THE EFFECTIVENESS OF LABORATORY INSTRUCTION IN A HIGH SCHOOL CHEMISTRY CLASS

by

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Caleb Dennis Dorsey

July 2013
# TABLE OF CONTENTS

INTRODUCTION AND BACKGROUND .................................................................1

CONCEPTUAL FRAMEWORK ...........................................................................3

METHODOLOGY ..............................................................................................10

DATA AND ANALYSIS .....................................................................................16

INTERPRETATION AND CONCLUSION ..........................................................28

VALUE .............................................................................................................31

REFERENCES CITED .......................................................................................34

APPENDICES ...................................................................................................42

APPENDIX A: Lab 1 .......................................................................................43

APPENDIX B: Lab 2 .......................................................................................46

APPENDIX C: Test 1 ......................................................................................54

APPENDIX D: Test 2 ......................................................................................58

APPENDIX E: Attitude Survey .......................................................................62

APPENDIX F: Interview Questions ...............................................................72

APPENDIX G: IRB Exemption Letter ..............................................................75

APPENDIX H: Sample Minute Paper Responses .........................................77

APPENDIX I: Survey Data .............................................................................79

APPENDIX J: Sample Interview Responses ................................................84

APPENDIX K: Administrator Exemption Regarding Informed Consent ........86

APPENDIX L: Administrative Approval .......................................................88
LIST OF TABLES

1: Data Triangulation Matrix ................................................................. 16

2: Normalized Gain, Lab-related Questions/Non-Lab-related Questions .... 21

3: g(lecture/lab) Lab Learners/Lecture Learners ................................... 24
LIST OF FIGURES

1: Treatment Phases .................................................................................................................. 13
2: Mean Test Scores ($N=19$) .................................................................................................. 18
3: Average Normalized Gain ($N=19$) .................................................................................... 19
4: Test 1, % of population, $g$(lab/lecture) ($N=19$) ............................................................ 20
5: Test 2, % of population, $g$(lab/lecture) ($N=19$) ............................................................ 20
6: Test 1 Post-lecture/Post-lab Score Difference vs. Lab Grade ........................................... 22
7: Test 2 Post-lecture/Post-lab Score Difference vs. Lab Grade ........................................... 22
Laboratory instruction has long been a staple of science education. This study investigated how laboratory instruction supported and enhanced the understanding of material taught in lecture and how it impacts student attitudes and teacher attitudes. Results suggested that the laboratory instruction showed no significant improvement of the students’ understanding of material taught in lecture, but many students found this style of instruction enjoyable, as did the teacher.
INTRODUCTION AND BACKGROUND

Background

When I first started teaching, I did not do many labs. Gradually, I began to increase the lab content of my courses. My goal became to make my program at least 20% lab-based. However, my students seemed to be learning the same amount of content that they learned when I didn't do many labs. This caused me to wonder if my students were learning anything from the labs, or if they were just learning most of the content from lecture.

For my Action Research project, I wanted to investigate the benefits of laboratory instruction, and how best practices in laboratory instruction can be used in conjunction with the lecture. Laboratory instruction has long been considered a staple of the high school science curriculum. The iconic image of students mixing chemicals in test tubes or dissecting frogs persists even when much of the educational world has changed dramatically. Lecture involves an authoritative expert explaining complicated concepts and disseminating uncommon information to a submissive audience of students. The two methods are often compared and pitted against each other. Of the two methods of instruction, laboratory instruction seems to have the greatest cost in time and money. Are its benefits worth its cost and can the two methods complement each other in some sort of happy medium? Ultimately, I wanted to know if my students were learning from my labs or from lectures.

Whenever I do a lab, I always wonder if my students actually learned something, or did they learn everything in lecture? Are my labs simply “playing” in the laboratory?
I hoped the results of my research would validate the cost of laboratory instruction and develop a sense of what makes a lab program effective. One goal of this research project was to learn how to prepare a lab program that truly develops conceptual understanding. Also, since lab instruction is costly, knowing what elements of a lab program don’t result in learning will help me budget time and expense more effectively.

In addition, I hoped the results of my research might help convince others in the district that investment in lab instruction is worth it, specifically in regards to my program. My district is not financially flush, so reassurance that the money spent on lab supplies and equipment is well spent would be welcome. I also hoped it might help in negotiating an expansion of the lab science budget allotment.

Finally, I hoped my study might lead to an informed discussion with the other teachers in my district about the benefits of laboratory instruction. There are two other science teachers in my district: one middle-school teacher who runs a primarily lab-based program and another high school teacher that who conducts a mostly lecture-based program.

Support for this project came from many sources. The principal of my school, Marla Stock, graciously allowed me to conduct this project in my chemistry class and also read my paper and gave advice stemming from what she learned from her master’s program. A math teacher on staff, Kim McKinney, gave me feedback on my project at various times in the process and helped me solidify my research questions. My father-in-law, John Mitchell, a retired teacher and current school accreditation chairperson, and my mother-in-law, Beverly Mitchell, a retired school teacher both reviewed my paper. My science reader, Dr. Chris Bahn, was available for any science related question, proffered
advice on types of data to gather, and reviewed my paper. Of course, my project chair, Walt Woolbaugh, and the ED 509 course assistants, Megan Hopkins and Laurie Rugemer, gave terrific guidance throughout the process and were a continuous source of feedback and advice. Finally, my wife, Donna, helped with the writing, grammar, and formatting.

Focus Question

To satisfy my curiosity about the learning taking place in my lab program, I developed the following primary focus question: *How does laboratory instruction support and enhance the understanding of the state-standards taught in lecture?* I was also interested in how students’ attitudes about lecture instruction compare with their attitudes about laboratory instruction? Finally, I wanted to know what impact laboratory instruction has on a teacher’s preparation time and attitude? I hoped these questions would provide me with enough insight to improve my science program.

CONCEPTUAL FRAMEWORK

A good starting point for this project is a review of the history of laboratory instruction. Since my project was conducted in a chemistry course, this history has an emphasis on chemistry laboratory instruction. Originally, pre-1880 science was taught for three reasons: 1) Descriptive, 2) Utilitarian, and 3) Religious. Science is still taught with descriptive and utilitarian aims, but using science to learn about God, the religious purpose of science instruction, is not as common now. Between 1880 and 1910, science instruction shifted to the training of the mind—drill on factual information and memory training (Blosser, 1980). Laboratory methods weren’t necessary in a high school
chemistry course if the aim was the training of the mind. Eventually the high school courses were influenced by college faculty to implement some laboratory methods. At the high school level, chemistry was the first course to make extensive use of a laboratory (Fay, 1931, as cited in Blosser, 1980).

Chemistry laboratory instruction was first offered in Europe to students of J. N. von Fuchs in 1802, Friedrich Stromyer in 1806, Döbereiner after 1811, N. W. Fischer after 1820, and Liebig in 1824 (Elliot, Stewart, & Lagowski, 2008). Liebig’s laboratory teaching methods seem to be the most notable because, according to Elliot, Stewart, & Lagowski (2008), they appear to be the precursors to the modern chemistry research program. His programs seemed to be designed to train students to conduct experiments and do chemical analysis. Basically, the students were the equivalent of modern day chemistry graduate students (Elliot, Stewart, & Lagowski, 2008). The first laboratory chemistry course in America was likely started by Benjamin Silliman, the younger, in 1842 at Yale University. This course taught chemical analysis (Elliot, Stewart, & Lagowski, 2008).

Prior to 1890, only 3.8% of high-school-aged pupils went to a secondary school, and the majority of those secondary science students went on to college (Hurd, 1961, as cited in Blosser, 1980). In 1886, Harvard changed its admission standards and created a physics requirement for incoming students requiring them to have taken a physics lab course that involved at least 40 experiments (Moyer, 1976, as cited in Blosser, 1980). Charles W. Eliot, president of Harvard in 1869 and professor of chemistry at the Massachusetts Institute of Technology (MIT) also put in place chemistry laboratory entrance requirements. As a result, high schools started developing laboratory courses
(Elliot, Stewart, & Lagowski, 2008). The National Education Association (NEA), in an effort to establish uniformity in science curricula and college admission standards, recommended that high school science courses contain four hours of lab work each week (Hurd, 1961, as cited in Blosser, 1980).

From 1910 – 1938 there seemed to have been a reaction against making college preparation the primary purpose of secondary schools. Schools began developing science courses for non-college-bound students. This was when the General Science course was born. The junior high school came to be in the 1900-1910 decade, and general science was first introduced to students in junior high. General science courses put more emphasis on demonstration activities instead of laboratory work (Hurd, 1961, as cited in Blosser, 1980). Laboratory work, however, didn’t disappear, but was still present in science courses. An NEA commission recommended that the aim of laboratory work be to “develop a consistent chain of significant ideas related to class work, with the laboratory serving to provide concrete experiences; laboratory work should precede textbook assignments, under most circumstances; laboratory work should be an end in itself and therefore, detailed microscope work, elaborate drawings, and excessive notebook making were not encouraged” (Hurd, 1961, as cited in Blosser, 1980, p. 13).

To fast forward to modern times, we go through the war era, 1938 - 1950, in which the primary purpose of lab instruction was to secure evidence for answers to problems (Henry, 1947, as cited in Blosser, 1980). The importance of laboratory work in this era was considered obvious and preferential to passive learning (Hurd, 1961, as cited in Blosser, 1980). Then we go through the atomic age, 1950 – 1970 in which the purpose of science instruction was society’s need for a scientifically literate public (Blosser,
1980). By this period of time the majority of American youth were in school and many of them were interested in higher education. The National Science Foundation was established in 1950. The purchasing of lab equipment became easier because of The National Defense Education Act of 1958 (Hurd, 1961, as cited in Blosser, 1980).

With regards to chemistry specifically, the facts of chemistry eventually became numerous enough to be organized into larger concepts. These concepts of chemistry could then be efficiently taught using a lecture model. The laboratory model could then be used to train students on how to use the knowledge they gained from lecture. Chemistry lectures have become somewhat standardized in the way concepts and principles are organized. The use of laboratory instruction now varies with the institution; some chemists even think laboratory instruction has become irrelevant (Elliot, Stewart, & Lagowski, 2008).

The laboratory experience is still viewed by many as an essential part of science (Elliot, Stewart, & Lagowski, 2008). The position of the National Science Teachers Association (NSTA) on the integral role of laboratory investigations is that all high school students should be involved with lab instruction every week. Students need to be involved with labs to learn how to use equipment and develop an understanding of measurement error, and to gain skills to aggregate, to interpret, and to present data. NSTA believes all lab instruction should have the following components: 1) Have a clearly stated purpose, 2) Focus on science as a process, 3) Incorporate student reflection and discussion, and 4) Enable students to develop safe and conscientious lab habits and procedures (National Science Teachers Association, 2007).
Does the type of instruction make a difference? Dr. Hake from the University of Indiana compared physics courses that used what he called “Interactive Engagement” (IE) with what he called “traditional” courses. He defined IE as those methods that are “designed at least in part to promote conceptual understanding through interactive engagement of students in head-on (always) and hands-on (usually) activities which yield feedback through discussion with peers and/or instructor” (Hake, 1998, p. 65). Traditional courses were defined as “those reported by instructors to make little or no use of IE methods, relying primarily on passive-student lectures, recipe labs, and algorithmic-problem exams” (Hake, 1998, p. 65). In his study, he found IE methods were more effective at teaching student mechanics than traditional methods (Hake, 1998). A paper from Montana State University titled, “Do They Stay Fixed?” compared different types of instruction. It compared courses that used traditional labs with courses that used IE methods in the form of inquiry-based Tutorials in Introductory Physics developed by the University of Washington. Just like the Hake study, the IE methods showed gains in conceptual understanding. Many of the students in the study were retested three years later and showed that their conceptual understanding persisted even after some years had passed (Francis, Adams, & Noonan, 1998). Some types of instruction might facilitate more learning than others, and students may remember the information longer.

The book, How People Learn: Brain, Mind, Experience, and School, by the National Research Council describes many facets of learning such as the difference between a novice and an expert, metacognition, the impact of pre-existing knowledge, and the transferability of knowledge. One research finding that may pertain to laboratory instruction is the idea that students tend to cling to their preconceptions unless those
preconceptions are engaged in some way. They may just learn the new material for a test, and then revert to their preconceptions (National Research Council, 2003). Labs might provide a great venue for challenging preconceptions.

I want my students to learn more than just enough to pass the test. I want to give them knowledge and skills that they will keep for the rest of their life, and I want them to be able to apply the knowledge or skill when appropriate. Lab instruction might increase the transferability of what I teach to the students. According the National Research Council, transferability is a characteristic of experts. To develop expertise, concepts must be covered in-depth (National Research Council, 2003). Lab instruction might provide the opportunity to go into more depth than a superficial lecture.

The design of my project was largely inspired by an article by Michael R. Abraham: “What Can Be Learned from Laboratory Activities? Revisiting 32 years of Research” published in the Journal of Chemical Education in 2011. In this article, Abraham compares three different types of instruction: traditional, inquiry-based, and discovery. He organizes each type of instruction into three different phases and noted in which phase the lab occurs. Traditional instruction is divided into inform/verify/practice. The lab instruction occurs in the verify phase. Inquiry-based has an explore/invent/apply cycle with the lab occurring in the explore phase. Discovery was described as explore/apply/invent with the lab in the explore phase. To compare the three instruction types Abraham gave the students a pretest, a test at the end of each phase, and a delayed test to measure retention, for a total of five tests. He displayed the test results with a line graph with the pretest being the first data point and the retention test the final point. Traditional instruction showed significant achievement gains after the first phase, but no
gains improvement after that. Inquiry-based instruction showed gains from all the phases and significant retention. Students actually did more poorly after the second application phase in discovery learning than they did on the pretest. The net gain achievement gains for discovery instruction seem minimal (Abraham, 2011). I liked the way Abraham measured achievement by breaking the instruction cycle into phases and taking a measurement at the end of each phase. My project was an adaptation of this design.

Abraham also used perception data. He wrote twenty-five descriptions of labs such as “Students follow the step-by-step instructions” and “Student identifies problems to be investigated” (Abraham, 2011). The students were then asked to sort descriptive statements according to what they felt was descriptive of their lab experiences. The statements described characteristics of the different lab types, traditional or inquiry-based. Abraham then correlated the students’ perceptions with the actual lab types to see if students were able to identify the differences in the lab types. He also gathered perception data from instructors. He had over 200 chemistry instructors and asked them to rank in order of importance the following goals for lab instruction: concepts, scientific process, lab skills, learning facts, and positive attitudes. Concepts were by far the most important, with scientific process ranking as second most important.

Abraham also measured attitude by having the students write what they liked and did not like about each lesson. Judgments were then made about whether the comments were positive, negative, or neutral. The ratio of positive to negative for traditional instruction was about 2:1 and for inquiry-based, it was 20:1 (Abraham, 2011).

Since laboratory instruction might have a significant impact on student’s attitude, and attitude is a tricky thing to quantify, I decided to measure how my laboratory
activities impact the attitudes of my students. A researcher named M. Freedman wrote an article titled, “Relationship among Laboratory Instruction, Attitude toward Science, and Achievement in Science Knowledge.” Within this article, he began with a technical definition of attitude and then used a modified version of a Q sort attitude questionnaire as a measurement instrument. The Q sort consisted of a series of positive and negative adjectives such as “capable,” and “stupid.” The students were to consider their ability to achieve in science and rank the adjective according to the degree to which match they felt about the ability, -5 (disagree the most), +5 (agree the most) (Freedman, 1996). While I didn’t use Freedman’s methodology, it did encourage me to analyze attitude. I hoped my project would help me understand what my students were taking from my labs. After researching laboratory instruction in general, it would be nice to know specifically how well my lab program was working.

**METHODOLOGY**

My treatment was not much different than my typical instruction. It was conducted in my chemistry classes. My chemistry classes consisted of two periods of college preparatory chemistry, which in California means it is a lab science class that should consist of at least 20% hands-on activities. At my high school, chemistry has an Algebra 2 co/pre-requisite and is usually taken by eleventh graders. The students have already taken biology and some of them have taken earth science. This particular class had 24 students: 5 sophomores, 14 juniors, and 5 seniors; 10 males and 14 females; 20 Caucasians students and 4 Latino students. None of the students had Individualized Education Plans or 504 plans. Twenty-nine percent of the students accessed the district’s
free and reduced lunch program. This year’s chemistry students have been less motivated than classes I have taught in the past. The students often do not complete much of the homework or study for tests.

Loyalton High School is a small school with an enrollment of around 120 and average science class sizes of about 13. Loyalton was a logging town, but the mill closed, and now there isn’t much local employment. It is an economically depressed community. Many parents have to commute to neighboring cities to find work.

When I teach a science unit, I typically lecture for a few days first, and prefer to include a lab in the unit before I test the students. My lectures consist of PowerPoint presentations that are sometimes accompanied with demonstrations, videos, or computer animations. Students are asked to read the textbook and take notes on the reading before I lecture, so that when they come to class, they have read about the topics first. I give quizzes over the textbook vocabulary, and I assign section review questions to get them to think about the topics during the lecture period.

My labs are mostly traditional verification labs with a few inquiry-based labs thrown into the mix. Traditional verification labs are those in which students are given pre-developed procedures with explicit data collection methods. Basically, the students follow the lab directions and then draw their conclusions or answer questions. Inquiry labs are those in which the students are given a question to answer or a problem to explore, but have to develop their own procedure and data collection methods as well as draw a conclusion. Sometimes they are guided inquiry labs in which I give students hints, or limit the available materials.
My data collection was conducted over the course of seven weeks. It consisted of two treatments, each an instructional unit. The first unit covered Chapter 10 in the textbook (Philips, Strozak, & Wistrom, 2005) which was about kinetic theory of matter including phase changes. The second treatment covered Chapter 11 which was about the behavior of gases including the gas laws. The gas laws unit required more mathematics, and some students are less comfortable with mathematics.

The treatments began with a lecture phase and ended with a lab phase. I often try to include a lab in a unit and the labs sometimes come at the end of the unit. I have all my students keep lab notebooks. Everything needs to be included in their lab notebooks, including the procedures. I have the students write the purpose/objectives, safety notes, and procedure in their notebooks before the lab. They work out of their notebooks during the lab and record data. After the lab, they do the analysis and answer any questions in their notebooks. The notebook is the only thing from the lab that is graded. I divide the grade into three parts: 1) Format/Pre-lab work, 2) Procedure/Data, 3) Analysis and Conclusion.

The first unit had a traditional lab from Chapter 10 of the textbook (Philips, Strozak, & Wistrom, 2005, pp. 362 - 363) in which students measured the temperature changes of stearic acids as they were heated from a solid to liquid. The students were then asked to graph a heat curve and answer the lab questions from the text (Appendix A).

The other unit had a series of lab station activities developed by Flinn Scientific, Inc. (Flinn Scientific, 2012). One activity demonstrated diffusion using ammonia and a phenolphthalein solution. Another activity had students crush a can dramatically by
reducing the pressure inside the can. One activity was supposed to demonstrate Boyle’s law with a bicycle pump and gauge and pressure bottle with a syringe inside to measure volume. During the lab, I couldn’t attach the gauge to the pump, so I attached it to a syringe and created a Boyle’s Law device as I had done in a different Flinn gas laws lab kit from a previous year (Flinn Scientific, 2009). The last lab activity was about Charles’s Law. It had students immerse a syringe in beakers of water that were different temperatures. Each activity had a separate set of lab questions associated with them (Appendix B). The students performed each activity and answered the questions in lab groups.

Tests preceded and followed each lecture and lab phase. As with all my tests, they each contained some new material and some review. Test 1 had review material over Chapters 8 and 9 which are over periodic properties of the elements and chemical bonding respectively; the new material was over Chapter 10 (Appendix C). Test 2 had review material from Chapters 9 and 10 and new material from Chapter 11(Appendix D). With regards to validity, I used only test items that were prepared professionally by the staff of Glencoe/McGraw-Hill and were included on the Examview Pro Test maker CD-ROM that came with the textbook (Philips, Strozak, & Wistrom, 2005). The following figure (Figure 1) shows the general treatment phases.

![Figure 1. Treatment phases.](image-url)
At the start of each instruction unit, the students were given the pre-test, which was used as a baseline. I then conducted lectures. At the end of each lecture, I had the students write what I called a “minute paper” in which students were asked to answer each of two questions: “How did you feel about today’s lecture?” and “What did you learn from today’s lecture?” After the lecture phase, the students were given a test with the same questions from the pretest. The students then did a lab that pertained to the topics covered in lecture. At the end of each lab, the students were asked to write a minute paper to answer the questions: “How did you feel about today’s lab?” and “What did you learn from today’s lab?” After the lab phase, the students were again given a test with same questions from the pretest and post-lecture test. The test contained some questions that were only related to material covered in lecture and other questions that related to both lab and lecture material.

At the end of the data collection period, I asked all the students to volunteer to take a survey which was intended to probe their attitudes (Appendix E). I also interviewed a stratified random sampling of students to expand on the information gathered from the surveys (Appendix F). These instruments were developed by me. They were reviewed by my project chairperson and multiple project committee members, and were piloted in my biology and physics classes, and all of this helped to insure validity and reliability.

I recorded data on student behavior using a field note journal. During or immediately after the lectures and labs, I recorded observations about student engagement, such as if students were doodling, taking notes, asking questions, or talking to a friend about something unrelated to the topic we’re studying. I also recorded notable
student comments. “That was cool,” and “It is so hard paying attention so long,” are examples of what I considered notable comments. These notes were typed into a field note document for analysis.

In addition to typing up the field notes, I also wrote in my teaching journal about the day’s chemistry activities from the teacher’s perspective. I recorded observations about my preparation for the lectures and /or lab and how successful they seemed to be as well as any notable impacts they had on my attitude. I recorded such factors such as my frustrations with certain labs or lectures as well as the times I had fun with the students or activities I particularly enjoyed.

The grade book also provided me a record of student activities. From the grade book I kept track of how well the students did in their labs and how well the students were doing overall in the class with the assumption that high grades correlated to more learning. For the sake of validity, triangulation was a central feature of my project design. I collected data about each focus question with various instruments--using a total of six different instruments for my main focus question. The table below (Table 1) displays the alignment of these instruments with my research questions.
Table 1:  
*Data Triangulation Matrix*

<table>
<thead>
<tr>
<th></th>
<th>Test Scores</th>
<th>Minute Paper</th>
<th>Interviews</th>
<th>Surveys</th>
<th>Grade Book</th>
<th>Field Notes</th>
<th>Teacher Journal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main Focus: The effectiveness of laboratory Instruction compared to lecture</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Sub-question 1: What impact does laboratory instruction have on student attitude?</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sub-question 2: What impact does laboratory instructions have on the teacher?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

The purpose of this study is to learn about my lab program; therefore, I endeavored to keep my treatment as close to my normal instruction as possible. The only alterations were the daily minute papers and the two extra tests each given in each unit. However the test styles and content were similar to my normal tests. The research methodology for this project received an exemption by Montana State University's Institutional Review Board and compliance for working with human subjects was maintained (Appendix G).

**DATA AND ANALYSIS**

Each treatment ended up with a population of only 19 (N=19) because five students from each treatment, not necessarily the same students, didn’t complete the treatment. They either didn’t do the labs, or they took their tests at the wrong time, i.e., they took the post-lecture test after they had done the lab. Because the data from these five students didn’t fit within the parameters of the treatment, I removed their scores from
the test analysis of whichever treatment they failed to complete. I didn’t remove their
data from the analysis of the other instruments, surveys, interviews, minute papers, etc.,
because these students were regular participants in my class and had at least done some
of the treatment.

Some of the students missed a lot of school (lecture) during the project. I only
removed their data if they missed a lab or a test because it would have impacted my
comparison. Some of our students have attendance issues, and since my intent was to
study my actual program, not one with artificially perfect attendance, I included the data
of the students with poor attendance in the analysis.

**Learning**

I hoped that I would find clear evidence of significant student learning after the
labs, but unfortunately this was not the case. In fact, for some students, the opposite was
true. Figure 2 shows the average scores for each test. There was a reasonable increase
in the mean test score between the pre-test and post lecture test, but the post lab test
didn’t show much gain; the difference between the post-lecture test and the post-lab test
was a -1 change in average score for Test 1 and only a 7 point increase in average scores
for Test 2. The slope of the lines in figure 2 flattens out after the post-lecture test. This
suggests that most of the learning took place during the lecture.
Figure 2. Mean test scores (N=19).

Test 1 reviewed material over Chapters 8 and 9 which are over periodic properties of the elements and chemical bonding respectively; the new material was over Chapter 10. Since Lab 1 was from the textbook, and the test items for all the tests were taken directly from the test generating software that was included with the textbook materials, it was fairly well aligned with the Chapter 10 material in the test. Test 2 had review material from Chapters 9 and 10 and new material from Chapter 11. Lab 2 was a lab kit about the gas laws; it covered much of the same material that was covered in Chapter 11. Many of the questions on Test 2 pertained to the gas laws, and were thus aligned to the material covered in the Lab 2. Both tests contained items about concepts covered in both lab and lecture and concepts that were cover just in lecture. Neither test contained concepts that were covered just in lab. The lab related material of the tests pertained to concepts covered in lab, but not to specifics of the lab skills or activities.
Another more informative method I used to analyze the test data was by calculating a normalized mean. I discovered this method in Richard Hake’s article about interactive engagement physics courses (Hake, 1998) and modified it to fit this project. The normalized gain, represented by the letter $g$, is the quotient of absolute gain in test score divided by the potential gain in test score:

$$g = \frac{(\text{initial test score}) - (\text{final score})}{(100, \text{maximum score}) - (\text{initial score})}$$

I calculated the average normalized gain for both tests scores (Figure 3).

<table>
<thead>
<tr>
<th></th>
<th>Test 1</th>
<th>Test 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>$g$ (Post-lecture/Pre)</td>
<td>0.38</td>
<td>0.29</td>
</tr>
<tr>
<td>$g$ (Post-lab/Post-lecture)</td>
<td>-0.02</td>
<td>0.13</td>
</tr>
</tbody>
</table>

*Figure 3. Average normalized gain ($N=19$).*

For the sake of this study, I divided my gains into categories similar to how Hake did in his study (Hake, 1998); I divided them into four categories: High ($g \geq 0.70$), Medium ($0.30 \leq g < 0.70$), Low ($0.00 < g < 0.30$), and added the category of Negative/None ($g \leq 0.0$). The average normalized gain from pre-test to post-lecture test was medium for Test 1 and low for Test 2 (Figure 3). Test 1 scores showed essentially no gain from post-lecture to post-lab, $g = -0.02$; and Test 2 showed a slight gain, 0.13.
This could indicate that they did not learn the material from the lab, but that they learned it from the lecture instead.

I looked at normalized gains on an individual basis. There was reasonable gain from the pre-test to the post-lecture test, but as shown in Figures 4 and 5, there was little gain from the post lecture test to the post lab test; only 5.3% experienced medium gain, and 52.6% experienced low gain.

**Figure 4.** Test 1, % of population, g(lab/lecture) (N=19).

**Figure 5:** Test 2, % of population, g(lab/lecture) (N=19).

In fact, there was negative gain for a large percentage of the population (42.1%). They did worse after lab. This would make sense if most of their learning was the result
of lecture because the post-lab test would have been given when more time had lapsed since the last lecture.

I also looked at the specific test questions and divided them up into questions that were related to the lab and those that were not. I calculated the normalized gain between the post-lecture and post-lab test for each group of questions. The gain was lower for lab related questions than non-lab related questions (Table 2).

Table 2: Normalized Gain, Lab-related Questions/Non-lab-related Questions.

<table>
<thead>
<tr>
<th></th>
<th>Test 1</th>
<th>Test 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lab-related questions</td>
<td>g= - 0.11</td>
<td>g=0.09</td>
</tr>
<tr>
<td>Non-lab-related questions</td>
<td>g=0.03</td>
<td>g=0.11</td>
</tr>
</tbody>
</table>

If the students did worse on the non-lab-related questions, but better on the lab related questions, then it might have been possible for a test to show little normalized gain between the post-lecture test and the post-lab test, even though they learned a lot from the lab. According to Table 2, this does not seem to be the case.

I was curious if there was a correlation between how well students did on the labs and how well they did on the post-lab tests. From looking at a scatter plot of lab grade to post-lab test scores for each lab and test (Figures 6 and 7), it would appear that there is no relationship between the lab grades and grades on the post-lab test. This might be evidence that there is a disconnection between lab and lecture. Perhaps the content/skills I am assessing from the lab vary greatly from what I am assessing in the tests.
I also noticed differences between the type of learning reported in the minute papers after the lecture and the type of learning reported after the labs (Appendix H). The responses from lecture tended to be related to the concepts and the main chemistry topics I was trying to teach the students. The following are a couple of responses from lecture: “I now understand the difference between polar, covalent, and fully covalent bonds and how to make a dot diagram for the bonds,” and “I learned today about the
kinetic theory of gas particles. I learned about how temperature is the average amount of energy particles have.”

The responses from the labs followed a different pattern. Much of the learning reported was specific to the lab and not tied to any big chemistry concept or idea. For example, one student wrote, “I learned to make sure everything is done correctly, including having the thermometer at Celsius not Fahrenheit.” Other students wrote, “I learned that the pressure outside of a can can crush it,” and “The mixture of ammonium, phenolphthalein and distilled water turns a pink color. I also learned that pressure is dependent on temperature. I also learned that latex gloves make your hands smell like balloons.” There were some responses that referred to general concepts; but for the most part, the minute paper data suggests that the material I tested them on was taught in lecture and not lab.

At first glance, the students’ perceptions of their own learning made it appear that they thought they learned from the labs (Appendix I). More students agreed that they learned more in lab than lecture (42.9%) than disagreed (33.4%). Most of the students thought the labs helped them understand what was taught in lecture (57.2 %). Some students used the terms “hands-on” to describe how they learned. However, one of the students who wrote that she was a “hands-on learner” and agreed that she learned more from lab than lecture, then went on to write that she was “just told to do things in labs. We don’t really ‘learn’ anything.” Later in the survey she also said she agreed that she learned a lot from lecture and disagreed that she learned a lot from lab.

When asked separately if they learned a lot from lecture, 71% agreed; but when asked separately if they learned a lot from labs, 52% agreed. The student who did the
best in both treatments and also had a high lab grade on both labs disagreed that he learned more from labs than lecture. He complained about the pace of the labs, and said they felt rushed, but he did think they helped him understand what was covered in lecture. Another student wrote that when she did a lab, she was just following instructions, but in lecture she got a full understanding.

I was curious as to whether the students who reported being “hands-on” learners showed a greater gain from the lab. I calculated the average normalized gain from the post-lecture test to the post-lab test for those who agreed that they learned more from lab and compared it to the average normalized gain of those who disagreed or strongly disagreed that they learned more from lab. Not every student who took the survey was in the treatment. As with the bulk of the data, there was not much gain from the post-lecture test to the post-lab test and the difference between the two groups was negligible as can be seen in Table 3 below.

Table 3:
$g(lecture/lab)$ Lab Learners/Lecture learners

<table>
<thead>
<tr>
<th></th>
<th>Test 1</th>
<th>Test 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agreed they learned more from lab</td>
<td>g=0.05</td>
<td>g=0.07</td>
</tr>
<tr>
<td>Disagreed or strongly disagreed that they learned more from lab</td>
<td>g=0.08</td>
<td>g=0.10</td>
</tr>
</tbody>
</table>

According to the survey, a majority of the students felt that labs helped them understand what was covered in lecture (57.2%) (Appendix I). Most of the students thought the melting point lab helped them understand the material from Chapter 10 (57.1%) and the gas laws lab helped with Chapter 11 (66.6%). Some students wrote the
labs helped them visualize what was covered in lecture or gave them a chance to apply what they learned. Of the six students I interviewed, only two of them said they thought labs helped them understand what was covered in lecture. One of them said they helped her visualize the material and the other one had trouble explaining how it helped. Of the four other students I interviewed, three said they didn’t think labs were helpful; one couldn’t clearly answer the question. One student said, “…the lab is just completely different from the lecture, or like I don’t understand how the concepts applied to the lecture, I guess.” Perhaps there is too much of a disconnection between lab and lecture.

I looked at the outliers, but I didn’t notice any patterns or themes of significance. I defined an outlier as anything greater than the sum of the standard deviation and the mean or less than their difference. Test 1 had 5 outliers (26% of the population) (N=19) and Test 2 had 7 outliers (37 % of the populations) (N=19). I also didn’t notice any anomalies in student performance. The students who usually do well, did better on the test than the students who usually do not do well.

The issue might have been just with these particular labs. It was the first time I had conducted these labs, so they were new for me as well as for the students. Some students didn’t finish the post-lab questions. One student said he didn’t do the post-lab questions because he didn’t know how to do them. Some lab groups may have had equipment issues during the melting point lab. One lab group ended up boiling their water, but their thermometer registered below 100° C. One group used less stearic acid in the melting point lab than others. I think this caused it to melt too quickly and made data collection more difficult. I also adjusted the lab the second day and told the students to record temperature every 10 seconds instead of every 30 seconds.
The second lab had issues with one of the four activities. The bicycle pump activity in the gas laws lab could not be done correctly because my bicycle pump couldn’t be connected to a gauge. So mid-lab, I ended up connecting a syringe to the gauge instead. But this activity became more of a demo than a quantitative lab. I gave all students credit for this activity, but it did not prevent the average grade of the lab from being 50%. If I were to do these labs again, they would go more smoothly.

**Student Attitudes**

Even if students might not have learned much from the labs, it is clear that they enjoyed them. The vast majority of the students surveyed, 81%, (N=21) agreed that labs are fun, with only one student disagreeing; and 52.3% agreed that they would like to do more labs, with no one disagreeing. (Appendix I). All the students I interviewed said they enjoyed the labs. When asked what they enjoyed about labs, they either said something along the lines of enjoying doing chemistry as opposed to just hearing about it, or they said that it was a nice break from regular class. In their minute papers, I had the students tell me how they felt about the labs at the end of each lab period. Five students described the lab as fun, three students said they were “enjoyable”; three students called the labs “cool.” This was over four lab days, and one lab make-up day. Many of the negative comments related to equipment difficulties.

Lectures, on the other hand, were only described as “fun” once and “cool” once over a total of seventeen lecture days. The lecture minute paper responses also had students reporting to be “bored.” One student wrote that the lecture “wasn’t entirely fun.” The positive comments about lecture related to how much students felt they were learning. For example, a student wrote, “Today’s lecture was helpful in my
understanding of matter.” Another student wrote, “I felt good about this lecture because I learned some new things.”

I could not tell from the data if there was difference in student engagement between the labs and lecture. On one hand, I recorded in my field notes on one lab day that all the students seemed “engaged – watching their lab apparatus, writing in their lab notebooks”; and on another day I recorded that “All students engaged – writing in lab notebooks, recording data.” On the other hand, I also recorded that one student just seemed to be watching while her partner did all the work. Another student said, “I enjoyed sitting there doing nothing for half an hour.” Over 4 days of lab field notes, I recorded 6 instances of poor engagement, an average of 1.5 instances per day. Over the course of 26 lecture/test days, I recorded 33 instances of poor engagement, an average of 1.26 instances per day. However, as stated previously, the students thought the labs were fun; this could be seen as engagement.

**Teacher Attitude**

The teacher is also a participant in the education process. My experience with labs and lecture had both pros and cons. I recorded in my journal that I had fun during the first lab, the melting point lab. I did not record that for the second lab, the gas laws, but I remember enjoying it. Students recorded in the minute papers that I was grumpy one of the lecture days, and maybe I was. I expressed frustration in my journal that the students did not seem to be paying attention during lecture or doing homework. I did mention in my journal that I enjoyed a particular lecture period. I speculated that it was because everyone seemed to be on task.
Labs require a greater investment in preparation time, per period, than lecture. According to my teacher journal, I spent at least two hours preparing for one 85-minute lab period after being at meetings until 5:30. This amount of time commitment for class preparation would be untenable for every class every day. Ideally, I would like to be able run through each lab once before having the students do it. This would improve effectiveness and safety. I usually just have enough time to gather the materials and do a quick skim of the lab to get the gist of it. However issues sometimes arise, as in Lab 2, when I had to modify the Boyle’s Law apparatus because I didn’t notice that the bicycle pump I brought in didn’t have a pressure gauge.

I also recorded multiple times in my journal about the messiness of my lab. I had trouble finding time to organize it and clean it up. I recorded that this project was having an impact on my time, but this year I am only teaching four different courses. Last year I taught six different courses, one of them being AP Chemistry. Next year I will be teaching six courses again, including AP Chemistry, and one course I have not taught before. So my time commitments this year are probably close to normal. I wanted the project to be as representative of my typical chemistry lab and lecture experience as possible so that I could gather real insight into my program.

INTERPRETATION AND CONCLUSION

The main focus of my paper was to 1) compare the effectiveness of my of laboratory instruction with my lecture, 2) investigate how laboratory instruction affects student attitude and 3) investigate how lab instruction impacts the teacher. With regards to the first question, I did not have any evidence besides student perception data that
indicates my students learned anything from lab. Between the post-lecture test and the
post-lab test there was a -1 change in the average score for Test 1 and only a 7 increase in
the average score for Test 2. There was a negligible normalized gain. The normalized
gain remained negligible even when limiting the analysis to lab-related items and non-
lab-related items. This implies that the laboratory instruction made no difference in the
normalized gain. It is possible that the tests themselves were not giving an accurate
measurement of lab learning. Perhaps there was some misalignment between the lab-
related test items and what was actually covered in lab.

Most students thought that labs helped them understand what was taught in
lecture (57.2 %) and 52% agreed that they learned a lot from labs. However, some
students further elaborated that they didn’t think they really learned anything from labs
and failed to see the connection with lecture. It is possible that the labs are disconnected
with lecture, or at least, they are disconnected from the material being assessed. The type
of material the students reported learning in the labs was very specific to the context of
the lab, but the material I tested them over was more general and related to the state-
standards, not specifics from their lab experiences.

There is the possibility that my labs are more of a form of authentic assessment
than instruction. Perhaps the labs required a certain amount of foundational
understanding of the material that was presented in lecture in order to function, and if the
students were deficient in this knowledge, then the labs provided no benefit. If this is the
case, then the labs aren’t enhancing the understanding of material taught in lecture, they
are instead utilizing that understanding. In the future, the students might need to be
provided with more scaffolding. It might also be wise to implement a pre-lab review
and/or quiz to help certain students understand the requisite material they need to do the lab.

The results might have been impacted by the kinds of labs I chose for the study. They were both traditional-verification labs. My original intention was to include an inquiry lab, but time constraints prevented it. The results may have been different with more of an inquiry-based approach. Also, this study was done with just two labs, and it was the first time I conducted these labs. Perhaps there were issues with the quality of the labs or my administration of the labs.

This study did not assess long term retention or lab skills. Students might be more likely to remember the material that was related to the lab than the material that was just covered in lecture. Also there might be some material, such as hands-on lab skills, that can only be taught in a laboratory setting. The tests didn’t measure the acquisition of these skills.

As to the second research question, how laboratory instruction impacts student attitudes, it is clear students love labs (Appendix I). Lecture can be boring or long, but students find labs “cool” and “fun.” Labs were engaging, but not for all the students. Some students let their lab partners do much of the work. Maybe this is a result of the labs being more a form of assessment, and the students who were not engaged could have been those less prepared.

With regards to the third research question, how laboratory instruction impacts the teacher, it is a mixed bag. The lab period itself is enjoyable for the students and the teacher, but lab preparation is time consuming. It took me two hours to prepare for one lab. Some labs, however, might be quick to plan and prepare. In addition to the lab
preparation, there is also the invested time in maintaining the laboratory. Cleaning up after the labs, stocking and disposing of chemicals all take time. The key is to make certain that the time results in a dividend in student learning. The two labs in this study didn’t provide any evidence of student learning.

In conclusion, this study seems to imply that lab instruction does not necessarily enhance the understanding of material taught in lecture. This does not mean that lab instruction is a waste of time or that lab instruction is a poor teaching device. There could be differences in types of laboratory instruction, such as inquiry versus traditional verification. Also, this study was done with just two labs. There could also be a large difference in the quality of labs. Students love labs and teachers can find them fun and exciting. These are good reasons to continue exploring laboratory instruction and trying to make it effective.

VALUE

In terms of specifics to my program, I still value laboratory instruction, but I will not assume that if it is “hands-on” it must be better. I think I need to refine my lab program and make an effort to “weed out” the ineffective labs. I could do this by keeping a lab log and making notes about specific labs-- problems that arise, procedures I need to tweak, student complaints, etc. It might result in more inquiry labs and fewer traditional labs.

I need to rethink the role labs play in my program. In my program, I sometimes do labs towards the end of the unit. In retrospect, I realize I have been calling them instruction, but they may be more like assessments. If I want a lab to be instructive, then
I should do it earlier, so it can be more of a formative device that I can mold my lecture instruction around. If I include some lecture after the lab, and include material from the lab in the lecture, the labs might not seem so disconnected. There might also be a place for using labs as a form of authentic assessment. At the end of a unit, I could give a written assessment and also have the students do a lab that requires them to use what they learned. I could also use labs as way to introduce students to material before I lecture. They could be a hands-on exploration and discovery of the topics I intend to teach them about in lecture.

Since the students enjoy labs and I enjoy labs, and also because of decades of lab tradition in science education, it is still my personal goal to increase the lab content of my science courses. I personally believe that experiencing something is more informative than hearing about the experience. However, this study has identified some areas to focus on to revise and improve my lab program.

In the future, I plan to be more conscientious about my labs. I will evaluate their effectiveness with pre-lab quizzes and post-lab quizzes and look for evidence of learning from these quizzes. If a lab seems ineffective, I’ll try to improve it or replace it. In this effort to improve my lab program, I will vary the style and types of labs I use. I will try to include more inquiry-based labs. I will also use labs in different roles. Sometimes they might be used as a pre-lecture topic exploration. Other times they could be a mid-lecture illustration. I could also use them as a post-lecture assessment or for concept validation. Eventually, I hope to develop a library of highly effective labs that could be used for various topics and situations. I want my students to not only learn about science,
but to also have the opportunity to do science and to know what science looks like, sounds like, and feels like.
REFERENCES CITED


APPENDICES
APPENDIX A

LAB 1
**Molecules and Energy**

**Time Allotment:** One class period.

**Objectives**
Review objectives with students before they begin the ChemLab.

**Process Skills**
Interpreting data, observing, measuring, formulating models, communicating.

**Safety Precautions**
Be sure students use beaker tongs when handling the beaker of hot water and test-tube holders when handling the test tube of hot stearic acid.

**PREPARATION**

**Alternative Materials**
- If a fume hood is available for student use, other materials such as paradichlorobenzene or acetanilide may be used.
- If you have a temperature probe and apparatus that may be connected to a computer input, you may be able to allow students to record and graph the temperature readings on the computer.

**PROCEDURE**

1. Prepare two tables like those shown. Label one **Heating** and the other **Cooling**.
2. Pour 300 mL of tap water into a 400 mL beaker and place the beaker on a hot plate.
3. Place a thermometer in the beaker of water. Turn on the heat and monitor the water temperature until it reaches 80°C. Maintain the water temperature at 80°C by using the heat control of the hot plate or by adding cold water.
4. Half fill the test tube with stearic acid. Gently push the bulb of the second thermometer down into the substance. After the temperature of the thermometer has adjusted to the stearic acid, record this temperature in the first line of the **Heating Data** table.
5. Attach the clamp to the test tube and immerse the tube in the beaker of hot water as shown. Read and record the temperature and the physical state of the stearic acid every 30 seconds until all of the material has melted and its temperature is about 80°C.
6. Pour 300 mL of cold tap water into the second 400 mL beaker.

**ANALYZE AND CONCLUDE**

1. **Heating Data**

   ![Graph of Heating Data](image)

   - **A** Initial liquid state
   - **B** Solid state
   - **C** Liquid state

2. **Cooling Data**

   ![Graph of Cooling Data](image)

   - **A** Solid state
   - **B** Initial liquid state
   - **C** Liquid state

3. **69-77°C**

4. **Segment A:** The kinetic energy of the molecules increased. **Segment B:** The kinetic energy of the molecules was unchanged. **Segment C:** The kinetic energy of the molecules increased. **Segment D:** The kinetic energy of the molecules decreased. **Segment E:** The kinetic energy of the molecules was unchanged. **Segment F:** The kinetic energy of the molecules decreased.
3. Remove the test tube and contents from the beaker and immerse it in the cold water in the second beaker. Read and record in the Cooling Data table the temperature and physical state or states of the stearic acid every 30 seconds until the material has solidified.

**ANALYZE AND CONCLUDE**

1. **Making Graphs** Graph the heating data by plotting temperature readings on the vertical axis and time on the horizontal axis. Connect the data points with straight lines or smooth curves. Label the appropriate segments of the graph solid, solid and liquid, or liquid. Graph the cooling data in the same way.

2. **Interpreting Data** Divide each graph into three intervals by drawing two vertical lines at the points where the slope of the graph changes. Label the intervals of the first graph A, B, and C and those of the second graph D, E, and F.

3. **Drawing Conclusions** According to your data, what is the approximate melting point of stearic acid?

4. **Relating Concepts** Describe how the kinetic energy of the stearic acid molecules changed during each interval.

**APPLY AND ASSESS**

1. Describe how the molecular motion changed during each segment of the heating and cooling curves.

2. Suppose twice as much stearic acid were used. What would the graph look like? Make a sketch.

**DATA AND OBSERVATIONS**

**Heating Data**

<table>
<thead>
<tr>
<th>Elapsed Time (s)</th>
<th>Temperature (°C)</th>
<th>Physical State</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>60</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Cooling Data**

<table>
<thead>
<tr>
<th>Elapsed Time (s)</th>
<th>Temperature (°C)</th>
<th>Physical State</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>60</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**16.3 Kinetic Energy and Changes of State**

**Performance:** Ask students to sketch a heating curve for carbon dioxide at normal atmospheric pressure from -100°C to 50°C. Tell students that carbon dioxide sublimes at -78.5°C. [1]
APPENDIX B

LAB 2
Properties of Gases and the Gas Laws
Activity Stations Lab

Introduction
The properties of gases and the gas laws are important in many science and engineering applications, including physiology, meteorology, scuba diving, and even hot-air balloonizing. Boyle’s law, for example, is demonstrated with every breath you take. Use this set of four “mini-lab” activities to study the properties of gases and to investigate the relationships among the four measurable gas properties—temperature, pressure, volume, and the number of moles.

Concepts
- Boyle’s law
- Atmospheric pressure
- Kinetic-molecular theory
- Pressure
- Charles’s law
- Diffusion

Background
Pressure is defined as force divided by area. According to the kinetic molecular theory, the particles in a gas are in constant, random motion. When the gas molecules collide with the “walls” of the container, the force of the resulting collisions causes the gas to exert a pressure against the container. The pressure of the gas is related to the total force exerted by the individual collisions divided by the area over which the collisions occur.

Experiment Overview
The purpose of this “activity-stations lab” is to investigate the properties of gases, derive the mathematical relationships among the gas variables, and explain the behavior of gases using the kinetic-molecular theory. Four mini-lab activities are set up around the classroom. Each activity focuses on a different relationship among the gas properties and is a self-contained unit.

A. Diffusion of Gas Molecules
B. Crush the Can
C. Boyle’s Law in a Bottle
D. Effect of Charles’s Law

Pre-Lab Assignment
Read the Background material and Procedure for each activity A-D. Write a brief, 1- to 2-sentence description of each experiment. Examples: In activity A, the ability of gas molecules to diffuse will be studied by observing the reaction of ammonia with an acid-base indicator.

Safety Precautions
Ammonia solution is toxic by ingestion and inhalation and is extremely to body tissues. Phenolphthalein solution contains alcohol and is a flammable liquid. Hot objects and escaping steam can cause severe burns. Handle hot objects with heat-resistant tongs and do not place your hands in the steam. The pressure bottle is safe if used properly. The bottle should not be inflated above 100 psi. At very high pressures, the bottle might explode, but it will not shatter. Do not use a thermometer as a stirring rod. Wear chemical splash goggles whenever working with chemicals, heat or glassware in the laboratory. Wash hands with soap and water before leaving the lab.
Activity A. Diffusion of Gases

The fact that many gases are colorless and odorless and cannot be seen may give us a misleading image of the properties of gas molecules. An accurate "molecular" picture of gases would show small particles very far away from each other, assuming about in great, rapid, and random motion, and colliding frequently with whatever "walls" the gas may be confined to. What evidence do we have for this "kinetic" picture of gas molecules and the motion of molecules?

Materials

Ammonia solution, NH₃, 5 M, 1 mL
Distilled water and wash bottle
Phenolphthalein indicator solution, 1 mL

Buret-type pipets, graduated, 3
Divided disposable Petri dish with cover
Paper, white

Procedure

1. Working in a fume hood, place the divided Petri dish on a sheet of white paper.
2. Using a graduated, Buret-type pipet, add 2 mL of ammonia solution to one compartment of the divided Petri dish.
3. Using a clean, dry pipet, add 1 mL of phenolphthalein solution and 1 mL of distilled water to a second compartment in the Petri dish. Place the covers on the divided Petri dishes. Note: Do not allow the phenolphthalein to drip into the ammonia compartment.
4. Observe any changes in the color and appearance of each solution in the Petri dish.
5. Wearing gloves, rinse the contents of the Petri dish into the large waste beaker provided at the activity station.
6. Answer the questions in the Observations and Analysis section.

Observations and Analysis

1. Describe the initial color and appearance of each solution and any changes that were observed when the Petri dish was covered.

2. What compound was responsible for the color change observed in the phenolphthalein solution? Assuming that none of the liquids were spilled or contacted each other in any other way, how did this compound "travel" to the indicator?

3. What is the role of the phenolphthalein "indicator" in this demonstration? Write an equation for the reaction of ammonia gas with water that explains the indicator color change.

4. What evidence does this demonstration provide that gas molecules are moving continuously about and randomly colliding with nearby walls and surfaces?

5. Describe two observations from daily life that also show us that gas molecules are able to move randomly through a "container."
Activity B. Crush the Can

Pressure—We all feel it! But what is it? In the case of the surrounding air, the pressure it exerts is a force, a surprisingly strong force. Use this "pressure-packed" activity to prove that air is a force to be reckoned with. When the water inside the can boils, it is converted to steam, which drives the air out of the can. When the can is then inverted and quickly cooled in a container of water, any steam remaining in the can condenses back to a liquid. Since there are fewer air or gas molecules remaining in the can than there were originally, the gas pressure inside the can after it cools is substantially lower than its original value. The external air pressure "pressing" on the outside of the can is normal atmospheric pressure (15 lbs/sq in).

Materials

- Aluminum pie pan
- Beaker tongs
- Graduated cylinder, 25-mL
- Hot plate
- "HOT" sign for hot plate
- Soda can, 12 oz, aluminum, empty
- Water, tap or deionized

Procedure

1. Rinse out an empty, 12-oz aluminum soda can, and then using the graduated cylinder, add about 15–20 mL of water to the can.
2. Fill the pie pan with 2–3 inches of water. Set the pan next to the hot plate. Warning: Notice the "HOT" sign in front of the hot plate!
3. Holding the aluminum can with a pair of beaker tongs, heat the can on the hot plate at a high setting until the water comes to a boil and steam is observed coming out of the can.
4. After steam has steadily come out of the can for 30–60 seconds, remove the can from the hot plate. Immediately turn the can upside down and plunge the open end of the can into the pan filled with water.
5. After the can is cool to the touch, discard the crushed can in the trash. Do not move the "HOT" sign!

Observations and Analysis

1. Describe your observations; be specific. What happened when the can was heated? When it was plunged into the water bath?

2. What "force" caused the can to collapse inward on itself?

3. What "drove" the air out of the can as it was heated?

4. Why was there less air pressure inside the can after it was quickly cooled in the water "bath"?
Activity C. Boyle’s Law in a Bottle

More than 350 years ago, Robert Boyle used air trapped in a glass tube above a column of mercury to study the relationship between the volume and pressure of air. The purpose of this activity is to carry out a modern version of Boyle’s classic experiment, using only a syringe and a special, “pressurized” soda bottle. Discover Boyle’s law in a safe and environmentally friendly manner!

Materials
- Barometer (optional)
- Bicycle pump with pressure gauge
- Graph paper or computer graphing program
- Petroleum jelly, small head
- Pressure bottle, 1-L, with tire valve cap
- Syringe, 10 mL, with syringe tip cap

Procedure
1. Using a barometer, measure and record the value of the local air pressure in the Data Table.
2. Remove the tip cap from the syringe and pull on the plunger to draw about 9 mL of air into the syringe. Replace the tip cap to seal the air inside the syringe.
3. Place the sealed syringe inside the 1-L pressure bottle.
4. Run a small bead of petroleum jelly around the rim of the 1-L bottle.
5. Cap the bottle with the special tire valve cap assembly. Tighten the cap securely.
6. Connect the tire valve to a bicycle pump. Pumps air into the pressure bottle to obtain a pressure reading of 50-60 psi or the attached pressure gauge. Record in the Data Table the initial gauge pressure and volume in the syringe. Do NOT exceed 100 psi. Note: Using a manual tire pump is a safety feature—it is very difficult to pump more than about 70 psi into the pressure bottle by hand.
7. Loosen the connection between the valve and the pump to release a very small amount of air from the bottle—as soon as you see the plunger in the syringe begin to move, immediately tighten the connection between the tire valve cap and the pump.
8. Measure the pressure using the attached pressure gauge and record the pressure to within ±1 psi in the Data and Results Table.
9. Measure the volume of air trapped in the syringe inside the pressure bottle and record the volume in the Data Table. Note: Measure the volume at the black insert rubber seal, not at the inverted V-like projection, as shown in Figure 1.
10. Loosen the connection between the pressure bottle, tire valve, and the pump to release some air from the pressure bottle and reduce the gauge pressure by about 10 psi. Immediately tighten the connection between the tire valve and the pump.
11. Measure the new gauge pressure and the resulting volume of air inside the syringe and record both values in the Data Table.
12. Repeat steps 10 and 11 to measure the volume of gas at several different gauge pressures down to about 15 psi. It should be possible to obtain at least 5–6 pressure and volume measurements in this range.
13. Remove the tire valve from the pump and press down on the brass pin to release the excess pressure in the pressure bottle. Measure and record the final volume of air contained in the syringe at atmospheric pressure. Note: The gauge pressure is equal to zero at atmospheric pressure.
Data and Results Table

<table>
<thead>
<tr>
<th>Barometric Pressure</th>
<th>Volume of Air in Syringe</th>
<th>Total Pressure*</th>
<th>L/V*</th>
<th>P × V</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*See Post-Lab Calculation #3.
**See Post-Lab Calculation #4.

Calculations and Analysis (Answer on a separate sheet of paper)

1. Convert the local barometric pressure to psi units and enter the value in the nearest psi in the Data and Results Table. 1 atm = 760 mm Hg = 29.92 in Hg = 14.7 psi.
2. The true pressure gauge measures the relative pressure in psi above atmospheric pressure. For each pressure reading in the Data and Results Table, add the local barometric pressure, in psi, to the gauge pressure to determine the total pressure of air inside the pressure bottle. Record the total pressure in the table.
3. a. Identify the independent and the dependent variable in this experiment.
   b. Plot a graph of the dependent variable on the y-axis versus the independent variable on the x-axis. Choose a suitable scale for each axis so that the data points fill the graph as completely as possible. Remember to label each axis (including the units) and to give the graph a title.
   c. Describe the shape of the graph. Draw a best-fit straight line or curve, whichever seems appropriate, to illustrate how the volume of a gas changes as the pressure is varied.
4. The relationship between pressure and volume is called an inverse relationship—the volume of air trapped inside the syringe decreases as the pressure increases. This relationship may be expressed mathematically as \( P \cdot V = \text{constant} \). Calculate the value of \( L/V \) for each volume measurement and enter the results in the table.
5. Plot a graph of pressure on the y-axis versus 1/V on the x-axis and draw a best-fit straight line through the data points. Choose a suitable scale for each axis. Remember to label each axis and to give the graph a title.
6. Another way of expressing an inverse relationship between two variables (\( P \cdot V = \text{constant} \)) is to say that the mathematical product of the two variables is a constant. \( P \times V = \text{constant} \). Multiply the total pressure times the volume for each set of data points. Calculate the average value of the \( P \times V \) "constant" and the average deviation.
Activity D. Charles’s Law — Effect of Temperature on the Volume of a Gas

Charles’s law describes the relationship between the temperature of a gas and its volume. In order to understand this relationship, we must imagine what happens to the particles in a gas when the gas is heated or cooled. The temperature of a gas measures the average kinetic energy of the moving gas particles — how fast they are moving. When a gas is heated, the average kinetic energy of the particles increases and they move faster. When a gas is cooled, the average kinetic energy of the particles decreases and they move slower.

Concepts

- Temperature
- Charles’s Law
- Kinetic-molecular theory

Materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot water</td>
<td></td>
</tr>
<tr>
<td>Ice</td>
<td></td>
</tr>
<tr>
<td>Graph paper</td>
<td></td>
</tr>
<tr>
<td>Paper towel</td>
<td></td>
</tr>
<tr>
<td>Petroleum jelly</td>
<td></td>
</tr>
<tr>
<td>Stirring rods, large</td>
<td>2</td>
</tr>
<tr>
<td>Syringe, 20 mL, with syringe tip cap</td>
<td></td>
</tr>
<tr>
<td>Thermometers, 4</td>
<td></td>
</tr>
<tr>
<td>Wood splint</td>
<td></td>
</tr>
<tr>
<td>Various temperature baths, 400-mL each</td>
<td></td>
</tr>
<tr>
<td>Salt-ice water, -15 to -20 °C</td>
<td></td>
</tr>
<tr>
<td>Ice-water, 0 to 5 °C</td>
<td></td>
</tr>
<tr>
<td>Hot water, 60 to 65 °C</td>
<td></td>
</tr>
</tbody>
</table>

Procedure

There are three water baths set up at this activity station — notice the temperature range specified for each bath in the Materials section. Add hot water or ice and stir as needed during the course of the activity to maintain the average temperature of each bath in the desired range. Note: Do not use thermometers as stirring rods.

1. Remove the tip cap, if necessary, from the 30-mL syringe, and take the plunger out of the syringe. Place a very small dab of petroleum jelly on the black rubber gasket, and spread the petroleum jelly out in a thin layer on the surface of the gasket using a wood splint.

2. Place the plunger back in the syringe and draw the syringe to about one-half full with air. Seal the syringe with the syringe tip cap.

3. Place the syringe on the lab table and measure the ambient air temperature around the syringe. Let the thermometer equilibrate in air for 1–2 minutes before measuring the temperature. Record the ambient "room temperature" reading in the Data and Results Table.

4. Measure and record the precise volume of air in the syringe at room temperature (see Activity C).

5. Place the syringe in the saltwater-ice bath (~15 to -20 °C) and submerge the syringe just to the bottom of the plunger as shown in Figure 2. Measure and record the temperature of the bath in the Data and Results Table.

6. Every 15 seconds, measure and record the precise volume of air in the syringe when the syringe stops moving.

7. Remove the syringe from the saltwater-ice bath and place the syringe in the ice-water bath (0-5 °C) as shown in Figure 2. Measure and record the temperature of the ice-water bath.

8. After two minutes, measure and record the volume of air in the syringe.

9. Remove the syringe from the ice-water bath and place the syringe in the hot water bath (60-65 °C) as shown in Figure 2. Measure and record the temperature of the hot water bath.

10. After two minutes, measure and record the precise volume of air in the syringe.

11. Remove the syringe from the hot water bath and remove the tip cap and plunger. Wipe the plunger and gasket with a paper towel.

Figure 2.
### Data and Results Table

<table>
<thead>
<tr>
<th>Water Bath</th>
<th>Temperature, °C</th>
<th>Volume of Air in Syringe, mL</th>
<th>Volume / T (mL/°C)</th>
<th>Absolute Temperature, K</th>
<th>Volume / T (mL/K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saltwater-Ice</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ice water</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Room Temperature</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hot water</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Calculations and Analysis

1. **Identify the independent and the dependent variable in this experiment.**
2. **Plot a graph of the dependent variable on the y-axis and the independent variable on the x-axis.** Choose a suitable scale for each axis so that the data points fill the graph as completely as possible. Remember to label each axis, including the units, and to give the graph a title.
3. **Draw a best-fit straight line through the data points on the graph. Describe the mathematical relationship between the temperature and volume of a gas.**
4. **For each of the four temperatures in this experiment, calculate the value of the volume/temperature (in °C) ratio. How do these ratios compare with one another?**
5. **Convert each of the temperature measurements in this experiment to absolute temperature (kelvins, K).** Calculate the value of the volume/temperature (in K) ratio for each of the four temperatures in this experiment. How do these ratios compare with one another?
6. **Which volume/temperature ratio (in °C or K) appears to be more constant?** Saying that the ratio of two variables is a constant is to say that the two variables are directly proportional to each other. Why is it important to specify absolute temperature (in K) when stating Charles’s law?
7. **According to the kinetic-molecular theory, the volume of the gas particles is extremely small compared to the volume the gas occupies—most of the volume of gas is “empty space.” Based on this theory, does Charles’s law depend on the identity of the gas? Would the results in this experiment have been different if different gases had been used in the syringe?** On the amount of gas in the syringe? Explain in terms of the KMT and the amount of empty space in gas.
APPENDIX C

TEST 1
Test 6: Chapters 8, 9 and 10 (Post-Lab)

Problem

1. Provide the missing data in the columns.

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Celsius, °C</th>
<th>Kelvin, K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Melting point of gold</td>
<td>1064</td>
<td>c. _______</td>
</tr>
<tr>
<td>Boiling point of carbon monoxide</td>
<td>a. _______</td>
<td>81.7</td>
</tr>
<tr>
<td>Cold winter night in Siberia</td>
<td>b. _______</td>
<td>233</td>
</tr>
<tr>
<td>Hot summer day in Phoenix, AZ</td>
<td>45</td>
<td>d. _______</td>
</tr>
</tbody>
</table>

The graph in Figure 10.1 shows what happens when 1 kg sample of each of two different substances are heated. Use the information in the graph to answer the questions. Assume that room temperature in this case is 300 K.

![Graph showing energy added vs. temperature for two substances](image)

Figure 10.1

2. What is the physical state of substance A at room temperature?

3. Estimate the heat of vaporization of substance B.

4. What is the melting point of substance B?

5. What is the physical state of substance B at room temperature?

6. If you mixed substance A, substance B, and water, and steadily increased the temperature, which would boil last?

7. Estimate the heat of fusion of substance B.
8. What is the melting point of substance A?

9. Estimate the heat of fusion of substance A. (Hint: Consider the length of the appropriate plateau.)

   Use a table of electronegativities to find the electronegativity difference between each of the following pairs of elements and to predict the kind of bond that will be formed.

10. calcium and fluorine

11. zinc and bromine

12. hydrogen and germanium

   The table shows the fusion and vaporization data for eight substances. Use the information to answer the following questions.

<table>
<thead>
<tr>
<th>Substance</th>
<th>Fusion Melting Point (°C)</th>
<th>Heat of fusion (joules/mole) (°C)</th>
<th>Vaporization Boiling Point</th>
<th>Heat of vaporization (joules/mole)</th>
</tr>
</thead>
<tbody>
<tr>
<td>O₂ oxygen</td>
<td>-219</td>
<td>444</td>
<td>-183</td>
<td>6820</td>
</tr>
<tr>
<td>N₂ nitrogen</td>
<td>-210</td>
<td>729</td>
<td>-196</td>
<td>5577</td>
</tr>
<tr>
<td>NH₃ ammonia</td>
<td>-78</td>
<td>5653</td>
<td>-33</td>
<td>23 351</td>
</tr>
<tr>
<td>CO₂ carbon dioxide</td>
<td>-56</td>
<td>8325</td>
<td>-78</td>
<td>25 234*</td>
</tr>
<tr>
<td>N₂O nitrous oxide</td>
<td>-91</td>
<td>6540</td>
<td>-89</td>
<td>16 552</td>
</tr>
<tr>
<td>I₂ iodine</td>
<td>114</td>
<td>15 648</td>
<td>183</td>
<td>4347*</td>
</tr>
<tr>
<td>H₂O water</td>
<td>0</td>
<td>6008</td>
<td>100</td>
<td>40 655</td>
</tr>
</tbody>
</table>

   *Data directly from solid. These are heats of sublimation.

13. Which substance has the lowest melting point? Which has the highest melting point?

14. Which substance changes from the solid state to the gaseous state with the least total change in temperature?

15. Which substance has the highest boiling point? Which has the lowest boiling point?

16. Draw the electron dot diagrams for this molecule: AsBr₃

17. Octane, C₈H₁₈, melts at -57°C and boils at 126°C. A few grams of octane are heated from -80°C to +140°C. Graph the heating curve for octane. Show time on the horizontal axis and temperature on the vertical axis.
Multiple Choice
Identify the choice that best completes the statement or answers the question.

18. Each row in the periodic table ends with a _____.
   a. nonmetal  c. noble gas
   b. metalloid  d. metal

19. In going from left to right in any given row in the periodic table, the size of atoms generally _____.
   a. stays the same  c. decreases
   b. increases  d. changes randomly

20. Alkaline earth metals lose _____ electrons to achieve the electron configuration of the noble gas in the preceding period.
   a. seven  c. six
   b. one  d. two

21. If the electronegativity of H is 2.20 and of Cl is 3.55, which type of bond is formed between H and Cl, when they form hydrogen chloride?
   a. Polar covalent  c. Polar ionic
   b. Covalent  d. Ionic

22. Compared to the neutral atom from which it is derived, a negative ion is _____.
   a. the same size
   b. always larger
   c. larger in some cases and smaller in others
   d. always smaller

23. Ionic radii _____ down a group in the periodic table.
   a. stay the same  c. decrease
   b. increase  d. follow no pattern

Short Answer

*Explain what is occurring during each of the following processes, in terms of particles and the kinetic theory.*

24. Freezing

25. Evaporation
APPENDIX D

TEST 2
Chemistry Test: Chapters 9, 10, and 11

Short Answer

<table>
<thead>
<tr>
<th>Element</th>
<th>Freezing Point, °C</th>
<th>Boiling Point, °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cadmium</td>
<td>321</td>
<td>770</td>
</tr>
<tr>
<td>Chlorine</td>
<td>-101</td>
<td>-34</td>
</tr>
<tr>
<td>Fluorine</td>
<td>-220</td>
<td>-188</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>44</td>
<td>230</td>
</tr>
</tbody>
</table>

1. Which of the elements are solids at 50°C? At -50°C?

2. Which element has the smallest temperature range as a liquid? The largest temperature range?

3. Which of the elements are gases at 50°C? At -50°C?

4. Which of the elements are liquids at 50°C? At -50°C?

5. If the gas pressure in an aerosol can is 166 kPa at 17°C, what is the pressure inside the can if it is heated to 195°C?


7. The volume of a sample of argon gas is 138 mL at -150°C and 1 atm. Predict the volume of the sample at +150°C and 1 atm.

   **Explain what is occurring during each of the following processes, in terms of particles and the kinetic theory.**

8. condensation

9. A barometer is carried to the bottom of a mine shaft, 1000 m beneath Earth's surface. What can you say about the level of mercury in the barometer?

10. A cylinder contains 6.54 L of a gas at a temperature of 15°C. The cylinder is heated, and a piston moves in the cylinder so that constant pressure is maintained. If the final volume of the gas in the cylinder is 8.50 L, what is the final temperature?

11. Explain why pumping additional air into a tire causes the pressure inside the tire to increase. Discuss the motion of air molecules in your answer.

12. At 525 mm Hg and 85°C, the volume of a sample of nitrogen gas is 26.8 L. What is the volume at STP?

13. A cylinder of compressed gas has a volume of 3.85 L and a pressure of 463 kPa. What volume would the gas occupy if it were allowed to escape into a balloon at a pressure of 110 kPa? Assume constant temperature.
Problem

14. The reading on a barometer is 764 mm Hg. If the barometer contained water instead of mercury, would you expect the reading to be more than, less than, or equal to 764 mm? Explain. Consider the densities of mercury and water.

The table shows the fusion and vaporization data for eight substances. Use the information to answer the following questions:

<table>
<thead>
<tr>
<th>Substance</th>
<th>Fusion Melting Point (°C)</th>
<th>Heat of fusion (joules/mole) (°C)</th>
<th>Vaporization Boiling Point</th>
<th>Heat of vaporization (joules/mole)</th>
</tr>
</thead>
<tbody>
<tr>
<td>O₂ oxygen</td>
<td>-219</td>
<td>444</td>
<td>-183</td>
<td>6820</td>
</tr>
<tr>
<td>N₂ nitrogen</td>
<td>-210</td>
<td>729</td>
<td>-196</td>
<td>5577</td>
</tr>
<tr>
<td>NH₃ ammonia</td>
<td>-78</td>
<td>5653</td>
<td>-33</td>
<td>23351</td>
</tr>
<tr>
<td>CO₂ carbon dioxide</td>
<td>-56</td>
<td>8325</td>
<td>-78</td>
<td>25234*</td>
</tr>
<tr>
<td>N₂O nitrous oxide</td>
<td>-91</td>
<td>6549</td>
<td>-89</td>
<td>16552</td>
</tr>
<tr>
<td>I₂ iodine</td>
<td>114</td>
<td>15648</td>
<td>183</td>
<td>4347*</td>
</tr>
<tr>
<td>H₂O water</td>
<td>0</td>
<td>6008</td>
<td>100</td>
<td>40659</td>
</tr>
</tbody>
</table>

*Goes directly to vapor from solid. These are heats of sublimation.

15. Which substance changes from the solid state to the gaseous state with the least total change in temperature?

16. Which substance has the highest boiling point? Which has the lowest boiling point?

17. Suppose you have equal volumes of liquid oxygen and liquid nitrogen sitting open in a warm room. Which would boil away first? Explain.

18. A pair of chemistry students worked together in the laboratory to collect data on the volumes, pressures, and temperatures of several samples of gases. One student worked on Tuesday and the other on Wednesday. Each student neglected to collect certain data from time to time. From the data reported in the table, calculate the missing information indicated by the numbers (1) through (5).

<table>
<thead>
<tr>
<th>Trial</th>
<th>Volume</th>
<th>Pressure</th>
<th>Temp.</th>
<th>Volume</th>
<th>Pressure</th>
<th>Temp.</th>
</tr>
</thead>
<tbody>
<tr>
<td>101</td>
<td>125 mL</td>
<td>1.00 atm</td>
<td>25°C</td>
<td>1.</td>
<td>1.00 atm</td>
<td>0.0°C</td>
</tr>
<tr>
<td>102</td>
<td>25.0 mL</td>
<td>650 mm Hg</td>
<td>22.5°C</td>
<td>2.</td>
<td>30.0 mL</td>
<td>22.5°C</td>
</tr>
<tr>
<td>103</td>
<td>39.0 mL</td>
<td>1.025 atm</td>
<td>0.0°C</td>
<td>3.</td>
<td>35.0 mL</td>
<td>1.025 atm</td>
</tr>
<tr>
<td>104</td>
<td>250.0 mL</td>
<td>750 mm Hg</td>
<td>32°C</td>
<td>4.</td>
<td>780 mm Hg</td>
<td>47°C</td>
</tr>
<tr>
<td>105</td>
<td>5.</td>
<td>25 mm Hg</td>
<td>-4°C</td>
<td>5.</td>
<td>0.079 L</td>
<td>6.0°C</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tuesday Data</th>
<th>Wednesday Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial</td>
<td>Volume</td>
</tr>
<tr>
<td>101</td>
<td>125 mL</td>
</tr>
<tr>
<td>102</td>
<td>25.0 mL</td>
</tr>
<tr>
<td>103</td>
<td>39.0 mL</td>
</tr>
<tr>
<td>104</td>
<td>250.0 mL</td>
</tr>
<tr>
<td>105</td>
<td>5.</td>
</tr>
</tbody>
</table>
19. A refrigeration system contains 575 mL of a gas at 22°C and 1.25 atm. The gas is compressed until it has a pressure of 2.00 atm and a temperature of 6°C. What is the new volume of the gas in the system?

The graph in Figure 10-1 shows what happens when 1 kg sample of each of two different substances are heated. Use the information in the graph to answer the questions. Assume that room temperature in this case is 300 K.

![Graph](image)

Figure 10-1

20. If you mixed substance A, substance B, and water, and steadily increased the temperature, which would boil last?

Completion
Complete each statement.

21. A bond formed by the sharing of two pairs of electrons is called a(n) _________________.

22. ________________ is a measure of the ability of an atom to attract electrons in a chemical bond.

23. A metal that can be hammered or rolled into thin sheets is said to be _________________.

24. The ________________ is caused when electrons in inner energy levels tend to block the attraction of the nucleus for valence electrons.

25. When electrons are shared unequally between two atoms, a(n) ________________ is formed.
APPENDIX E

ATTITUDE SURVEY
Lecture-Lab Survey

Identify the choice that best represents how much you agree with the statement.

1. I learn more from labs than from lectures.
   a. Strongly agree
   b. Agree
   c. Neither agree nor disagree
   d. Disagree
   e. Strongly disagree

Why did you put the above answer?

______________________________________________________________________
______________________________________________________________________
______________________________________________________________________
______________________________________________________________________
______________________________________________________________________
______________________________________________________________________
2. I would like to do more labs.
   a. Strongly agree
   b. Agree
   c. Neither agree nor disagree
   d. Disagree
   e. Strongly disagree

3. Labs help me understand the material covered in lecture.
   a. Strongly agree
   b. Neither agree nor disagree
   c. Disagree
   d. Strongly disagree

   Why did you put the above answer?

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
4. Labs are fun.
   a. Strongly agree
   b. Agree
   c. Neither agree nor disagree
   d. Disagree
   e. Strongly disagree
   Please explain your answer.
   ___________________________________________
   ___________________________________________
   ___________________________________________
   ___________________________________________
   ___________________________________________

5. I learn a lot from lecture.
   a. Strongly agree
   b. Agree
   c. Neither agree nor disagree
   d. Disagree
   e. Strongly disagree
6. I learn a lot from labs.
   a. Strongly agree
   b. Agree
   c. Neither agree nor disagree
   d. Disagree
   e. Strongly disagree

Why did you put the above answer?
7. Labs are easy to understand.
   a. Strongly agree
   b. Agree
   c. Neither agree nor disagree
   d. Disagree
   e. Strongly disagree

What parts of labs are easy (or difficult) for you to understand?

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________

8. I often don’t understand what I am doing in a lab.
   a. Strongly agree
   b. Agree
   c. Neither agree nor disagree
   d. Disagree
   e. Strongly disagree
Why did you put the above answer?

______________________________________________________________________
______________________________________________________________________
______________________________________________________________________
______________________________________________________________________
______________________________________________________________________
______________________________________________________________________

____ 9. The melting point lab really helped me understand some of the material from Chapter 10.
   a. Strongly agree
   b. Agree
   c. Neither agree nor disagree
   d. Disagree
   e. Strongly disagree

____ 10. The gas laws lab really helped me understand some of the material from Chapter 11.
   a. Strongly agree
   b. Agree
   c. Neither agree nor disagree
   d. Disagree
   e. Strongly disagree
11. The stoichiometry lab really helped me understand some of the material from Chapter 12.
   
   a. Strongly agree
   b. Agree
   c. Neither agree nor disagree
   d. Disagree
   e. Strongly disagree

   From which of the above three labs did you learn the most? Please explain why.
   
   __________________________________________________________
   __________________________________________________________
   __________________________________________________________
   __________________________________________________________
   __________________________________________________________

12. I like science.

   a. Strongly agree
   b. Agree
   c. Neither agree nor disagree
   d. Disagree
   e. Strongly disagree
Why did you put the above answer?

______________________________________________________________________
______________________________________________________________________
______________________________________________________________________
______________________________________________________________________
______________________________________________________________________

13. I like chemistry.
   a. Strongly agree
   b. Agree
   c. Neither agree nor disagree
   d. Disagree
   e. Strongly disagree

14. Chemistry is easy.
   a. Strongly agree
   b. Agree
   c. Neither agree nor disagree
   d. Disagree
   e. Strongly disagree

Please explain your answer.
Identify one or more choices that best complete the statement or answer the question.

___ 15. How often would you like to do labs?

a. Never
b. Once a month
c. One every other week
d. Once a week
e. Every class period

Other ______________________________
APPENDIX F

INTERVIEW QUESTIONS
Interview Questions

1. Do labs help you understand what is covered in lecture?
   a. Possible probing questions:
      i. Can you give me an example of something labs helped you understand?
      ii. How could I improve labs to make them more helpful to understand the lecture material?
         1. Is the pre-lab work helpful?
         2. Could I do anything before the lab to make them more helpful?
         3. Could I do anything at the end of the lab to help you understand what you did?

2. Do you enjoy labs?
   a. Possible probing questions:
      i. What is it that you enjoy about labs?
      ii. What do you like least about labs?
      iii. How could I make labs more fun?
      iv. Which labs did you particularly enjoy?
      v. Have you done labs in other classes? What good (bad) memories do you have in terms of what you learned?
3. How do you feel about lectures?
   a. How could lecture be made more interesting?
   b. What would help you learn more from lecture?
   c. Do you learn a lot from lecture?

4. Do you think you learn more from labs or lectures?
   a. Why do you think that?
   b. Can you recall for me a lab you learned quite a bit from?
      i. What did you learn?
   c. Can you recall a lecture you learned quite a bit from?
      i. What did you learn?

5. Do you like science?
   a. Why do you like science?
   b. Why don’t you like science?
      i. Have you always liked (not liked) it?
      ii. When was the first time you started liking (or not liking) science?

6. Do you like chemistry?
   a. What is it about chemistry that you like?
   b. What don’t you like about chemistry?
      i. Have you always liked (not liked) it?
      ii. When was the first time you started liking (or not liking) science?
APPENDIX G

IRB EXEMPTION LETTER
MEMORANDUM

TO: Caleb Dorsey and Walt Woolbaugh
FROM: Mark Quinn, Chair
DATE: November 26, 2012
RE: “The Effectiveness of Laboratory Instruction” [CD112612-EX]

The above research, described in your submission of November 26, 2012, is exempt from the requirement of review by the Institutional Review Board in accordance with the Code of Federal Regulations, Part 46, section 101. The specific paragraph which applies to your research is:

X (b) (1) Research conducted in established or commonly accepted educational settings, involving normal educational practices such as (i) research on regular and special education instructional strategies, or (ii) research on the effectiveness of or cooperation among instructional techniques, curricula, or classroom management methods.

X (b) (2) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures, or observation of public behavior, unless: (i) information obtained is recorded in such a manner that human subjects can be identified, directly or through identifiers linked to the subjects; and (ii) any disclosure of the human subjects’ responses outside the research could reasonably place the subjects at risk of criminal or civil liability, or be damaging to the subjects’ financial standing, employability, or reputation.

(b) (3) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures, or observation of public behavior that is not exempt under paragraph (b)(2) of this section. If: (i) the human subjects are elected or appointed public officials or candidates for public office; or (ii) federal statute(s) without exception that the confidentiality of the personally identifiable information will be maintained throughout the research and thereafter.

(b) (4) Research involving the collection or study of existing data, documents, records, pathological specimens, or diagnostic specimens, if these sources are publicly available, or if the information is recorded by the investigator in such a manner that the subjects cannot be identified, directly or through identifiers linked to the subjects.

(b) (5) Research and demonstration projects, which are conducted by or on behalf of an agency, and which are designed to study, evaluate, or otherwise examine: (i) public benefit or service programs; (ii) procedures for obtaining benefits or services under those programs; (iii) possible changes in or alternatives to those programs or procedures; or (iv) possible changes in methods or levels of payment for benefits or services under those programs.

(b) (6) Taste and food quality evaluation and consumer acceptance studies, if wholesome foods without additives are consumed, or if a food is consumed that contains a food ingredient at or below the level and for a use found to be safe, or agricultural chemical or environmental contaminant at or below the level found to be safe, by the FDA, or approved by the EPA, or the Food Safety and Inspection Service of the USDA.

Although review by the Institutional Review Board is not required for the above research, the Committee will be glad to review it. If you wish a review and committee approval, please submit 3 copies of the usual application form and it will be processed by expedited review.
APPENDIX H

SAMPLE MINUTE PAPER RESPONSES
<table>
<thead>
<tr>
<th>Topic</th>
<th>Question</th>
<th>Sample Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lecture</td>
<td>How did you feel about today’s lecture?</td>
<td>• “Today’s lecture was informative.”&lt;br&gt;• “Good.”&lt;br&gt;• “I felt good about this lesson today but it’s a little boring.”&lt;br&gt;• “During the lesson I felt a little bored, but there were things that caught my attention.”&lt;br&gt;• “I felt good. The lecture was good today. I think when you interact with the class we pick up more as opposed to just staring at you for an hour and a half. Breaks would be nice.”</td>
</tr>
<tr>
<td></td>
<td>What did you learn from today’s lecture?</td>
<td>• “I learned how to write Lewis dot structure for compounds and what electronegativity was and how to find electronegativity of atoms. Also how to find the difference in electronegativity and an acronym for diatomic molecules.”&lt;br&gt;• “I learned about phase changes, the variations of boiling points, freezing points and basic properties.”&lt;br&gt;• “I learned that when you freeze something it gives off energy to slow down the liquid particles.”&lt;br&gt;• “I learned a lot but now I finally understand how sweat cools you down. Sweat takes energy from your body to evaporate, this energy is heat. Less heat = cools down.”&lt;br&gt;• “I learned how to do temperature conversions.”</td>
</tr>
<tr>
<td>Lab</td>
<td>How did you feel about today’s lab?</td>
<td>• “I liked today’s lab. It was kind of fun because it was sort of a waiting game. The only part that I didn’t like was when it took forever to heat up.”&lt;br&gt;• “It sucked our hot plate was slow or our thermometer sucked…took too long.”&lt;br&gt;• “The lab wasn’t too difficult. I understood what to do.”&lt;br&gt;• “I enjoyed today’s lab.”&lt;br&gt;• “I felt good about today’s lab. I especially like the soda can crushing activity.”</td>
</tr>
<tr>
<td></td>
<td>What did you learn from today’s lab?</td>
<td>• “I don’t know if I learned anything new. I learned how many millimeters are in 25.34 inches though.”&lt;br&gt;• “I learned that gas vapors can change the color of liquids.”&lt;br&gt;• “I learn the multiple things about pressures and how they change with a simple temperature change.”&lt;br&gt;• I learned that cans crush when they go from hot to cold.&lt;br&gt;• Learned how to crush a can!</td>
</tr>
</tbody>
</table>
APPENDIX I

SURVEY DATA
### Learning

<table>
<thead>
<tr>
<th>Statement</th>
<th>0.0%</th>
<th>20.0%</th>
<th>40.0%</th>
<th>60.0%</th>
<th>80.0%</th>
<th>100.0%</th>
<th>120.0%</th>
</tr>
</thead>
<tbody>
<tr>
<td>I learn a lot from labs.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I learn a lot from lecture.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Labs help me understand the...</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I learn more from labs than...</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I learn more from labs than from lectures.</td>
<td>0.0%</td>
<td>14.3%</td>
<td>19.0%</td>
<td>4.8%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Labs help me understand the material covered in lecture.</td>
<td>14.3%</td>
<td>42.9%</td>
<td>52.4%</td>
<td>47.6%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I learn a lot from lecture.</td>
<td>19.0%</td>
<td>52.4%</td>
<td>47.6%</td>
<td>42.9%</td>
<td>14.3%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I learn a lot from labs.</td>
<td>4.8%</td>
<td>47.6%</td>
<td>42.9%</td>
<td>14.3%</td>
<td>0.0%</td>
<td></td>
<td></td>
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</tbody>
</table>

### Labs Helping with Lecture

The gas laws activities lab really helped me understand some of the material from Ch. 11.

The melting point lab, "Molecules and Energy," really helped me understand some of...

<table>
<thead>
<tr>
<th>Statement</th>
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<th>40.0%</th>
<th>60.0%</th>
<th>80.0%</th>
<th>100.0%</th>
<th>120.0%</th>
</tr>
</thead>
<tbody>
<tr>
<td>The melting point lab, &quot;Molecules and Energy,&quot; really helped me understand some of the material from Ch. 10.</td>
<td>0.0%</td>
<td>57.1%</td>
<td>57.1%</td>
<td>57.1%</td>
<td>4.8%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The gas laws activities lab really helped me understand some of the material from Ch. 11.</td>
<td>9.5%</td>
<td>28.6%</td>
<td>28.6%</td>
<td>28.6%</td>
<td>4.8%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Strongly agree | 0.0% | 9.5%   |
| Agree          | 57.1% | 57.1%  |
| Neither agree nor disagree | 33.3% | 28.6%  |
| Disagree       | 9.5%  | 4.8%   |
| Strongly disagree | 0.0% | 0.0%   |
Labs are easy to understand. I often don't understand what I am doing in a lab.

<table>
<thead>
<tr>
<th></th>
<th>Labs are easy to understand.</th>
<th>I often don't understand what I am doing in a lab.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strongly agree</td>
<td>4.8%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Agree</td>
<td>28.6%</td>
<td>23.8%</td>
</tr>
<tr>
<td>Neither agree nor disagree</td>
<td>57.1%</td>
<td>23.8%</td>
</tr>
<tr>
<td>Disagree</td>
<td>9.5%</td>
<td>47.6%</td>
</tr>
<tr>
<td>Strongly disagree</td>
<td>0.0%</td>
<td>4.8%</td>
</tr>
</tbody>
</table>

I like science. I like chemistry. Chemistry is easy.

<table>
<thead>
<tr>
<th></th>
<th>I like science.</th>
<th>I like chemistry.</th>
<th>Chemistry is easy.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strongly agree</td>
<td>19.0%</td>
<td>9.5%</td>
<td>9.5%</td>
</tr>
<tr>
<td>Agree</td>
<td>28.6%</td>
<td>33.3%</td>
<td>4.8%</td>
</tr>
<tr>
<td>Neither agree nor disagree</td>
<td>33.3%</td>
<td>33.3%</td>
<td>19.0%</td>
</tr>
<tr>
<td>Disagree</td>
<td>14.3%</td>
<td>23.8%</td>
<td>47.6%</td>
</tr>
<tr>
<td>Strongly disagree</td>
<td>4.8%</td>
<td>0.0%</td>
<td>19.0%</td>
</tr>
</tbody>
</table>
I would like to do more labs. Labs are fun.

<table>
<thead>
<tr>
<th></th>
<th>I would like to do more labs.</th>
<th>Labs are fun.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strongly agree</td>
<td>19.0%</td>
<td>14.3%</td>
</tr>
<tr>
<td>Agree</td>
<td>33.3%</td>
<td>66.7%</td>
</tr>
<tr>
<td>Neither agree nor disagree</td>
<td>47.6%</td>
<td>14.3%</td>
</tr>
<tr>
<td>Disagree</td>
<td>0.0%</td>
<td>4.8%</td>
</tr>
<tr>
<td>Strongly disagree</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
</tbody>
</table>
I learn more from labs than from... 

Labs help me understand the... 

I learn a lot from lecture. 

Labs are easy to understand. 

The melting point lab, "Molecules...

Weighted Average

SA=5, A=4, N=3, D=2, SD=1

How often would you like to do labs?

Never  Once a month  One every other week  Once a week  Every class period
APPENDIX J

SAMPLE INTERVIEW RESPONSE
<table>
<thead>
<tr>
<th>Topic</th>
<th>Question</th>
<th>Sample Responses</th>
</tr>
</thead>
</table>
| Learning: Lab vs. Lecture   | Do labs help you understand what is covered in lecture?                   | • “Yah, cause um, there’s more a visual aspect of it.”  
• “Not really. Not for me.”                                                                                                                   |
| How do you feel about lectures? |                                                                           | • “I like them… Yah, because it’s easier to learn stuff. Take more notes and stuff.”  
• “Um, they can be good, too…when the…they got lots of notes to be taken.”                                                                          |
| Do you think you learn more from labs or lectures? |                                                                           | • “Um…that one’s kind of a hard one, because it can go both ways. Like, if you’re working on something that you need to know more like with hands on or if there’s a kid that learns more hands on, then the labs will obviously help, but if someone likes the lectures more and can understand more from the lecture then the labs probably won’t do them much good.”  
• “Definitely lectures.”                                                                                                                        |
| Lab Enjoyment               | Do you enjoy labs?                                                        | • “I enjoy them…I enjoy them, just because it’s like time away from class, you know.”  
• Yes, I do. (What is it about them that you enjoy?) I don’t know. It’s just like…you’re not sitting there at a book and your actually, you know, trying stuff with your hands and doing something different and relating ’em to actual what you’d actually do with them in the real world. |
| Subject Enjoyment           | Do you like science?                                                      | • “Uh…yes and no. Some subjects I like more than others.”  
• “Yes, I do. (Why do you like science) Cause it’s fun and it’s interesting.”                                                                    |
| Do you like chemistry?      |                                                                           | • “Not really. (laughs) It’s…it’s just really hard for me. I don’t know. It’s just like…I’m not really very good at math and so it’s like.”  
• “Uh, yah, but it’s kind of hard…well, most of the time it’s hard.”                                                                             |
APPENDIX K

ADMINISTRATOR EXEMPTION REGARDING INFORMED CONSENT
Administrator Exemption Regarding Informed Consent

I, Marla Stock, Principal of Loyalton High School, verify that the classroom research conducted by Caleb Dorsey is in accordance with established or commonly accepted educational settings involving normal educational practices and that I approve the project. To maintain the established culture of our school and not cause disruption to our school climate, I have granted an exemption to Caleb Dorsey regarding informed consent.

Marla H. Stock, Principal
(Signed Name, Title of Position)

MARLA H. STOCK
(Printed Name)

November 23, 2012
(Date)
APPENDIX L

ADMINISTRATIVE APPROVAL
Administrator Approval

I, Marla Stock, Principal of Loyaton High School, verify that I approve of the classroom research conducted by Caleh Dorsey.

[Signature]

(Signed Name, Title of Position)

[Name]

(Printed Name)

[Date]

(Date)