find ΔT_{fb}, the temperature decrease of the metal sample.

5. The heat transfer (q_{hi}) from the metal sample of mass m_m is exactly equal in magnitude (but opposite in sign) to the heat gained by the calorimeter.

\[ s_M = -q_{hi} / (m_m \times \Delta T_{hi}) \]

6. Insert your experimental values and solve for the specific heat capacity of each metal.

Questions:
1. How did your trials compare to each other?
2. How did your results compare to the accepted values? Calculate the percent error.
3. What do you think is the biggest source of error in this experiment?
Chemical Bonding Lab

Materials:
- Water
- Ethanol
- Cyclohexane
- Naphthalene
- Sodium chloride (table salt)
- Sucrose (table sugar)
- Test-tube rack
- Test tubes
- Stoppers to fit test tubes
- Pipettes
- Waste container
- Unknown white solid

Procedure:
***Use the attached “Coach Lewis” instructions to do the Lewis structures for this lab.***

Part A: Lewis Structures
1. You will be assigned one of the sets of eight substances (shown in the table below) for which you will create models using the appropriate Lewis structures.

<table>
<thead>
<tr>
<th>Sets of substances.</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CF3Cl</td>
<td>ClO2^-</td>
<td>AsF6^-</td>
<td>SeBr3^+</td>
</tr>
<tr>
<td></td>
<td>SnCl4</td>
<td>BrO2^-</td>
<td>AlF6^3-</td>
<td>H3O^+</td>
</tr>
<tr>
<td></td>
<td>CIO4^-</td>
<td>OI2</td>
<td>SbF6^-</td>
<td>PF3</td>
</tr>
<tr>
<td></td>
<td>ClF2O2^+</td>
<td>SCl2</td>
<td>BrF6^+</td>
<td>SeI3^+</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>ICl2^-</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>SO2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>SeBr4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>ClF4^-</td>
</tr>
</tbody>
</table>

2. Use the program in the teaching labs called “Molecules 3D” to build each of the molecules assigned to your group. Make a perspective drawing of your molecule using your 3D model.

Part B: Polarity of Liquids
1. Add one full pipet of water to test tubes 1 and 2.
2. Add one fill pipet of ethanol to test tubes 1 and 3.
3. Add one full pipet of cyclohexane to test tubes 2 and 3.
4. Stopper the open end of each test tube and agitate the liquids to thoroughly mix.
5. Examine what happens to the liquids after agitation and record your observations in Table 5.
6. Dispose of liquids properly and clean your glassware.

Part C: Polarity of Solids
1. Add one full pipet of water into test tubes 1 through 4.
2. Add one full pipet of ethanol into test tubes 5 through 8.
3. Add one full pipet of cyclohexane into test tubes 9 through 12; you should now have a 3 x 4 grid of solvent-filled tubes.
4. In tubes 1, 5, and 9 add enough NaCl to cover the bottom of the tube. Stopper those tubes and invert to agitate the mixture. Repeat several times until no further changes take place. Carefully examine the contents of each tube and record your observations in Table 6.
5. Repeat step 4 with sucrose (tubes 2, 6, and 10).
6. Repeat step 4 with naphthalene (tubes 3, 7, and 11).
7. Repeat step 4 with the unknown solid (tubes 4, 8, and 12).
8. Dispose of tube contents properly and clean your glassware.

Part D: Conductivity & Solubility
1. Test the conductivity of each of the solvents by dipping the conductivity probe into approximately 20 mL of each solvent. In your notebook, indicate the result as HC (high conductivity), LC (low conductivity) or NC (no conductivity).
2. Observe the solubility of the solvents in one another by mixing 10 mL of each with 10 mL of the other two. Fill in the data table in your notebook with either VS (very soluble), SS (slightly soluble) or IS (insoluble).
3. Observe the solubility of each of the solutes in every solvent by mixing 0.200 g of the solute in 30 mL of solvent. Stir the solution for approximately 1 minute, then observe. Fill in the data table in your notebook with either VS (very soluble), SS (slightly soluble) or IS (insoluble). Test the conductivity of the resulting solution using the conductivity probe, indicating the result as HC (high conductivity), LC (low conductivity) or NC (no conductivity).

Questions:
1. What are some of your more interesting observations made during the course of this activity?
2. What correlations (if any) did you observe between polarity and solubility or conductivity?
STEP 1: Click on either Molecules Pro or the icon

STEP 2: Click on the C with the four lone pairs of electrons:

STEP 3: This is the dialog box that you will enter information about the molecule that you are interested in looking at. It is VERY important that you do this part correctly and count the proper number of valence electrons AND do not exchange the letter “O” for the number “0”.

As an example, the molecule CH₃Cl will be created using the software.
STEP 4: CH₃Cl is called either chloromethane or methyl chloride. It has no charge (the charge would be given as +1 or -2 as an example as a superscript over the formula. The valence electrons are added up from looking at the periodic table. Carbon has 4, hydrogen has 1 (and since there are 3 hydrogens, 3 electrons) and chlorine has 7. Add 4 + 3 + 7 = 14. Then click “OK”.

STEP 5: The next screen has you move the elements into the working area to set up the molecule. In these steps, follow the directions.
STEP 6: Now move the electrons in to create bonds.

STEP 7: The next step involves the remaining three lone pairs of electrons. These need to go onto the chlorine. The eccentricity of the software requires you to put the electrons on top of the chlorine.

When all of the electrons have been assigned and no formal charge differences exist, click done. Your TA will explain how to work with formal charge issues and resonance.
STEP 9: The last 2 steps for this molecule are given in the picture. The icon that looks like a roll of paper towels will enable the computer to convert the 2-D representation you created at STEP 7 into a 3-D image by using part of the software to "optimize" the structure. Auto-rotating the structure allows you to see the entire structure in virtual 3-space.

Good Luck!!
Careers in Science

1. When you think of careers in science, what comes to mind? Try listing 4-5 thoughts about careers in science.

2. Select two of the careers you listed in question 1 and identify the “training and or education” you think might be required.

Stoichiometry

Shondra and Liz are students in Mr. Flitwick’s chemistry class. The class today is focused on measurement, students were asked to demonstrate their knowledge and skill in regard to reading laboratory equipment. The first task was to read the volume of water in a graduated cylinder.

1. The first task is to use a graduated cylinder to determine the volume of water within. Use the diagram below and indicate the volume of water in the graduate.

![Graduated Cylinder Diagram](image)
2. Mr. Flitwick asked students to approximate the volume of 7.2 ml using the diagram below.

![Diagram showing 15 ml, 10 ml, and 5 ml markings]

3. During the short film about chemistry, the main character, Dr. Dudley, writes the following equation on his lab whiteboard: \( \text{Ti} + \text{C} + 2\text{Cl}_2 \rightarrow \text{TiCl}_3 + \text{C} \). Is this equation correct? _____ In the space below explain your answer.

4. Jane needs to make a 0.230 M solution of CuSO\(_4\). What mass of CuSO\(_4\) will Jane measure to make 200 ml of the solution?
5. Using a balance, Jane measures out the mass of CuSO₄ required to make the 0.230 M solution and records the mass on a handy piece of paper. She then scoops the powder from the balance to a 500 mL beaker and adds water until it reaches the 200 mL line. The CuSO₄ does not dissolve right away, so she puts the beaker with the CuSO₄ on a hotplate to heat the solution till it boils to help it dissolve more quickly. She then allows the solution to cool before using it in further experiments.

a. What mistakes did Jane make along the way to make her 0.230 M CuSO₄ solution? What should she have done differently? Rewrite the procedure the way Jane should have done it to make a 0.230 M CuSO₄ solution.
Chemical Bonding

Desmond and Alice are lab partners in Ms. Diggory's Chemistry I class. The students are challenged to draw Lewis structures for the following compounds. Help the students with this challenge:

1. CCl₄
2. CO₂
3. C₂H₂

4. At lunch, Beth is about to put oil and vinegar dressing on her salad. Mark exclaimed, “Beth, you forgot to shake it up before you pour the dressing on your salad. If you pour it now, you will only get the oil and not the vinegar.” Ms. Diggory was passing by the table just then and asked the students why it was necessary to shake the dressing. Help the students answer Ms. Diggory’s question.

5. Mr. Black is explaining electrical conduction through water. He begins with distilled water. After placing the electrodes in the water, the students note that there is little or no current conducted by the water. Harry raises his hand and asks, “Hey, my mom said that you can be electrocuted in water, so the water should conduct electricity. Right?”
   a. Is Harry correct in his assertion? _______ Explain your answer.
6. Next, Mr. Black adds 10g of NaCl to the 250 ml of water in the beaker. Before placing the electrodes in the water, he asks the students to predict what will happen. The class is divided, 15 of the 26 students say the water will now conduct electricity and 11 students say that it will not.
   a. Which group is correct in their prediction? ___________________
   b. Explain your answer, provide evidence to support your claims.

**Thermochemistry**

Trevon and Enrique are lab partners in Mr. Porter’s chemistry class. Yesterday, the class completed a calorimetry experiment to determine the specific heat of lead. Trevon and Enrique discovered their laboratory results had a percent error of 17.3%. Trevon explained, “This isn’t good, the percent error is way high! What did we do wrong?” Enrique scratched his head as he studied the results. “First, I think we should review what we did during the investigation, maybe we can find a clue to help us with this problem,” Enrique said. Reviewing their lab notebook, the students noted that for each of the three trials, they carefully measured the masses and the temperatures of the dry, lead sinker and the water in the calorimeter before and after they submerged the hot lead sinker. Trevon pointed to his lab notebook and said, “Maybe this was not related to what we did, our technique might have been good. I think we should look into the design of the experiment and think about how we can investigate further.”
The students recalled the equation used to determine the specific heat of lead \( c_{\text{lead}} \) was derived from showing that the quantity of heat lost by the lead sinker equals the quantity of the heat gained by the water.

\[
q_{\text{lead}} + q_{\text{water}} = 0
\]

\[
q_{\text{lead}} = -q_{\text{water}}
\]

Trevon sketched the process represented by the equations above. His work is shown in the space below:

1. Using the scenario above, identify what key variable was left out of the equation to calculate heat capacity?

2. In the space below draw a picture of a simple calorimeter to show the direction of heat transfer within the system.

<table>
<thead>
<tr>
<th>Initial Temperature of sinker</th>
<th>95°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial temperature of water</td>
<td>22.1°C</td>
</tr>
<tr>
<td>Final temperature of water and sinker</td>
<td>25°C</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mass of sinker</th>
<th>23.5 g</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass of water</td>
<td>50 g</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Specific Heat Capacity of lead</th>
<th>0.129 J/(g \cdot °C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific Heat Capacity of water</td>
<td>4.18 J/(g \cdot °C)</td>
</tr>
</tbody>
</table>
3. Use the data provided in the table above to determine the value of $q_{\text{calorimeter}}$. What is the significance of this measurement, $q_{\text{calorimeter}}$?

Mr. Porter provided students with the graph pictured below. He instructed his students to use the graph to extrapolate the final temperature of the water.

![Graph of Calorimeter Data]

4. Final temperature of water: __________________
Ideal Gas Laws

Your young cousin, Sarah, receives a helium-filled balloon for her birthday on July 4th. She is so excited by the balloon that she decides to “preserve” it as her mother preserves food. Sarah places the balloon in the freezer. Two hours later, she decides to show the balloon to her grandparents.

1. When Sarah removes the balloon from the freezer, she discovers that the balloon appears to be deflated, but there are no apparent leaks or tears in the balloon. What happened to the balloon? If you could zoom into the molecular level, what would the interior of the balloon look like?

2. Sarah’s friend, Marsha, has come to play and the balloon is left on the counter in the kitchen. The air conditioner has stopped working and the house is warm at 87° F. What condition will the balloon be in when Sarah and Marsha come into the kitchen for a cool drink three hours later? Using diagrams, explain the change in the contents of the balloon on the molecular level.

David and Sonia are students in Ms. Granger’s Chemistry II class. There are two sealed containers filled with two different gases in the front of the classroom. The containers are the exact same size and are at the exact same temperature and pressure as well.

3. Ms. Granger asks the class to list everything they can assume about the gases. David and Sonia create the list below, identify the one assumption that cannot be made at this time:
   a. When the temperature is increased, the volume of both containers will increase
   b. When the pressure of both containers is increased, the volume of both containers will decrease
   c. Both containers contain the same number of gas particles
   d. When the pressure is decreased, the temperature of both containers will increase

4. If we use the Ideal Gas Law constant which has a value of 0.0821 L·atm/(mol·K), what other information would we need to calculate the volume of a gas?
5. Teshia and Caleb are working on the completion of questions for Mr. Jordan’s Chemistry I class. They are stumped by the relationship between temperature, volume, and pressure identified in the gas laws. Help Teshia and Caleb by inserting the terms *direct* or *inverse* in the concept map below:
Interest and Awareness of STEM Careers

1. When you think of science, technology, engineering, or mathematics (STEM) what careers come to mind?

2. What types of classes and/or training do you think you would need to prepare for a career in (chemistry, physics, engineering, medicine, etc.)?

3. What do you think working as a (chemist, engineer, biologist, physician, nurse, etc.) would entail?

4. Do you know someone who is employed in a scientific (STEM) field?

5. Did your school host a career day?

6. Have you completed an internship with a local firm, veterinarian, physician, engineer, etc.?

7. How often do you design and conduct experiments in your science classes?

8. Have gathered and analyzed data from experiments conducted in a science classes?

9. Have you drawn upon your data to provide evidence in support of a conclusion or claim?

10. Have you used technology in science labs at your school? Technology would include temperature probes, oxygen or pressure sensors, digital thermometers, digital pH meter, digital balance, etc.
## CHIP EVALUATION RANKINGS

<table>
<thead>
<tr>
<th>Statement</th>
<th>Individual Rankings</th>
<th>Overall Ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>The content of the CHIP program chemistry investigations was relevant to</td>
<td>4 5 5 5 5 5 5 5 5</td>
<td>4.9</td>
</tr>
<tr>
<td>my interests in science.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I felt the pace of the laboratory investigations was just right.</td>
<td>4 5 4 5 4 4 4 5 4</td>
<td>4.4</td>
</tr>
<tr>
<td>I did not feel rushed and I was not bored.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The chemistry laboratory investigations planned and implemented by Dr.</td>
<td>5 5 5 5 5 5 5 5 5</td>
<td>5.0</td>
</tr>
<tr>
<td>Jiji’s team for the morning CHIP session were interesting and well</td>
<td></td>
<td></td>
</tr>
<tr>
<td>organized.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ms. Harbert was very knowledgeable and she organized the morning</td>
<td>5 5 5 5 5 5 5 5 5</td>
<td>5.0</td>
</tr>
<tr>
<td>laboratory sessions very well. She was always available and able to help</td>
<td></td>
<td></td>
</tr>
<tr>
<td>everyone understand the protocol and also how to use the equipment.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ms. Harman was very knowledgeable and explained key concepts in</td>
<td>5 5 4 5 5 5 5 5 5</td>
<td>4.9</td>
</tr>
<tr>
<td>chemistry in a way which was easy to understand.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The biochemistry laboratory investigations planned and implemented by Dr.</td>
<td>5 5 5 5 5 4 5 5 5</td>
<td>4.9</td>
</tr>
<tr>
<td>Cornish’s team for the afternoon CHIP session were interesting and well</td>
<td></td>
<td></td>
</tr>
<tr>
<td>organized.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I enjoyed working with other students during the activities and</td>
<td>5 5 5 5 5 5 5 5 5</td>
<td>5.0</td>
</tr>
<tr>
<td>investigations.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I would recommend the CHIP program to my friends as an interesting and</td>
<td>5 5 5 5 4 5 5 5 5</td>
<td>4.9</td>
</tr>
<tr>
<td>fun way to learn chemistry.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Student housing (Schurz Hall) was comfortable and supplied the</td>
<td>5 5 5 4 5 5 4 5 4</td>
<td>4.8</td>
</tr>
<tr>
<td>materials needed to make my stay comfortable.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The Plaza 900 Dining Hall offered a wide culinary diversity and the</td>
<td>5 5 5 5 5 5 5 5 5</td>
<td>5.0</td>
</tr>
<tr>
<td>food was good.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The meals in the Chemistry Building were always good and I was able to</td>
<td>4 5 5 5 3 5 4 5 5</td>
<td>4.5</td>
</tr>
<tr>
<td>select what I wanted from a menu.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The evening seminars were interesting and engaging. I believe I</td>
<td>4 5 4 5 3 4 5 5 5</td>
<td>4.4</td>
</tr>
<tr>
<td>expanded my understanding of chemistry and careers related to</td>
<td></td>
<td></td>
</tr>
<tr>
<td>chemistry. The time was well spent.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CHIP EVALUATION COMMENTS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>What was the most interesting and enjoyable aspect of the Chemistry Immersion Program?</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Physically being exposed to labs/people/equipment</td>
<td>One of the speeches at 6:00 pm was exactly what I expected</td>
<td>So glad I came</td>
</tr>
<tr>
<td><strong>What was the least interesting aspect of the Chemistry Immersion Program?</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Realistically with time/budget restraints I can’t think of anything more to ask for</td>
<td>Maybe make them more hard science oriented like the second one but I am glad the first wasn’t the hard science in the end because it reminds me I’m not alone in this field</td>
<td></td>
</tr>
<tr>
<td><strong>Please offer any topic suggestions for evening seminars...</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maybe extend # of days and decrease schedule (sic) from a 12 hour agenda to an 8. Or something along those lines</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Please share any additional thoughts with us...</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I enjoyed absolutely everything; I’m really glad I came to this program</td>
<td></td>
<td></td>
</tr>
<tr>
<td>This experience is something I would have never imagined. It was incredible to have met so many different people with a lot of different ideas. It was also very helpful to get familiarized with the labs I will use eventually at Mizzou</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I thought it was very interesting too (sic) see where others have taken their science background and apply that into careers. I also enjoyed the DNA lab and all the morning labs as well</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I really liked all of it, even the things that didn’t sound very interesting initially</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I feel that if you had an even more diverse program, that would be great, but you had a pretty good schedule</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Labs were very interesting but near the end it got tiring, felt a little overwhelming. I (sic) would have been nice for the camp to go on longer and have a little more time to work/think things out</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Some of the biochemistry seemed a lot more challenging so I lost some interest quickly, especially on the first few days</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I think it’s important to show career based seminars. I would have liked to see another one more in the medical field</td>
<td></td>
<td></td>
</tr>
<tr>
<td>My favorite part was doing the PCR to our DNA. That lab was very interesting and I learned a lot</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I didn’t really enjoy the evening seminars. I found them pretty boring. Also I think you all should add more breaks between learning</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maybe have a career fair type thing one night with a bunch of different employees that we could speak with</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Getting to fully dive into how labs in college work &amp; being able to easily socialize with a small group helped &amp; was joyful</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The program could have gone on for another day (end Saturday morning)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>More chemistry specific related such as the function of electrons in electricity, technology &amp; lightning</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I enjoyed the talks a lot, especially the one on droughts</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Curfew</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10:00 curfew isn’t that bad, but being in dorms at 9:00 I did not feel comfortable with. Although hanging out with our new friends from 9:00 to 10:00 was good</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The easy-going nature of the staff and other students made it much more comfortable and easier to learn</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Curfew // Protip: Maybe a 10 pm curfew?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I was pleasantly surprised by how engaging each seminar was</td>
<td></td>
<td></td>
</tr>
<tr>
<td>In all, the entire experience was thorough, very well organized, and very well thought out. There’s nothing about this program I didn’t like. But maybe, for the sake of the future CHIP participants, extend the curfew</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**APPENDIX 2.4**
RAMAN SPECTROSCOPY LAB

Lab Procedure Part #1: Synthesizing Oil of Wintergreen

Materials Needed:

- 2 aspirin tablets
- Filter paper
- Test tube holder
- Test tube rack
- Mortar and pestle
- Gloves
- Test tube
- 10-mL graduated cylinder
- Funnel
- Safety glasses

In the hood (get only as needed):

- 5-mL of methanol
- drops of H$_2$SO$_4$
- Hot water bath

1. Use a mortar and pestle to grind two aspirin tablets into a fine powder.
2. Observe and list three physical properties for your starting material.
3. Add 5mL of methanol to your mortar and mix gently using the pestle. This will dissolve the aspirin but not the other materials in the tablet.
4. Fold your filter paper as demonstrated by the instructor and put it in your funnel. Place the funnel into the top of the large test tube. Slowly pour the liquid into the filter and wait to add the solids until most of the liquid has gone through.
5. Add three drops of sulfuric acid to your test tube.
6. Place the test tube in the hot water bath in the hood and let it heat at 70°C for 30 minutes.
7. After 30 minutes, remove your sample from the hot water bath. Observe and list three physical properties of your product. Save your product for the rest of the experiment.

Please watch the Introduction to Spectroscopy Video before moving on.

The link to the video is:
http://prezi.com/kyxuohg8233v/?utm_campaign=share&utm_medium=copy
**Lab Procedure Part #2: Introducing the Raman Spectrometer**

The Raman spectrometer we are working with today uses a 785 nm wavelength laser. (Where does that fall in the electromagnetic spectrum?) **DO NOT REMOVE THE PROBE AND CABLES FROM THE SAMPLE HOLDER!** Because this laser is powerful enough to damage your eyes and you can’t necessarily see the laser light coming out of the probe, you MUST wear your laser safety goggles at all times while operating the laser. The laser is safe to use as long as you follow these instructions.

1. Make sure the shutter on the probe is closed (no red appears on the switch) and that the laser key is turned to the “On” position. While holding the power button down, left-click on the dark light bulb. Let go of the power button.

2. Place the sample labeled “Maltol” into the holder and open the shutter on the probe so that you see the red marking. **DO NOT REMOVE THE PROBE FROM THE SAMPLE HOLDER!** Hold the laser power button until you have seen the spectrum move a little bit. This may take about 30 seconds. You should see a spectrum that looks something like this:

   ![Maltol Spectrum](image)

3. While continuing to hold the laser power button down, left-click the picture of a camera. This will freeze your spectrum so you can look at it without pressing the power button. Let go of the power button.

4. Save your spectrum by clicking the picture of the disk. Use the name of the sample and your group name/number for the file name so we can retrieve it later.

5. Left click the picture of the camera to release the spectrum you saved.
6. Repeat steps 2 – 5 for your next sample until you have run and saved all of the samples below.
   a. aspirin powder
   b. methanol
   c. aspirin dissolved in methanol
   d. oil of wintergreen liquid (pure)
   e. Your product from Part #1

7. Close the shutter on the laser probe, turn the laser key to the off position, and remove the final sample.

**Lab Procedure Part #3: Analyzing Oil of Wintergreen**

1. Spectra for the following samples were collected for you. Use the data provided for the rest of the analysis.
   a. Wintergreen (5%)
   b. Wintergreen (20%)
   c. Wintergreen (50%)
   d. Wintergreen (75%)
   e. Wintergreen (100%)

2. Look at the large peak near 810 cm\(^{-1}\) in your wintergreen samples. Notice how it becomes more intense as the wintergreen gets more concentrated? We can graph those changes in intensity versus concentration and make something called a standard curve. We can then use this standard curve to determine more closely how much wintergreen is in our product.

3. Using Excel, plot the concentration on the x-axis and the intensity of the 810 cm\(^{-1}\) peak on the y-axis. You should see an increasing slope. Plot a line of best fit and display the equation on the chart.

4. Next, find your sample’s intensity at that same peak and then use your equation to determine the concentration of wintergreen in your sample.
SPECTROSCOPY POST-LAB QUESTIONNAIRE

Please answer the following questions as completely as possible.

1. What is spectroscopy?

2. How does spectroscopy work?

3. What did you know about spectroscopy prior to completing this lab?

4. Which aspects of this lab did you enjoy the most? Explain.

5. Which aspects of this lab did you enjoy the least? Explain.

6. Did this lab contain a “wow” factor? If so, what was it?

7. What would you change about this lab in future?

8. Is there anything else you would like to mention?
VITA

Emily Harbert was born in a small town in Illinois to Ray and Ann Harbert. She attended college at Southwest Missouri State University in Springfield, Missouri, where she earned her B.S. in Geology in 2001. Emily returned to school in 2005 at the University of Missouri – Columbia, where she then earned an M.S. in Analytical Chemistry in 2008, followed by a M.Ed. in 2009. After teaching at a local high school for a few years, she returned to the University of Missouri – Columbia to pursue a Ph.D. in Chemistry Education, which she received in 2014. Emily has accepted a position at Clayton State University in Morrow, Georgia, as an Assistant Professor of Science Education.