

PHENOMENA IN HIGH SCHOOL CHEMISTRY

by

Thomas Quackenbush

A thesis submitted in partial fulfillment
of the requirements for the degree

of

Master of Science

in

Science Education

MONTANA STATE UNIVERSITY
Bozeman, Montana

July 2020

©COPYRIGHT

by

Thomas Quackenbush

2020

All Rights Reserved

TABLE OF CONTENTS

| | |
|--|----|
| 1. INTRODUCTION AND BACKGROUND | 1 |
| School Demographics | 1 |
| Focus Question..... | 2 |
| Classroom Description | 2 |
| 2. CONCEPTUAL FRAMEWORK | 7 |
| Laboratory Instruction in the United States | 4 |
| Goals of Laboratory Instruction..... | 5 |
| Styles of Laboratory Instruction | 6 |
| Phenomena-Based Instruction | 7 |
| 3. METHODOLOGY | 9 |
| IRB Exemption | 9 |
| Data Collection | 9 |
| Phenomenon Activity | 9 |
| Content Tests | 10 |
| Engagement Surveys | 10 |
| Observations and Interviews | 10 |
| 4. DATA ANALYSIS | 12 |
| Results | 12 |
| Content Mastery | 12 |
| Engagement | 16 |
| 5. CLAIM, EVIDENCE, AND REASONING | 19 |
| Claims From the Study | 19 |
| Value of the Study and Consideration for Future Research | 20 |
| Impact of Action Research on the Author | 20 |
| REFERENCES CITED..... | 22 |
| APPENDICES | 25 |
| APPENDIX A: Institutional Review Board Exemption | 26 |
| APPENDIX B: Clock Phenomenon Worksheet | 28 |
| APPENDIX C: Kinetics Content Test | 30 |

TABLE OF CONTENTS CONTINUED

| | |
|---|----|
| APPENDIX D: Calorimetry Content Test..... | 35 |
| APPENDIX E: Acid/Base Content Test..... | 40 |
| APPENDIX F: Student Engagement Survey..... | 45 |
| APPENDIX G: Student Interview Questions | 47 |

LIST OF TABLES

| Table | Page |
|--|------|
| 1. Data Triangulation Matrix | 11 |
| 2. P values derived from applying a Wilcoxon Signed-Rank test to Student Engagement Survey responses from Treatment ($N=14$), Comparison 1 ($N=12$), and Comparison 2 ($N=12$) labs..... | 14 |

LIST OF FIGURES

| Figure | Page |
|--|------|
| 1. Boxplots showing score distribution of the Treatment Kinetics ($N=10$), Comparison 1 Calorimetry ($N=13$), and Comparison 2 Titration ($N=13$) content tests..... | 12 |
| 2. Scatterplot showing normalized gains from the Treatment Kinetics ($N=10$), Comparison 1 Calorimetry ($N=13$), and Comparison 2 titration ($N=13$) content tests. | 13 |
| 3. Student Engagement Survey results for questions 3, 4, 5, and 6 from the Treatment ($N=14$), Comparison 1 ($N=12$), and Comparison 2 ($N=12$) labs. | 15 |
| 4. Student Engagement Survey results from the Treatment ($N=14$), Comparison 1 ($N=12$), and Comparison 2 ($N=12$) labs. | 16 |

ABSTRACT

This study aimed to determine the effect on student engagement and content mastery of using phenomena as a precursor to lab instruction. The study was conducted with 14 students in an 11th and 12th grade AP Chemistry class at St. Monica Academy. The treatment lab was preceded by a phenomenon activity and was compared to labs not preceded by phenomenon activities. Data collected from pre- and post-lab content tests, student interviews and surveys, and teacher observations suggested that using phenomena before labs significantly improved content mastery in some cases, but not all.

INTRODUCTION AND BACKGROUND

School Demographics

St. Monica Academy (SMA) is a small, Catholic, classical academy located in Montrose, California, twenty minutes outside of Los Angeles. SMA is a K-12 school, with 111 students in the high school, and 277 students overall. Many students in the high school previously attended the elementary or middle school as well. The school is a tight-knit community, with high parent participation in activities. The most recent enrollment records show that 53% of the student body is White, 20% Hispanic, 6% Asian, 11% Filipino, 1% African-American, and 1% of Native American descent, and 7% Multi-racial (St. Monica Academy, 2020). The school culture is strongly rooted in the Catholic and classical traditions, and most students are Catholic. The average family has two students at the school, and more than 26 families have three or more children at the school. Many families in the SMA community are relatively affluent, with incomes above \$90,000, but more than a quarter of the student body receives financial aid (St. Monica Academy Midterm Progress Report).

SMA is only 19 years old and has limited classroom space. In particular, the lab room is shared by history, literature, and math classes. The only preparation space is a small closet adjoining the room. This has led to a natural lack of emphasis on labs as a principle method of instruction at SMA. Instead, labs tend to be more like glorified demonstrations of previously taught concepts. These labs are heralded by students more for the break they provide from the normal routine than because they are revelatory or helpful. While acknowledging the constraints that existed, I was looking for a way to

increase student engagement in labs in a way that improved the function of labs as a part of the teaching process. When I was introduced to the idea of phenomenon-based instruction I saw that this pedagogy had the potential to accomplish just that.

Phenomena are merely observable events carefully chosen to provoke student-generated questions. Many phenomena would be called demonstrations when used to illustrate a previously learned concept. Using these same observable events as phenomena instead of demonstrations, on the other hand, generates questions and acts as an anchor for subsequent student learning (National Science Teachers Association, 2016). By beginning with an engaging and unexplained phenomenon I hoped to spark students' wonder and inquisitiveness in the topic that would be covered in a subsequent lab. I hoped that this increased interest would result in increased engagement during the lab and ultimately lead to improvement in understanding of the concept being studied.

Focus Question

The focus question for this study was, What is the effect on student engagement and content mastery of using phenomena as a precursor to lab activities?

Classroom Description

I conducted this investigation in an advanced placement (AP) chemistry classroom with 14 students from the 11th and 12th grades. These students had previously taken a general chemistry course, were highly motivated, and were among the top students in their respective classes. In the small classroom setting, students had unique access to individual time with the instructor. They also worked closely with each other to

complete the tasks assigned to them. The project consisted of three labs – one lab preceded by phenomena and two labs without phenomena – and took place between January and March 2020. The three labs were drawn from units on kinetics, thermodynamics, and acids.

CONCEPTUAL FRAMEWORK

Laboratory Instruction in the United States

During the 19th century, the chemistry laboratory was principally a space dedicated to furthering that scientific field. Although ostensibly part of university education, the teaching laboratory was necessary to train people capable of collecting the kind of data required by the master of the laboratory. This model, pioneered by Justus von Liebig beginning in 1826, resembled an apprenticeship. Liebig consistently produced chemists who were able to produce high-quality data on many new compounds every year (Elliot, Stewart, & Lagowski, 2008).

Due to the consistent quality of the research produced by Liebig in his laboratory, people came from around Europe to the United States to learn from him. One student, Eben Horsford, brought Liebig's method of laboratory education to Harvard in 1846 and helped to establish the Lawrence Scientific School (Sheppard & Horowitz, 2006). This coincided with the founding of the Sheffield School of Science at Yale University and was partly motivated by the developing interest in agricultural chemistry in the country (Elliot et. al., 2008). Charles W. Eliot, Horsford's successor as the director of the Lawrence Scientific School and a Harvard graduate himself, dramatically changed the way science was taught in the United States when he made chemistry and physics mandatory entrance requirements at Harvard in 1869 (Elliot et. al., 2008; Sheppard & Robbins, 2005). In 1892, Eliot was asked to chair a committee of ten prominent educators, called the Committee of Ten, in order to set out guidelines for high schools to ensure that first-year university students had standard preparation for college. This

committee considered ancient and modern languages, mathematics, history, and the sciences. The subcommittee concerned with the physical sciences determined that one half of instructional time ought to be dedicated to laboratory work (Sheppard & Robbins, 2005). From this point on, work in the laboratory was established as a component of secondary school education and was widely assumed to be essential and beneficial (American Chemical Society, 2017; Hofstein & Lunetta, 1982).

Goals of Laboratory Instruction

After the laboratory became a feature of secondary school science education, questions arose regarding its goals and benefits. In the early part of the 20th century, objections were raised against the central role of lab work in schools. It was argued that the narrow and utilitarian nature of the lab manuals led to a narrow and utilitarian understanding of science and the scientific process, and that the lab work was trivial and uninteresting to the students (Hofstein & Lunetta, 1982; Kapuecinski, 1981). As well, it was argued that teachers were generally underprepared to lead students through the lab work effectively. As the century progressed, the perception of the goals of laboratory work changed from confirming scientific phenomena and training in laboratory skills to allowing students to learn how to inquire and investigate (Hofstein & Lunetta, 1982).

In the latter part of the 20th century, researchers attempted to articulate the goals of laboratory instruction more formally. These goals included acquisition of technical laboratory skills and improving student motivation and satisfaction, but they focused on higher order thinking skills, like critical thinking and problem solving, as well as

understanding the role of the scientist and the nature of science (Hofstein & Lunetta, 1982).

Styles of Laboratory Instruction

Science education can be abstract and divorced from sense experience. This makes it difficult for students to understand that the object of study is nature, and that the primary mode of understanding nature is the senses. Instead, they are overwhelmed by mathematical and technical accounts, and asked to master skills. A mode of laboratory instruction that returns the focus to the phenomena of nature offers a compelling remedy to this problem (Østergaard, Dahlin, & Hugo, 2008).

The principle styles of laboratory instruction today are generally understood to be expository, discovery, problem based, and inquiry. Expository labs, also commonly referred to as cookbook labs, have an outcome known to student and teacher, as well as a provided procedure. Discovery labs, also known as guided inquiry labs, have an outcome known to the teacher but not the students, and the teacher provides the procedure in the form of close guidance, if not step-by-step instructions. Problem based labs have predetermined outcomes but use student-generated procedures. Finally, inquiry labs have undetermined outcomes, and students generate their own procedures (Domin, 1999).

Inquiry has grown in favor along with the constructivist theory of learning. According to this theory, students generate knowledge through interaction with their environment (Bächtold, 2013). In addition, this method most closely resembles the laboratory methods employed by Liebig in the 19th century (Elliot et. al., 2008). Although many teachers begin their careers using the inquiry method, they tend to move away from

this style as they proceed in their teaching career (Wong, Firestone, Luft, & Weeks, 2013). One possible explanation for this trend is that the expertise and support required to continue this practice is frequently lacking, echoing the objections raised in the early part of the 20th century against laboratory work in general. Another possible cause for this trend is that the time and expense required to effectively implement the inquiry method is significantly greater than for the expository style (Wong et. al., 2013; Hofstein & Lunetta, 1982).

Phenomena-Based Instruction

An essential component of inquiry lab instruction is the use of natural phenomena. Phenomena-based instruction attempts to connect science instruction to concrete, everyday, sensible experience. Through the careful observation, description, reflection, and discussion of interpretations of natural phenomena, students are more engaged with the actual object being studied. This in turn leads to more effective learning and a decrease in misunderstandings (Østergaard et. al., 2008). A student who is taught a scientific concept and then provided with a demonstration of that concept after the fact may rightly wonder what the point of learning is. A student who is faced with a natural phenomenon for which he or she has no explanation, on the other hand, might not ever get to the point of wondering about the purpose of learning. The phenomenon the student observes provides relevant, immediate motivation for him to engage in the practices of formulating good questions and designing ways to answer those questions (National Science Teachers Association, 2016). The more students are given the opportunity to engage in these practices, the more likely students will be to develop the

habits of mind necessary to be scientifically literate and apply what they learn to their own lives. Presenting students with phenomena that don't fit into their current mental model gives them the opportunity to confront the attendant disequilibrium, use their senses and reason to explore the nature of the event, and construct a new understanding (Llewellyn, 2013).

If there is institutional skepticism regarding the benefits of the inquiry methodology or the adoption of the Next Generation Science Standards (NGSS), the use of phenomenon to engage students and enhance the effectiveness of expository labs seems to be a fruitful area for research. If this method proves to be effective, it would justify further attempts to implement a pedagogy aligned with the NGSS (National Science Teachers Association, 2016).

METHODOLOGY

IRB Exemption

In order to determine the effects of using phenomenon before expository labs, a series of labs were conducted with 11th and 12th grade students in an AP chemistry classroom. One was preceded by a phenomenon activity (treatment lab), and two labs were not preceded by a phenomenon activity (comparison labs). The research methodology for this project received an exemption by Montana State University's Institutional Review Board and compliance for work with human subjects was maintained (Appendix A).

Data Collection

In order to answer the focus question of this study, data were collected from four sources: a phenomenon activity, content tests, the Student Engagement Survey, and observations and interviews.

Phenomenon Activity

The treatment lab was preceded by a phenomenon activity in which students were shown a phenomenon related to the concept to be covered in the subsequent lab (Appendix B). Students were then encouraged to make observations, ask questions, and generate hypotheses to explain and explore the phenomenon they had witnessed. Finally, students suggested possible experiments that could answer the questions they asked or

test the hypotheses they had generated. By contrast, the non-treatment labs were not preceded by a phenomenon activity.

Content Tests

Students took content tests before and after each treatment and non-treatment lab (Appendices C – E). In the case of the treatment lab, the pre-test was administered before the phenomenon activity. These tests covered concepts from the same unit as those covered in the corresponding lab. Class average scores were analyzed using box-and-whisker plots for distribution, mean, and median to assess improvement as a class. Individual students' scores were analyzed using normalized gains. Normalized gains were divided into high, normal, and low ranges, and average normalized gain was used to characterize the normalized gain of the whole class. A permutation test was used to determine whether differences in average normalized gain were statistically significant.

Engagement Surveys

After each lab, students completed the Likert-type Student Engagement Survey concerning their engagement with the lab and confidence in related concepts (Appendix F). Responses were compared using juxtaposed bar plots to reveal any differences between the treatment and non-treatment units. A Wilcoxon Signed-Rank Test was used to compare responses for each question to determine whether there was any significant difference in response frequency.

Observations and Interviews

These quantitative data were supported by teacher observations during the phenomenon activities and labs, as well as by student interviews. Teacher observations of student engagement were recorded after each phenomenon activity and lab, aided by reviewing audio and video recordings. Students were also randomly selected to participate in interviews after each phenomenon activity and after every lab (Appendix G). These interviews and observations were analyzed for themes and used to support the quantitative data generated by the content tests and Student Engagement Surveys. Data sources are summarized in the Data Triangulation Matrix (Table 1).

Table 1. Data Triangulation Matrix.

| Focus Question | Source 1 | Source 2 | Source 3 | Source 4 |
|--|-----------------------------------|---|---|------------------------------------|
| What is the effect of using phenomenon as a precursor to lab activities? | Pre-lab and post-lab content test | Teacher observations during labs and phenomena. | Post-phenomena, and post-lab interviews | Post-lab Student Engagement Survey |

DATA ANALYSIS

Results

Data were grouped for analysis depending on whether they pertained to content mastery or student engagement.

Content Mastery

Students' scores on the 15-point treatment content test increased from an average of 10.8 to 13.1 ($N=10$). The median score increased from 11 to 14 and the lower quartile on the post-test exceeded the median score of the pre-test (Figure 1). Comparing the pre and post-tests revealed an average normalized gain of 0.5. Normalized gains that fall in the range of 0.3—0.7 are considered moderate. Sixty percent of students achieved

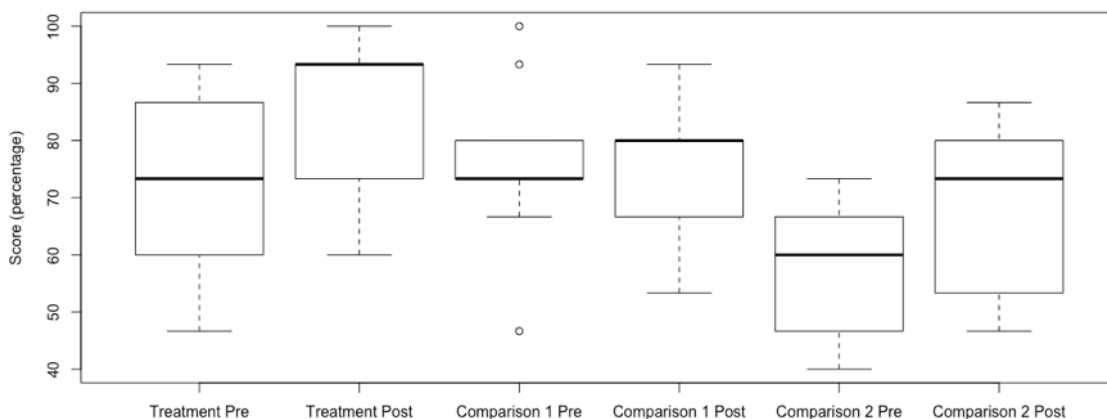


Figure 1. Boxplots showing score distribution of the Treatment Kinetics ($N=10$), Comparison 1 Calorimetry ($N=13$), and Comparison 2 Titration ($N=13$) content tests.

normalized gains in this moderate range, while 20% achieved normalized gains in the high range of >0.7 (Figure 2). This moderate increase in understanding was reflected in student interviews as well. When asked whether the lab helped understand the concepts

in this unit better one student replied, “Kinda, I guess, not a crazy amount, but it was fun. I guess it reinforced it.”

In contrast, comparing the pre- and post-test scores from the first comparison lab, on calorimetry, revealed an average normalized gain of -0.3 ($N=13$) (Figure 2).

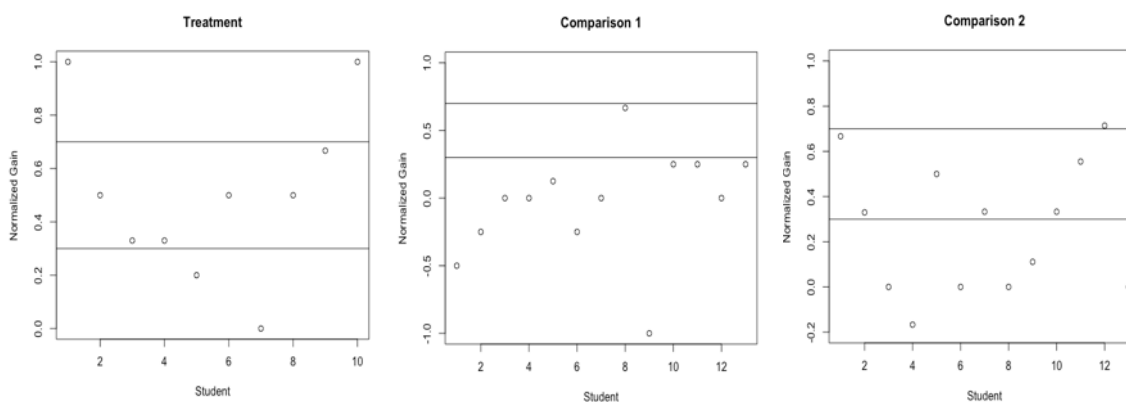


Figure 2. Scatterplot showing normalized gains from the Treatment Kinetics ($N=10$), Comparison 1 Calorimetry ($N=13$), and Comparison 2 Titration ($N=13$) content tests.

However, this included a student whose score decreased from 15 (100%) to 14 (93%) for a normalized gain of -1 . Discounting this, the average normalized gain was 0.045.

More than half of students showed no improvement or a decrease in performance, while only one student fell into the moderate range. A permutation test was used to compare the normalized gains observed in the treatment and first comparison tests.

The permutation test rejected the null hypothesis of no difference between the two values, indicating a significant difference in average normalized gain ($p=0.002$).

A similar examination of the scores from the second comparison lab, on titration, revealed an average normalized gain of 0.26 ($N=13$). Although this is in the low range, a permutation test did not reject the null hypothesis that the average normalized gain was

equal to 0.3 ($p= 0.19$). Thus, this normalized gain must be considered to be in the moderate range. Forty-six percent of students had normalized gains in the moderate range and one student had a normalized gain in the high range. Student interviews likewise indicated a moderate increase in understanding. One student reported, “I think it helped me visualize the titration graph...The lab helped me realize that there were different zones with different calculations.” Another student said, “Honestly, it did [help] because of the calculations at the end, but the actual doing it was just fun. Like, I knew everything from before that.” The same student didn’t think there would have been much difference if the calculations had been performed from data given by the teacher as opposed to collected by the student, but she reiterated that “it was more fun” to collect the data herself. Again, a permutation test was used to compare the normalized gains observed in the treatment and second comparison lab. The permutation test failed to reject the null hypothesis of no difference between the two values, indicating no significant difference in average normalized gain at the 0.05 level but providing compelling evidence of a potential relationship ($p=0.07$).

Table 2. P values derived from applying a Wilcoxon Signed-Rank test to Student Engagement Survey responses from Treatment ($N=14$), Comparison 1 ($N=12$), and Comparison 2 ($N=12$) labs.

| | Question | | | | | | | |
|----------------------------|----------|-----|-----|-----|-----|------|-----|-----|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Treatment vs. Comparison 1 | 0.3 | 0.5 | 0.4 | 0.8 | 0.9 | 0.04 | 0.3 | 0.8 |
| Treatment vs. Comparison 2 | 1 | 0.4 | 0.4 | 0.8 | 1 | 0.09 | 0.3 | 0.5 |

Four of the questions on the Student Engagement Survey related to students' perceptions of their understanding of relevant concepts (Figure 3). In each lab, almost 100% of students agreed or strongly agreed with the statement, "Before doing the lab, I understood what question we were trying to answer" and 100% of students agreed or strongly agreed with the statement, "I understand what our results mean." In both cases, a Wilcoxon Signed-Rank test failed to reject the null hypothesis of no difference in response frequency between treatment and comparison labs (Table 2). When asked whether they understood the question they were trying to answer before the lab, students generally agreed. One student interviewed after the calorimetry lab said, "We were trying to find out which one [salt] was the most exothermic, right? I was thinking about it, oh, this one won't work because it doesn't create as much heat."

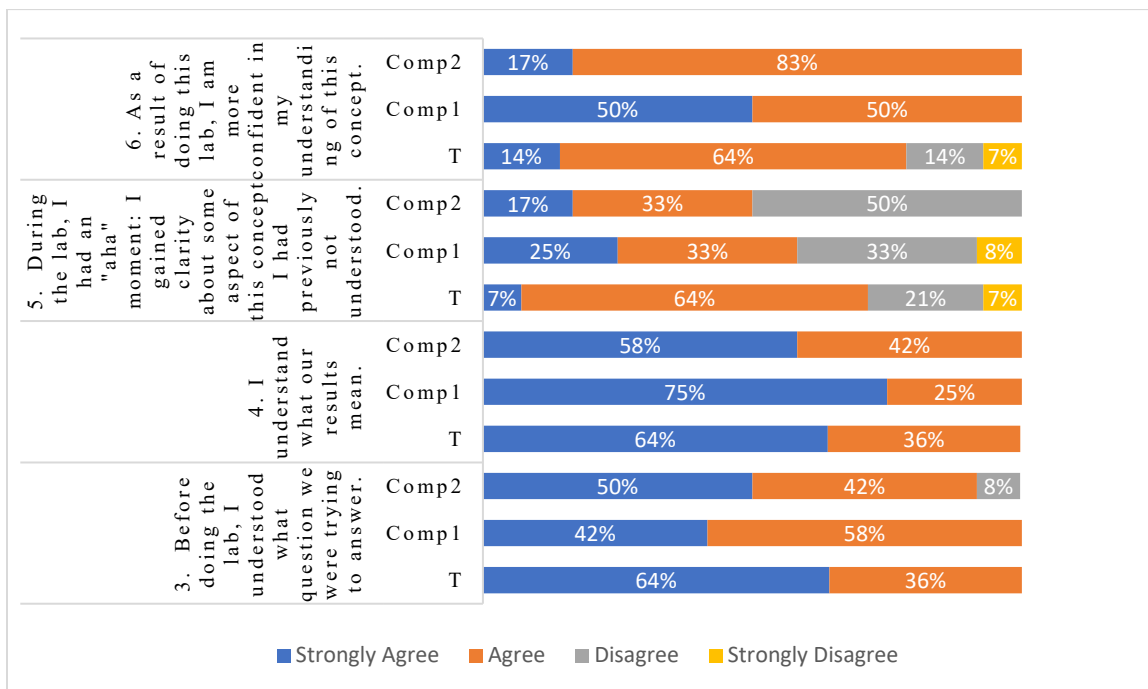


Figure 3. Student Engagement Survey results for questions 3, 4, 5, and 6 from the Treatment ($N=14$), Comparison 1 ($N=12$), and Comparison 2 ($N=12$) labs.

Students were less uniformly positive when asked if the lab helped them to gain clarity. After the treatment lab, 64% of students agreed that they had gained clarity about some aspect of the concept being covered, but only 7% strongly agreed. Meanwhile, 50% of students disagreed with the same statement after the second comparison lab, and 41% of students disagreed or strongly disagreed after the first comparison lab. However, a Wilcoxon Signed-Rank test failed to reject the null hypothesis of no difference in response frequency between treatment and comparison labs.

Although only 58% of students agreed or strongly agreed that they had gained clarity during the first comparison lab, 100% of students agreed or strongly agreed that they were more confident in their understanding of calorimetry after the lab. Meanwhile, only 78% of students felt more confident after the treatment lab, and 21% did not feel more confident. In this case, a Wilcoxon Signed-Rank test rejected the null hypothesis of no difference in response frequency, indicating a significant difference between the treatment and first comparison lab.

Engagement

The other four questions on the Student Engagement Survey related to student perception of their own engagement (Figure 4). Students almost all strongly agreed that they were active members of their groups during the labs, and no students disagreed. Ninety-two percent of students strongly agreed that they were active participants during the second comparison lab. Teacher observations during the second comparison lab also recorded “notable intragroup conversation” during the titration, “likely due to navigating

the technical aspects of performing a titration.” A Wilcoxon Signed-Rank test failed to reject the null hypothesis of no difference in response frequency.

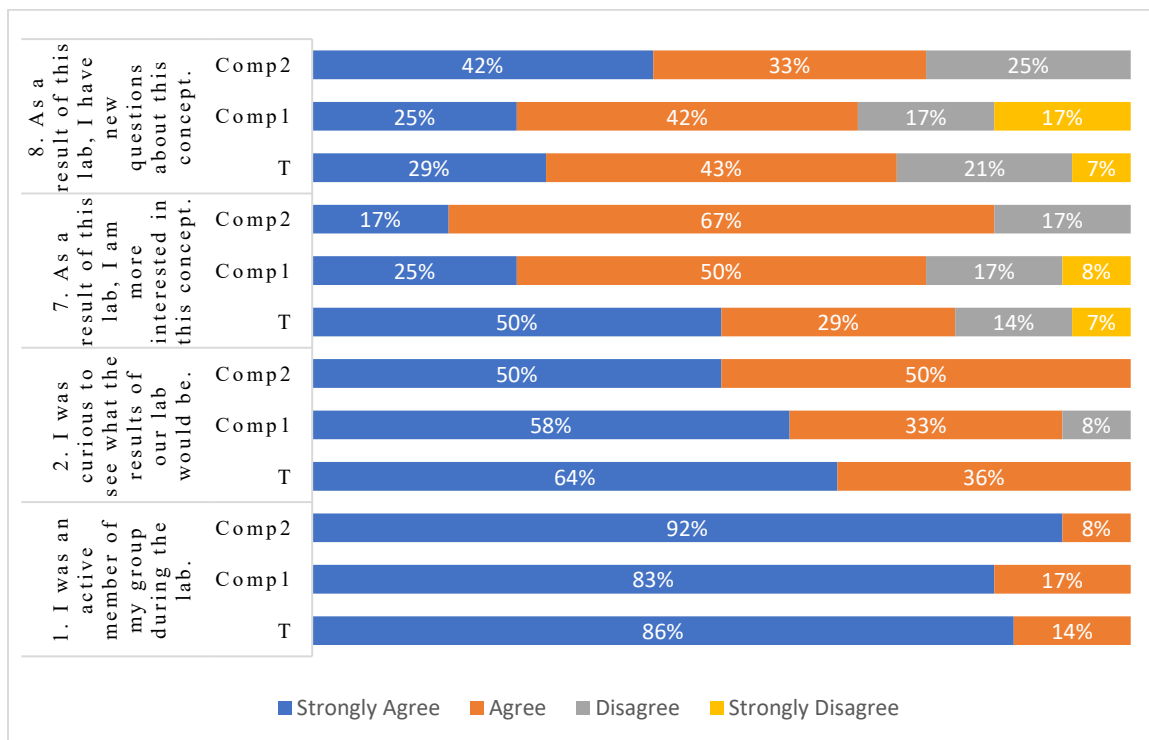


Figure 4. Student Engagement Survey results from the Treatment ($N=14$), Comparison 1 ($N=12$), and Comparison 2 ($N=12$) labs.

Students almost universally agreed or strongly agreed that they were curious to see the results of each lab, but responses were more evenly distributed than those regarding active participation. After the treatment lab, a few students expressed that the phenomenon activity dampened their curiosity about the lab. One student said, “I was a little less curious because you know what was going to happen. There was no suspense of ‘Oh, what’s the lab going to be?’” Another student noted that, while the phenomenon activity “made [the lab] clearer, it would have been cooler if we didn’t know what was going to happen.”

Although students were critical of some aspects of the phenomenon activity, they also expressed a preference for the treatment as opposed to the comparison. Regarding the treatment lab, one student remarked, “The demo that we did was really cool and fun, and I was thinking about it during the lab.” Additionally, after the first comparison lab, another student expressed that she thought she would have been more engaged in the lab if there had been a phenomenon activity beforehand.

Students generally agreed or strongly agreed that each lab increased their interest in, and that they had new questions about, the relevant concept. However, around 20% of students disagreed or strongly disagreed in each case. Again, a Wilcoxon Signed-Rank test failed to reject the null hypothesis of no difference in response frequency for either of these questions.

CLAIM, EVIDENCE, AND REASONING

Claims From the Study

Although there was a significant difference between the treatment lab average normalized gain and the calorimetry comparison lab average normalized gain, there was no significant difference between the treatment and titration comparison. Similarly, the only significant difference in response frequency on the Student Engagement Survey was seen between the treatment and the calorimetry comparison lab. One might reasonably conclude, therefore, that there are other factors at play that led to the treatment being effective in one case but not the other. For example, the time required to collect one set of data in the titration lab was much greater than in the calorimetry lab. Additionally, students were required to pay much closer attention to the technical details of the lab procedure during the titration lab than during the calorimetry lab. It seems plausible that the greater quantity of data collected, and the corresponding practice in calorimetry calculations and interpretations, contributed to the greater improvement in student understanding. As well, being less preoccupied with executing the lab technically may have allowed students to spend more of their energy during and after the lab processing the conceptual meaning of the lab. Both of these would contribute to higher normalized gains.

The lack of significant difference in response frequency across all but one of the Student Engagement Survey questions also corresponded to a uniformity in student interview responses. Students were positive about doing labs in general, but more ambivalent about the effect they had on understanding. They expressed a preference for

the treatment, but mostly expressed an appreciation for labs generally. As one student put it, “the more experience that we have, you know, the more labs that we do it helps me remember and helps me visualize.”

Considering these points, this study did not demonstrate that using phenomenon as a precursor to lab activities universally had a significant effect on engagement or concept mastery. Nevertheless, the effectiveness of the treatment in one instance suggests that the treatment has the potential to be more universally effective.

Value of the Study and Consideration for Future Research

One factor that affected the quality of this study was the unexpected closure of St. Monica Academy due to the COVID-19 pandemic. The school closed the day before the intended administration of the second treatment lab and precluded the possibility of collecting any more data. With this in mind, this same topic would benefit from further investigation. In particular, it would be valuable to reflect on the current study to isolate and control the confounding factors that may have led to the discrepant results.

Based on the experience of this study, it also seems valuable to investigate the impact of phenomena-based pedagogy as a whole, not merely in lab instruction. Students have a tendency to approach their learning with a lack of wonder and critical engagement. Surely this is partly due to pedagogies that take for granted that knowledge is something passed on from teacher to student. This mindset does not incentivize student ownership of learning, nor does it correspond to the way students actually come to know. Although the current study did not manage to conclusively demonstrate the effectiveness of phenomena-based lab instruction, the process of implementing the study

was effective in convincing my students and some of my colleagues that there is merit in a phenomena-based approach to science education.

Impact of Action Research on the Author

Based on the literature review conducted for this study and an examination of my own experience during the study, I have become convinced that not only could a pedagogy that begins with phenomena be effective, but also that it corresponds with the most natural mode of learning for students. Although the current study was limited in scope to lab instruction, I began to use the same philosophy when introducing concepts during lectures. This did not always take the form of a demonstration, but it began to supplant my previous practice of using examples to illustrate a concept already taught. In addition, learning about and implementing the Action Research process fundamentally altered my perspective on my own practice. In particular, it shifted my attention from mastering material to the reflective, collaborative, and cyclical process of examining and improving my teaching in my particular circumstances. I more frequently sought feedback from my students in the form of interviews and formative assessments when I wanted to know whether my teaching was effective. I have become more open to collaborative feedback from colleagues and students alike, and I have become an advocate among my colleagues for this process as an effective – even essential – practice for teachers.

REFERENCES CITED

- American Chemical Society. (2017). Importance of hands-on laboratory science. Retrieved from <https://www.acs.org/content/acs/en/policy/publicpolicies/education/computersimulations.html>
- Bächtold, M. (2013). What do students “construct” according to constructivism in science education? *Research in Science Education*, 43(6), 2477. doi:10.1007/s11165-013-9369-7
- Domin, D. S. (1999). A review of laboratory instruction styles. *Journal of Chemical Education*, 76(4), 543. doi:10.1021/ed076p543
- Elliott, M. J., Stewart K. K., & Lagowski, J. J. (2008). The role of the laboratory in chemistry instruction. *Journal of Chemical Education*, 85(1), 145. doi:10.1021/ed085p145
- Hofstein, A., & Lunetta, V. N. (1982). The role of the laboratory in science teaching: Neglected aspects of research. *Review of Educational Research*, 52(2), 201. doi:10.1002/sce.10106
- Kapuecinski, B. P. (1981). The purpose of laboratory instruction in high school. *Journal of Chemical Education*. 58(2), 194. doi:10.1021/ed058p194
- Llewellyn, D. (2013) *Teaching High School Science Through Inquiry and Argumentation* (2nd ed.). Corwin.
- National Science Teachers Association (2016). Using phenomena in NGSS-designed lessons and units. Retrieved from <https://www.nextgenscience.org/sites/default/files/Using%20Phenomena%20in%20NGSS.pdf>
- Sheppard, K, & Horowitz, G., (2006). From Justus von Liebig to Charles W. Eliot: The establishment of laboratory work in U.S. high schools and colleges. *Journal of Chemical Education*, 83(4), 566. doi:10.1021/ed083p566
- Sheppard, K, & Robbins, D. M. (2005). Chemistry, the central science? The history of the high school science sequence. *Journal of Chemical Education*, 82(4), 561. doi:10.1021/ed082p561
- St. Monica Academy. (2020). *Ensuring Education Excellence*. Internal St. Monica Academy self-study: unpublished.
- St. Monica Academy Midterm Progress Report. (n.d.) Retrieved from www.stmonicaacademy.com/wp-content/uploads/WASC%20Midterm%20Report.pdf

- Østergaard, E, Dahlin, B, & Hugo, A., (2008). Doing phenomenology in science education: A research review. *Studies in Science Education*, 44(2), 93-121. doi:10.1080/03057260802264081
- Wong, S. S., Firestone, J. B., Luft, J. A., & Weeks, C. B. (2013). Laboratory practices of beginning secondary science teachers: A five-year study. *Science Educator*, 22(1), 1–9. Retrieved from <https://files.eric.ed.gov/fulltext/EJ1062174.pdf>

APPENDICES

APPENDIX A

INSTITUTIONAL REVIEW BOARD EXEMPTION



**INSTITUTIONAL REVIEW BOARD
For the Protection of Human Subjects
FWA 00000165**

2155 Analysis Drive
c/o Microbiology & Immunology
Montana State University
Bozeman, MT 59718
Telephone: 406-994-4706
FAX: 406-994-4303
E-mail: cherylj@montana.edu

Chair: Mark Quinn
406-994-4707
mquinn@montana.edu
Administrator:
Cheryl Johnson
406-994-4706
cherylj@montana.edu

MEMORANDUM

TO: Thomas Quackenbush and John Graves
FROM: Mark Quinn *Mark Quinn*
Chair, Institutional Review Board for the Protection of Human Subjects
DATE: November 12, 2019
RE: "The Effect of Phenomena on Lab Engagement and Concept Mastery" [TQ111219-EX]

The above research, described in your submission of November 12, 2019, 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:

- (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 the comparison among instructional techniques, curricula, or classroom management methods.
- (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; and (iii) the information obtained is recorded by the investigator in such a manner that the identity of the human subjects can readily be ascertained, directly or through identifiers linked to the subjects, and an IRB conducts a limited IRB review to make the determination required by section 16.111(a)(7).
- (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 subject to the approval of department or agency heads, 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, (i) if wholesome foods without additives are consumed, or (ii) 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 B

CLOCK PHENOMENA WORKSHEET

Clock Phenomenon

Name _____

Observations:

Questions:

Hypotheses:

APPENDIX C

KINETICS CONTENT TEST

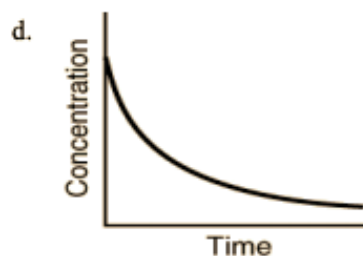
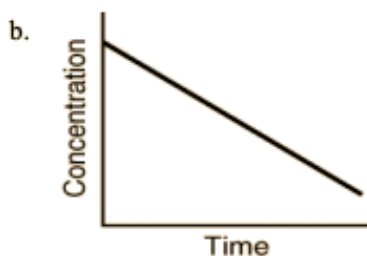
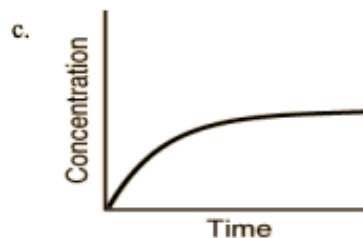
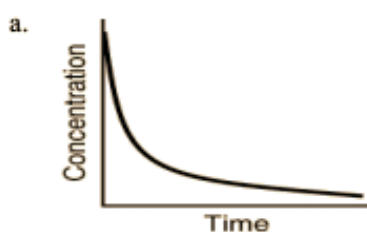
Kinetics Test

Name: _____

Participation in this pre/post test is **voluntary** and participation or non-participation will **not** affect your grade or class standing in any way.

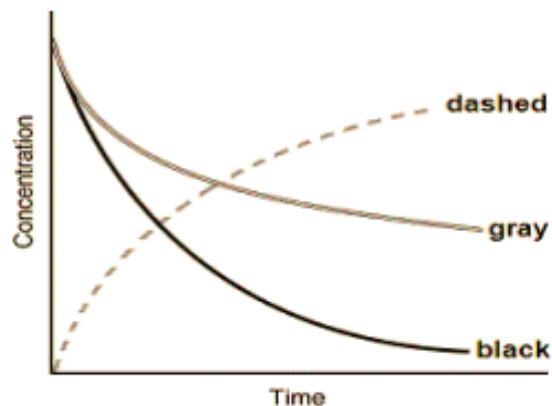
1. A reaction that is considered to be fast is likely to have which of the following characteristics?
 - a. A high activation energy
 - b. A high temperature
 - c. A low collision frequency
 - d. Reactants in low concentrations
2. When solid zinc metal reacts with an aqueous solution of hydrochloric acid, which factors are relevant in determining the rate of the reaction?
 - a. Temperature and surface area only
 - b. Temperature and concentration only
 - c. Concentration and surface area only
 - d. Temperature, concentration and surface area
3. Which situation best describes a successful collision (one that leads to a chemical reaction)?
 - a. The reactants collide
 - b. The reactants collide with sufficient energy
 - c. The reactants collide with sufficient energy and the correct orientation
 - d. All collisions are successful
4. Which of the following is a bimolecular reaction?
 - e. $A + A \rightarrow B$
 - f. $A \rightarrow B$
 - g. $2A + B \rightarrow C$
 - h. $A + 2B \rightarrow C + D$
5. In which of the following rate laws will the units of rate are equal to the units of the rate constant?
 - a. $\text{Rate} = k [A]^0$
 - b. $\text{Rate} = k [A]$
 - c. $\text{Rate} = k [A] [B]$
 - d. $\text{Rate} = k [A] [B] [C]^0$

6. For the reaction $A + 3B \rightarrow 2C$, how does the rate of disappearance of B compare to the rate of production of C?
- the rate of disappearance of B is $\frac{1}{2}$ the rate of appearance of C
 - the rate of disappearance of B is $\frac{3}{2}$ the rate of appearance of C
 - the rate of disappearance of B is $\frac{2}{3}$ the rate of appearance of C
 - the rate of disappearance of B is $\frac{1}{3}$ the rate of appearance of C
7. Which of the following could **not** be a possible graph of concentration versus time for a reactant?

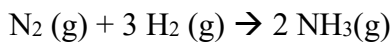


8. The following graph shows the kinetics curves for the reaction of oxygen with hydrogen to form water: $O_2(g) + 2H_2(g) \rightarrow 2H_2O(g)$. Which curve is hydrogen?

- the dashed curve
- the gray curve
- the black curve
- either the gray or the black curve



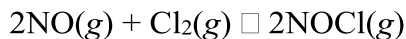
9. If the rate of formation of ammonia is 0.345 M/s, what is the rate of disappearance of N_2 ?



- a. 0.173 M/s
 b. 245 M/s
 c. 0.345 M/s
 d. 0.518 M/s
10. The reaction $A + 2B \rightarrow C$ is first order in B and A. The overall order of the reaction is:
 a. First
 b. Second
 c. Third
 d. Fourth

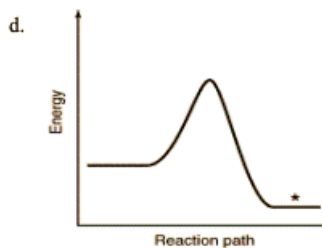
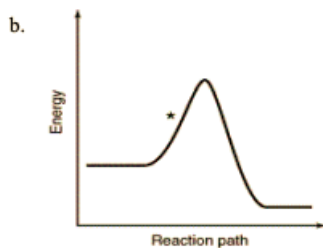
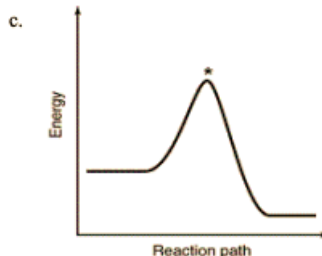
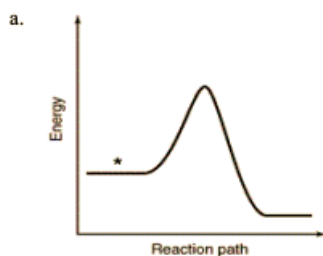
11.

Given the following data, determine the order of the reaction with **respect to Cl_2** .

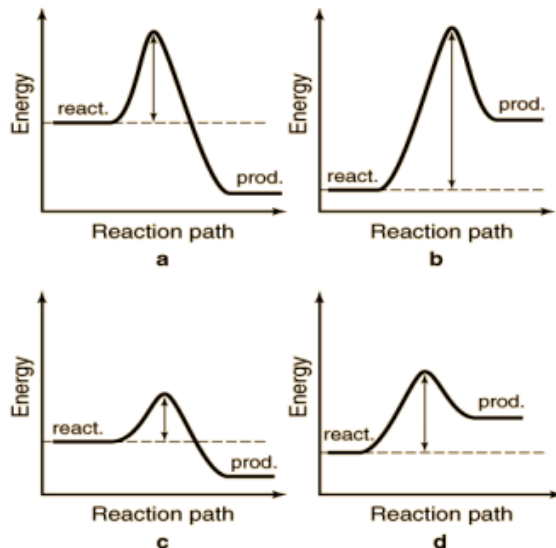


| <i>Experiment</i> | <i>[NO] (M)</i> | <i>[Cl₂] (M)</i> | <i>Rate (M/s)</i> |
|-------------------|-----------------|-----------------------------|---------------------|
| 1 | 0.0300 | 0.0100 | $3.4 \cdot 10^{-4}$ |
| 2 | 0.0150 | 0.0100 | $8.5 \cdot 10^{-5}$ |
| 3 | 0.0150 | 0.0400 | $3.4 \cdot 10^{-4}$ |

12. Which point as labeled by an asterisk (*) on the following energy profile is the transition state?



13. Which reaction is the most endothermic?



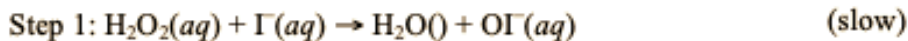
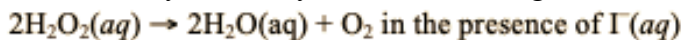
14. A proposed mechanism for the reduction of nitrogen as NO by hydrogen is:



What is the rate law?

- Rate = $k[\text{H}_2][\text{NO}]$
- Rate = $k[\text{H}_2]^2[\text{NO}]$
- Rate = $k[\text{H}_2][\text{NO}]^2$
- Rate = $k[\text{H}_2]^2[\text{NO}]^2$

15. Identify the catalyst in the following reaction:



- H_2O_2
- H_2O
- OI^-
- O_2
- I^-

APPENDIX D

CALORIMETRY CONTENT TEST

Calorimetry Test

Name _____

Participation in this pre/post test is **voluntary** and participation or non-participation will **not** affect your grade or class standing in any way.

1. What does the symbol ΔH stand for?
 - a. Specific heat of a substance
 - b. Heat capacity of a substance
 - c. Heat of reaction for a chemical reaction
 - d. The spontaneity of a reaction
2. When matter made up of particles with relatively high kinetic energies is brought into contact with matter made up of particles with relatively low kinetic energies, what will likely occur?
 - a. A transfer of energy from cold matter to hot matter
 - b. Ultimately, the establishment of a thermal equilibrium
 - c. Work being done by the low energy particles on the high energy particles
 - d. An overall loss of energy
3. What is the heat (or enthalpy) of solution?
 - a. The amount of heat required to change a solid into a liquid
 - b. The amount of heat absorbed or released when a substance dissolves
 - c. The amount of heat required to change a vapor into a liquid
 - d. The amount of heat absorbed or released as a substance precipitates out of solution.
4. In an exothermic chemical reaction, where the reaction is considered to be the system:
 - a. Energy is transferred from the system to the surroundings and ΔH_{system} is positive.
 - b. Energy is transferred from the system to the surroundings and ΔH_{system} is negative.
 - c. Energy is transferred to the system from the surroundings and ΔH_{system} is positive.
 - d. Energy is transferred to the system from the surroundings and ΔH_{system} is negative.

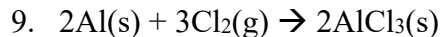
5. When two bodies at different initial temperatures reach thermal equilibrium after being in thermal contact, which of the following is true?
- The average kinetic energy of the particles in both bodies will be the same
 - Energy will have been transferred from the cold body to the hot body in the process of achieving thermal equilibrium
 - The temperature at thermal equilibrium will be exactly halfway between the initial colder body and the initial warmer body.
 - Energy will be transferred in the form of work
6. ΔH_{son} is
- Always positive
 - Always negative
 - Always zero
 - Sometimes positive, sometimes negative
7. Which equation below best represents the energy associated with the system and the surroundings when energy is transferred via heat from one to the other?
- $q_{\text{system}} = q_{\text{surroundings}}$
 - $q_{\text{system}} = -q_{\text{surroundings}}$
 - $-q_{\text{system}} = -q_{\text{surroundings}}$
 - $q_{\text{system}}/q_{\text{surroundings}} = 0$
8. A 100.0 gram sample of aluminum metal is heated to 80.00°C and then immersed in a relatively cold water bath containing 0.1000 kilograms of water until thermal equilibrium is established. The specific heat capacity of water is known to be 4.200 J/g°C, and the apparatus is considered to be perfectly insulated. The following data are collected.

Initial temperature of water: 25.00°C

Final temperature of water and metal: 34.79°C

According to the data, which of the following is the correct set-up for the calculation of the specific heat capacity of Al, if it is assigned a value of x?

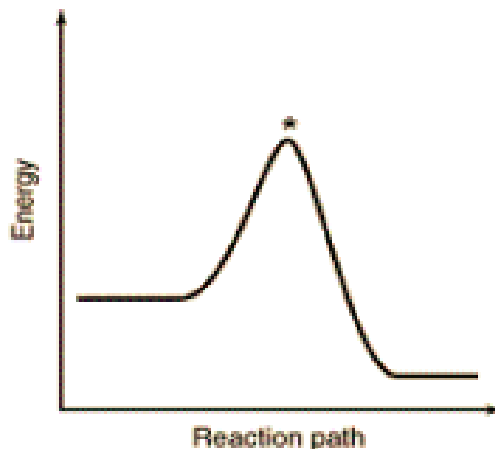
- $(0.1000)(4.200)(34.79-25.00) = -(100.0)(x)(34.79-80.00)$
- $(100.0)(4.200)(34.79-25.00) = (100.0)(x)(34.79-80.00)$
- $(0.1000)(4.200)(34.79-25.00) = (100.0)(x)(34.79-80.00)$
- $(100.0)(4.200)(34.79-25.00) = -(100.0)(x)(34.79-80.00)$



The reaction above is *not* thermodynamically favored under standard conditions, but it becomes thermodynamically favored as the temperature decreases toward absolute zero. Which of the following is true at standard conditions?

- ΔS and ΔH are both negative
 - ΔS and ΔH are both positive
 - ΔS is negative and ΔH is positive
 - ΔS is positive and ΔH is negative
10. When ammonium chloride dissolves in water, the temperature drops. Which of the following is a valid conclusion?
- Ammonium chloride is more soluble in cold water
 - The heat of solution for ammonium chloride is endothermic
 - The heat of solution for ammonium chloride is exothermic
 - Ammonium chloride has a low lattice energy.
11. A solution is prepared by dissolving solid ammonium nitrate in water. The initial temperature of the water was 25°C , but after the solid had dissolved, the temperature fell to 20°C . What conclusions may be made about ΔH and ΔS ?
- $\Delta H < 0$ $\Delta S > 0$
 - $\Delta H > 0$ $\Delta S > 0$
 - $\Delta H > 0$ $\Delta S < 0$
 - $\Delta H < 0$ $\Delta S < 0$
12. When 45 g of an alloy at 25°C are dropped into 100.0g of water, the alloy absorbs 956 J of heat. If the final temperature of the alloy is 37°C , what is its specific heat in $\text{J/g}^\circ\text{C}$?
- 0.423
 - 1.77
 - 9.88
 - 48.8
13. Two metals of equal mass but different specific heats absorb the same amount of heat. Which metal undergoes the *smaller* change in temperature?
- The metal with the higher specific heat
 - The metal with the lower specific heat
 - Both undergo the same change
 - Cannot be determined

14. Potassium iodide is an ionic solid. When it dissolves in water, $\Delta H > 0$. Which of the following interactions is the best explanation for this fact?
- The attraction between the K^+ and the hydrogen side of water molecules, and the attraction between I^- ions and oxygen side of water molecules in solution.
 - The attraction between the K^+ and the oxygen side of water molecules, and the attraction between I^- ions and hydrogen side of water molecules in solution.
 - The attraction between the K^+ and I^- ions in the crystal lattice and the attraction between the water molecules in liquid water.
 - The heat capacity of KI is smaller than the heat capacity of water.
15. Consider the reaction represented in the diagram below. Which of the following is true?



- The reaction is endothermic because the reactants have more potential energy than the products.
- The reaction is endothermic because the reactants have less potential energy than the products.
- The reaction is exothermic because the reactants have more potential energy than the products.
- The reaction is exothermic because the reactants have less potential energy than the products.

APPENDIX E

ACID/BASE CONTENT TEST

Acid/Base Test

Name _____

Participation in this pre/post test is **voluntary** and participation or non-participation will **not** affect your grade or class standing in any way.

1. What is the pH of a 0.001 M solution of a strong, monoprotic acid?
 - a. 1
 - b. 3
 - c. 11
 - d. The value of K_a is needed.
2. Which of the following salts will produce an *acidic* solution?
 - a. Sodium acetate
 - b. Potassium chloride
 - c. Ammonium chloride
 - d. Sodium nitrate
3. Which of the following acids would be the strongest?
 - a. 0.1 M ($K_a = 7.1 \times 10^{-3}$)
 - b. 0.2 M ($K_a = 7.1 \times 10^{-7}$)
 - c. 0.1 M ($K_a = 7.1 \times 10^{-10}$)
 - d. 0.2 M ($K_a = 7.1 \times 10^{-12}$)

4. At normal body temperature of a human, 37°C, the equilibrium constant for the dissociation of water is higher than it is at 25°C, as shown in the equilibrium expression.

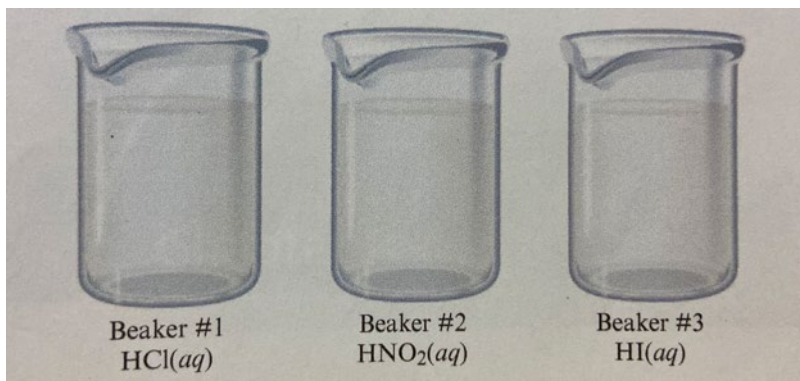
$$K_w = [\text{H}^+][\text{OH}^-] = 2.42 \times 10^{-14}$$

What is true of pure water at 37°C?

- a. Water is neutral because the hydrogen and hydroxide ion concentrations are equal.
 - b. Water is basic because the hydroxide ion concentration is greater than $1 \times 10^{-7} \text{ M}$
 - c. Water is acidic because the hydrogen ion concentration is greater than $1 \times 10^{-7} \text{ M}$
 - d. Water is neutral because the hydrogen and hydroxide ion concentrations are each $1 \times 10^{-7} \text{ M}$
5. What is the conjugate acid of HPO_4^{2-} ?
 - a. H_3O^+
 - b. PO_4^{3-}
 - c. H_2PO_4^-
 - d. H_3PO_4

6. A weak acid, HZ, has K_a of 1.0×10^{-7} . What is the pH of a 0.10 M solution of HZ?
- 1.00
 - 3.50
 - 4.00
 - 7.00

Questions 7 – 9 refer to the following solutions



Each beaker contains 100 mL of the indicated acidic solution, all with a pH of 3.00

$$K_a \text{ for } \text{HNO}_2 = 4.0 \times 10^{-4}$$

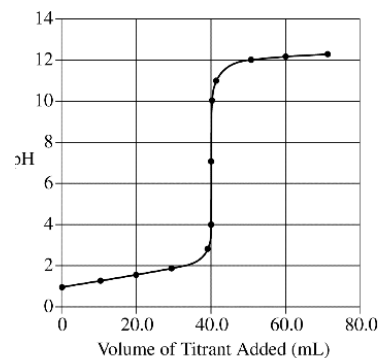
7. Which beaker would have the highest hydrogen ion concentration?
- Beaker 1 has the highest hydrogen ion concentration
 - Beaker 2 has the highest hydrogen ion concentration
 - Beaker 1 and 3 are equally high.
 - All have the same concentration.
8. Which solution has the highest percent ionization?
- Beaker 1 has the highest percent ionization.
 - Beaker 2 has the highest percent ionization
 - Beakers 1 and 3 are equally high.
 - All have the same percent ionization.
9. If 50 mL of 0.1 M NaOH was added to each beaker, which resulting solution would have the lowest pH?
- Beaker 1 would have the lowest pH
 - Beaker 2 would have the lowest pH
 - Beakers 1 and 3 are equally low.
 - All would have the same pH

Questions 10 and 11 refer to the following information:

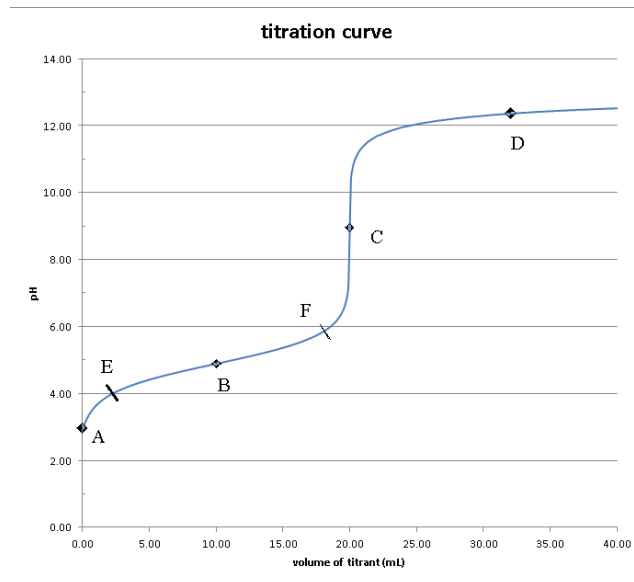


10. Which acid solution has a greater pH?
- HA because it dissociates less than HX
 - HA because it dissociates more than HX
 - HX because it dissociates less than HA
 - HX because it dissociates more than HA
11. How would diluting HA from 0.15 M to 0.005 M affect the pH of the solution?
- The pH would decrease because the $[H^+]$ decreases.
 - The pH would decrease because the $[H^+]$ increases.
 - The pH would increase because the $[H^+]$ decreases.
 - The pH would increase because the $[H^+]$ increases.
12. A 0.10 M HCl solution may be titrated with two different bases: 0.10 M NaOH or 0.10 M $Ca(OH)_2$. Which statement best describes the volumes of bases necessary to reach the equivalence point?
- Half as much NaOH is needed.
 - Equal volumes of NaOH and $Ca(OH)_2$ are needed.
 - Twice as much $Ca(OH)_2$ is needed.
 - Twice as much NaOH is needed.
13. A student uses acetic acid to titrate a solution of copper(I) hydroxide to determine the concentration of the copper(I) hydroxide. If 30.0 mL of 0.250 M acetic acid is needed to neutralize 15.0 mL of copper(I) hydroxide, what is the molarity of the copper(I) hydroxide solution?
- 0.125 M
 - 0.250 M
 - 0.375 M
 - 0.500 M

14. Which of the following best describes the titration data below:
- Titration of strong acid by weak base
 - Titration of strong base by weak acid
 - Titration of strong acid by strong base
 - Titration of weak acid by weak base.



15. Which of the following best describes the titration data below:
- Titration of strong acid by weak base
 - Titration of strong base by weak acid
 - Titration of strong acid by strong base
 - Titration of weak acid by weak base.



APPENDIX F

STUDENT ENGAGEMENT SURVEY

Please consider each of the following statements and choose the answer that best describes your agreement with the statement. Participation in this survey is **voluntary** and participation or non-participation will **not** affect your grade or class standing in any way.

| | Strongly Agree | Agree | Disagree | Strongly Disagree |
|---|----------------|-------|----------|-------------------|
| I was an active member of my group during the lab. | | | | |
| I was curious to see what the results of our lab would be. | | | | |
| Before doing the lab, I understood what question we were trying to answer. | | | | |
| I understand what our results mean. | | | | |
| During the lab, I had an "aha" moment: I gained clarity about some aspect of [insert concept] I had previously not understood. | | | | |
| As a result of doing this lab, I am more confident in my understanding of [insert concept] . | | | | |
| As a result of doing this lab, I am more interested in [insert concept] . | | | | |
| As a result of doing this lab, I have new questions about [insert concept] . | | | | |

APPENDIX G

STUDENT INTERVIEW QUESTIONS

Interview questions to be asked after phenomena activity:

1. What did you enjoy about observing and hypothesizing about the phenomena?
2. Was there anything you didn't enjoy or think could have been done differently?
3. How did today's activity affect your attitude towards the lab we're doing next time?
4. What questions did today's activity raise?
5. Do you have anything else you want me to know?

Interview questions to be asked after each lab:

1. Do you think that this lab helped you understand the concepts in this unit better?
 - a. (If yes, follow up with): How?
 - b. (If no, follow up with): Why not? What could be changed about the lab to improve this?
2. What parts of the lab did you enjoy? What parts did you not enjoy? Why?
3. Did you feel like you were engaged in answering a question during the lab?
4. What are some procedural questions that you or your team had during the lab?
What are some conceptual questions that you or your team had during the lab?
5. (If after a treatment lab) How did observing and hypothesizing about the phenomena affect your experience during the lab?
6. Do you have anything else you want me to know?