TEACHING CHEMISTRY THROUGH REAL-WORLD APPLICATIONS

by

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ABSTRACT

Context-based approaches to chemistry aim to increase student engagement and understanding by framing learning in a meaningful, real-world context. This study examined the effect of teaching high school chemistry in the context of environmental issues. The purpose of this study was to determine whether a context-based approach to chemistry improved conceptual understanding and desire for inquiry among learners. Content assessments, attitude and motivation surveys, and student interviews were conducted and analyzed to examine the effect of a context-based approach to chemistry.

INTRODUCTION AND BACKGROUND

The Urban School of San Francisco is an innovative, independent high school in San Francisco, California. The mission of The Urban School "seeks to ignite a passion for learning, inspiring its students to become self-motivated, enthusiastic participants in their education – both in high school and beyond" (Mission and Core Values, 2016). Students at the Urban School tend to be highly motivated, engaged, and genuinely excited about learning. The student body consists of about 400 students from the Bay Area, with 81% living in the city of San Francisco. Our student population consists of 39% students of color, with 27% of our students receiving a total of $3.36 million in tuition assistance. Our school culture aligns with our mission statement, as collaborative learning and encouraging students to be active participants in their own education are highly valued (Diversity and Inclusion at Urban, 2016).

Structures at The Urban School support students as they strive to develop a thorough understanding of new ideas. Our school has a block schedule that allows for hands-on learning and encourages a deep exploration of concepts. The school culture around grading is rather progressive, as students receive letter grades only at the end of a term. At the midway point of the term, students receive an interim report for each class. This consists of a rubric that lists key habits, skills, and understandings for each class, along with written feedback from each teacher emphasizing areas for growth. Additionally, each student has a one-on-one conversation with their teachers to review their interim report, discuss progress and learning in the class, and set goals for the remainder of the term. This approach to evaluation allows students to focus on growing as learners, rather than focusing on their grade (Diversity and Inclusion at Urban, 2016).

The philosophy of the science department at The Urban School mirrors this commitment to deep understanding. Students actively participate in hands-on laboratory investigations. The two-year core science curriculum at The Urban School integrates topics from biology and chemistry to emphasize the multidisciplinary nature of science. Throughout the core sequence, students are encouraged to develop their own laboratory investigations as they build their ability to solve problems, analyze data, and evaluate scientific claims, both in their science classes and beyond.

Despite this progressive approach to science education, the final course in the core science sequence at The Urban School, Science 2B, remained a rather traditional chemistry course. Students explored foundational chemistry topics such as stoichiometry, equilibrium, gases, and acids and bases. Most labs did not require students to formulate their own procedures or experimental set-ups. Problem solving in Science 2B was rather algorithmic and rarely required higher order thinking skills like application and evaluation. The existing curriculum in Science 2B seemed to build a topical, superficial understanding of chemical concepts rather than the deep, meaningful understanding we strive to develop. Because this is the culminating course in our science sequence, it should draw heavily on the higher order thinking skills that are developed in our other core classes. These other core classes identify significant connections among different areas of science. For example, in Science 1B, students learn about intermolecular attractions and relate this to the function of the cell membrane. These connections were fundamentally lacking in Science 2B.

The motivation for this action research project arose from reflection about the limitations of the current iteration of Science 2B. I began to consider ways to build a deeper understanding of chemical concepts by altering the curriculum of Science 2B. My main goal was to promote the development of higher order thinking skills in my students by incorporating assignments that required them to engage deeply with new concepts, apply their understanding in novel situations, analyze experimental results, and develop their own laboratory investigations. As I began to research alternative chemistry curricula, I came across an approach that struck me as particularly relevant in light of my goals. Teaching chemistry in the context of real-world problems requires students to go deeper than a topical understanding of chemical ideas. This context-based approach to chemistry required a significant change in curriculum, as chemical concepts are taught so that students can better understand the real-world application of chemistry. By emphasizing the application of chemical principles, I hoped that students would be able to utilize higher order thinking skills as they developed a deeper understanding of chemistry. Furthermore, I hoped that students would be more motivated to identify and explore their own questions to pursue through laboratory investigations.

The purpose of this research was to examine the question “Does teaching chemistry in the context of real-world applications lead to improved conceptual understanding and increased desire for inquiry among learners?” In addition, the following sub-questions were addressed.

1. What is the effect of teaching chemistry in context on student engagement and motivation for learning?

2. How does teaching chemistry in context affect the development of higher order thinking skills in students throughout Science 2B?

3. What is the effect of teaching chemistry in context on the ability of students to apply their understanding of chemistry in novel situations?

CONCEPTUAL FRAMEWORK

Framing chemistry curricula in the context of real-world applications is a new and innovative approach to teaching chemistry. Several context-based chemistry curricula have been successfully integrated into science classrooms, both in the United States and abroad. Shifting to a context-based approach to chemistry aims to increase student engagement, motivation, and deep understanding by making the learning process more meaningful for students (King, 2012).

Before exploring the literature about the impact of shifting to a context-based approach to teaching, it is important to first define what it means for an approach to be context-based. According to King (2012), understanding the application of chemical concepts to real world situations is essential to the teaching of chemistry. In this approach, the curriculum is developed in response to the question, what do students need to know in order to more fully understand this real-world application. Alternatively, Overman, Vermunt, Meijer, Bulte, and Brekelmans (2014) explain that a “context-based approach is characterized by the use of societal, technical, or scientific contexts as the starting point for developing chemical understanding, with the intent of making chemical content more relevant to students" (p. 1871). These authors assert that the context or application is the driving force in informing the chemical curriculum. This is a fundamental and essential pedagogical shift when moving away from a traditional chemical curriculum toward a context-based curriculum. These contexts can include the social, economic, technological, and environmental applications of chemistry. (Bennet, Gräsel, Parchmann, & Waddington, 2005). Ideally, a context-based curriculum helps foster the development of skills which encourage students to be responsible and engaged participants in their daily lives, both in school and beyond (King, Bellocchi, & Ritchie, 2008).

While best practices in chemistry have changed over time, many traditional chemical curricula have remained somewhat stagnant. In traditional chemistry classrooms, learning can feel like climbing an endless ladder with too many rungs. Too often, students do not recognize why they need to climb this ladder. Furthermore, they cannot see the relationship between different rungs on the ladder they are climbing. As a result of this emphasis on facts and memorization, students have trouble seeing the relevance of what they are studying (Ültay & Çalik, 2012). Traditional chemistry instruction typically contains a significant load of facts, concepts, and equations that seem unrelated to the lives of students. These rote topics appear unrelated to other areas of science and are too often memorized rather than understood (Avargil, Herscovitz, & Dori, 2012). This traditional approach to chemistry emphasizes abstract and conceptual knowledge as paramount. Understanding how this knowledge relates to societal and technological concepts is viewed as a less significant learning objective and is often overshadowed by the emphasis on content knowledge (Overman et al., 2014).

In the early 1980's, concern arose in the science education community about the number of students pursuing science beyond required courses. Educators felt that by making science more interesting and engaging, students would see it as more relevant to their daily lives. If the learning of science could become more meaningful for students, it would potentially lead to deeper engagement with science content and activities. As a result, the 'Salters approach' was developed and ultimately became an exemplar of a context-based chemistry curriculum (Bennet and Lubben, 2006).

Many context-based approaches aim to address these weaknesses with traditional chemical courses. Avargil and colleagues (2012) examined an Israeli chemistry curriculum that sought to develop the scientific literacy of chemistry students while also building their critical thinking skills. Other context-based programs were implemented to more actively engage students in the learning process by exciting their intellectual curiosity (Ültay and Çalik, 2012). Schwartz-Bloom, Halpin, and Reiter (2011) examined the implementation of a pharmacology-based chemistry curriculum as a way to increase motivation and achievement in high school students. Finally, Demircioğlu, Demircioğlu, and Çalik (2009) suggest that the context-based approach strives to inspire a sense of curiosity and wonder about the natural world in young learners. While there are a myriad of reasons to implement a context-based curriculum, they all focus on empowering students to become more active and engaged participants in their own learning.

After a substantial literature review, King (2012) reported that context-based approaches could increase a student's interest and motivation in chemistry, while not diminishing their conceptual understanding. In some cases, a context-based approach led to an improved conceptual understanding. Bennett and colleagues (2005) argue that implementing student-centered activities that require active investigation provides students with increased independence as learners. The results of their study indicated that teachers of both context-based and traditional chemistry classes believed that the context-based course led to increased student motivation and interest. Additionally, this more positive view of chemistry led to an increase in the number of students who wanted to pursue chemistry at the post-secondary level (Bennett et al., 2005). Glaser and Carson (2005) suggest that chemistry in-context is aimed at providing a clear link between societal issues and chemical concepts. Ültay and Çalik (2012) expanded on this framework, explaining "this connection not only makes students think critically about societal issues but extends that critical thinking to scientific enquiry and communication in the class" (p. 696).

Another study examined the observations of a student who had the unique experience of taking a traditional concept-based and a context-based chemistry class with the same teacher at her school. As a result, the student could compare her experiences in both types of learning environments. The student mentioned the word “independent” six different times in her interviews when articulating how her experience with Extended Experimental Investigations compared with her previous experience of more traditional lab reports. The student noted that she preferred the context-based approach, explaining that she valued the increased independence she felt when conducting her own research experiments. She indicated that she was more engaged in the experiment as a result of increased choice and felt she learned more through the context-based approach (King et al., 2008). This student’s comments support existing research, which indicates that students become more interested in the study of science and feel more ownership over their investigations when learning in a context-based environment (King et al., 2008).

Evidence about the impact of a context-based chemistry curriculum on student understanding is somewhat unclear. While Bennett and Lubben (2006) were unable to make a direct comparison of student understanding in context-based and traditional courses, they cited the work of Barker and Millar (1996), which showed no significant difference in understanding among students in context-based and traditional classes. Additionally, Barker and Millar (1996) found that students in context-based courses developed a better understanding of the topics of chemical bonding and thermodynamics. King (2012) similarly concluded that a context-based approach to chemistry instruction does not compromise the conceptual understanding of students.

Schwartz-Bloom, Halpin, and Reiter (2011) found a positive correlation between teaching chemistry in-context and student achievement. Their study examined the effect of using a pharmacology curriculum, the Pharmacology Education Partnership (PEP), to increase interest and achievement in high school students. The curriculum utilized pharmacology topics like drugs, which they viewed as highly interesting to high school students, to provide a specific context for teaching chemistry. The results of the study indicated that using PEP modules correlated with increased student achievement on basic and advanced tests that assessed chemistry and biology knowledge. Furthermore, they found that using all six PEP units "produced robust results: students scored on average 19 and 49 percentage points higher on the basic and advanced tests in chemistry and biology, respectively, than students not using any modules" (p. 748).

In conclusion, context-based chemistry programs are often aimed at addressing some of the common problems associated with traditional chemistry courses: too much content, unnecessary emphasis on memorization and facts, lack of meaning for students, and low interest in pursuing science later in life. By connecting learning to their everyday lives, students can see the significance and relevance of chemical concepts. Studies have indicated that a context-based approach to chemistry leads to increased student engagement and motivation. Furthermore, context-based courses increase student independence and autonomy.

Finally, using a context-based curriculum does not hinder conceptual understanding, and, in some cases, can improve understanding. Thus, context-based chemistry classes are an exciting and innovative way to spark scientific curiosity in students.

METHODOLOGY

Science 2B is a core sophomore science class that mainly focuses on chemistry. Historically, this class has been taught with a fairly traditional approach to chemistry. Each week has explored a new chemical concept: stoichiometry, solubility, gases, acids and bases, and more. Given the block schedule at Urban School, we have developed our curriculum so that it is centered on the long, 130-minute, double period during the middle of each week. The weekly double period has been extensively utilized for laboratory investigations. In Science 2B, these laboratory investigations have allowed students to expand their knowledge of chemical concepts, develop their facility with laboratory techniques, and take an active role in their learning of science. While many of the laboratory activities throughout our core sequence are open-ended and inquiry-based, labs in Science 2B have been much more ‘cookbook-style’ and have explored only specific chemical concepts. Thus, while the Science 2B curriculum has been active and laboratory-based, it has been focused on learning discrete chemical concepts. Little emphasis has been placed upon integration of different chemical concepts and application of these concepts to new situations.

The treatment of this study shifted away from this content-based approach to a more context-based approach. Rather than structuring each week around an organizing lab, each week was structured around a guiding question. These questions placed chemical concepts in the context of larger, environmentally focused phenomena. This shift required chemical concepts to be taught in a manner that allowed students to gain the knowledge necessary to answer these guiding questions. As a result, the context-based approach required the integration of different chemical concepts into a single unit. Additionally, laboratory activities were revised and adapted to allow for more inquiry-based investigation. Rather than following procedural steps, students were asked to formulate their own questions and design their own experimental procedures. 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 A).

Data were collected and triangulated to thoroughly evaluate the focus question and sub-questions presented earlier (Table 1).

Table 1
Data Triangulation Matrix

Focus Question	Data Source 1	Data Source 2	Data Source 3
Primary Question: 1. Does teaching chemistry in the context of real-world applications lead to improved conceptual understanding and increased desire for inquiry among learners?	Chemistry Content Assessment Scores	Chemistry Application and Higher Order Thinking Skills Assessment	Attitudes and Motivations Survey
Sub-questions: 2. What was the effect of teaching chemistry in context on student engagement and motivation for learning?	Attitudes and Motivations Survey	Student Interviews	Teacher Surveys
3. How does teaching chemistry in context affect the development of higher order thinking skills in students throughout Science 2B?	Chemistry Application and Higher Order Thinking Skills Assessment	Attitudes and Motivations Survey	Student Interviews and Teacher Surveys
4. What is the effect of teaching chemistry in context on the ability of students to apply their understanding of chemistry in novel situations?	Chemistry Content Assessment Scores	Chemistry Application and Higher Order Thinking Skills Assessment	Attitudes and Motivations Survey

Data collection began in the spring term of the 2016-2017 school year. At the start of the term, students were given the Chemistry Attitudes and Motivation Survey to gather information about their attitudes, motivation, and engagement with learning chemistry (Appendix B). The survey was given to all Science 2B students and was re-administered at the midpoint and conclusion of the term in order to track changes in attitude, engagement, and motivation. Each survey item was scored from one to five points, with one representing *strongly disagree* and five representing *strongly agree*.

The Chemistry Attitudes and Motivation Survey was divided into several subsections, which were analyzed individually. Questions one to thirteen of the survey evaluated students' perceptions of their conceptual understanding of chemistry. Student responses to positive-response statements in this section of the survey were aggregated and averaged. This section contained several subsections, including attitude about higher order thinking skills, problem solving confidence, and sense-making ability. Questions 14 to 19 of the Chemistry Attitudes and Motivation Survey addressed the enthusiasm students had for learning through inquiry and evaluated student confidence in lab skills. Thus, these questions were divided into two subcategories: desire for conceptual inquiry and confidence in lab skills. Questions 20 to 24 of the survey evaluated students' motivation for learning. Finally, questions 25 to 30 evaluated students' willingness to make real-world connections between new chemical concepts and their everyday experiences.

The results of the Chemistry Attitudes and Motivation Survey were analyzed using the Wilcoxon Signed Rank test to evaluate whether there was a statistically significant difference in the distribution of responses before and after the treatment. The pre- and post-treatment average response to each survey item was calculated. Pre-treatment responses were compared to post-treatment responses to evaluate changes in motivation and engagement. Additionally, the distribution of survey responses was evaluated to identify changes in attitudes throughout the treatment. A small group of students were interviewed individually in order to gather qualitative data about their experiences in a context-based chemistry class (Appendix C). Additionally, a survey was administered to teachers who utilized this context-based curriculum in their Science 2B classes (Appendix D) to gather their feedback about the impact of this approach on student learning, understanding, and engagement.

In order to determine whether a context-based approach had an impact on student understanding of chemistry, a Chemistry Content Assessment was given after each context-based unit (Appendix E). These assessments evaluated student understanding of chemistry content. The results of the Chemistry Content Assessments were analyzed by comparing treatment scores to previous data. These assessments had been utilized in the previous content-based version of Science 2B. Because the goal of this assessment was to gather data about student understanding of chemical concepts, I was able to compare the treatment to historical Science 2B data from the 2015-2016 school year. The results were analyzed using the Wilcoxon Rank Sum Test. Test scores were evaluated to identify changes in student understanding in moving from a content-based approach to a context-based approach.

Data were collected to identify changes in students' ability to apply their understanding of chemistry in new situations. Students completed two laboratory practicals throughout the treatment, one midway through the treatment and another at conclusion of the treatment. These lab practicals assessed whether students could analyze experimental results and accurately interpret their findings. Students worked independently to complete these practicals and did not have advanced notice about the content of the practical. Additionally, Chemistry Application and Higher Order Thinking Skills (CAHOTS) Assessments were given to students following two units throughout the treatment (Appendix F). The goal of these assessments was to gather data about students' ability to transfer their knowledge of chemical content to novel situations. The questions on these assessments were designed to evaluate higher order thinking skills such as synthesis and evaluation. These questions were given to students as a challenge quiz. The CAHOTS quizzes were scored and analyzed to evaluate trends in the ability of students to apply their conceptual understanding of chemistry in a new context. Quiz scores were analyzed using the Wilcoxon Signed Rank test to determine if there was a statistically significant difference in score distributions from the beginning of the treatment to the end of the treatment.

DATA AND ANALYSIS

The results of this treatment indicate that a context-based approach to chemistry did not have a statistically significant impact on conceptual understanding (*N*=46). Results of the Chemistry Content Assessments from the treatment group were compared to quiz and exam data from past years (Figure 1).

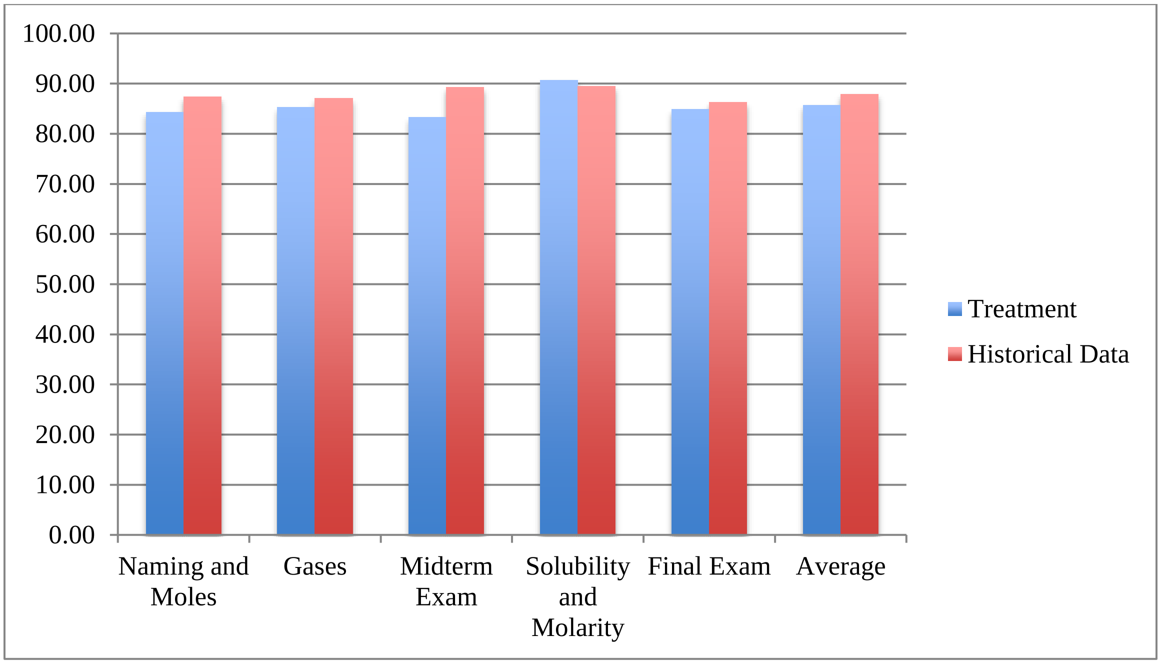

Figure 1. Comparison of treatment and historical assessment scores, (*N*=46).

A Wilcoxon Rank Sum test was performed on the quiz scores to determine if there was a statistically significant change in the distribution of assessment scores between groups. The results showed that the *p*-value for each comparison was well above the alpha level of 0.05, indicating that the distribution of treatment scores was not significantly different from those of past years (Table 2).

Students scored an average of 87.88% on all past assessments combined (*N*=32). The treatment group averaged an 85.72% across all quizzes (*N*=14). Additionally, the change in standard deviation between quiz scores remained relatively consistent, indicating that the spread of the test scores was similar between the treatment group and the historical averages. Statistical analysis indicated that a context-based approach to chemistry did not have a significant impact on assessments scores.

Table 2
Comparison of Treatment and Historical Assessment Scores

		Standard Deviation	
Quiz Topic	*p*-value	Treatment	Historical Data
Naming and Moles	0.56	10.93	7.86
Gases	0.53	10.21	11.06
Midterm Exam	0.14	11.83	7.54
Solubility and Molarity	0.84	12.54	16.80
Final Exam	0.95	6.47	8.90

Student survey responses mirrored these results. A Wilcoxon Signed Rank test was performed on pre- and post-treatment average responses to the conceptual understanding section of the Chemistry Attitudes and Motivation Survey. The *p*-value that resulted from this test, *p*=0.85, is vastly above the alpha level of 0.05. Thus, student attitudes about their conceptual understanding did not change significantly over the course of the treatment. Initially, student responses in this section averaged 3.62, falling between *neutral* and *agree.* After the treatment, the response was relatively unchanged, averaging 3.63. Student interviews also indicated that students felt positively about their conceptual understanding of concepts. One student explained, “I feel as though I understand the formulas, but I also understand the science that is going on beneath them and how the formulas were derived.”

Student desire for inquiry was also evaluated throughout the treatment. The results of this analysis suggest that a context-based approach to chemistry positively impacted students’ desire for inquiry. Students began the treatment with very favorable opinions about conceptual inquiry, starting the treatment with a 3.68 average response to statements in this section. A Wilcoxon Signed Rank test was performed on the aggregate desire for conceptual inquiry responses. The results of the test suggest that there was not a statistically significant difference in students’ desire for conceptual inquiry from the beginning to the end of the treatment, as p=0.20.

Responses to the second conceptual inquiry question, “I enjoy the opportunity to learn concepts through demonstrations and experiments, rather than being taught concepts directly,” were especially positive. Students averaged a 4.23 response to this statement; this was the second highest average response to a question in the entire survey. Prior to the treatment, 82.98% of responses to this question were positive, with 44.68% of students indicating that they *strongly agreed* with the statement. Only 4.26% of responses were negative, falling into the *disagree* or *strongly disagree* categories. Attitudes remained positive after treatment, as 78.72% continuing to respond positively to the statement, and only 4.26% responding negatively. One student explained, “I have enjoyed the hands-on labs and experiments that we have performed throughout the term." She went on to say that these, "First-hand examples help me to envision complicated chemical concepts and solidify my understanding."

Significant positive changes were observed in students' attitudes about their confidence in lab skills. The average response to each statement in this subcategory rose throughout the treatment. In particular, student confidence in designing experimental investigations rose from 2.49 pre-treatment to 3.21 post-treatment (Figure 2). This was a statistically significant difference. The *p*-value from a Wilcoxon Signed Rank test performed on the pre- and post-treatment responses to the statement, "I feel confident designing my own experiments to investigate questions" fell below the 0.05 alpha-level, as $p=0.001$. Negative responses to the statement dropped by 60.7%, while positive responses grew by 110.0% (Figure 2).

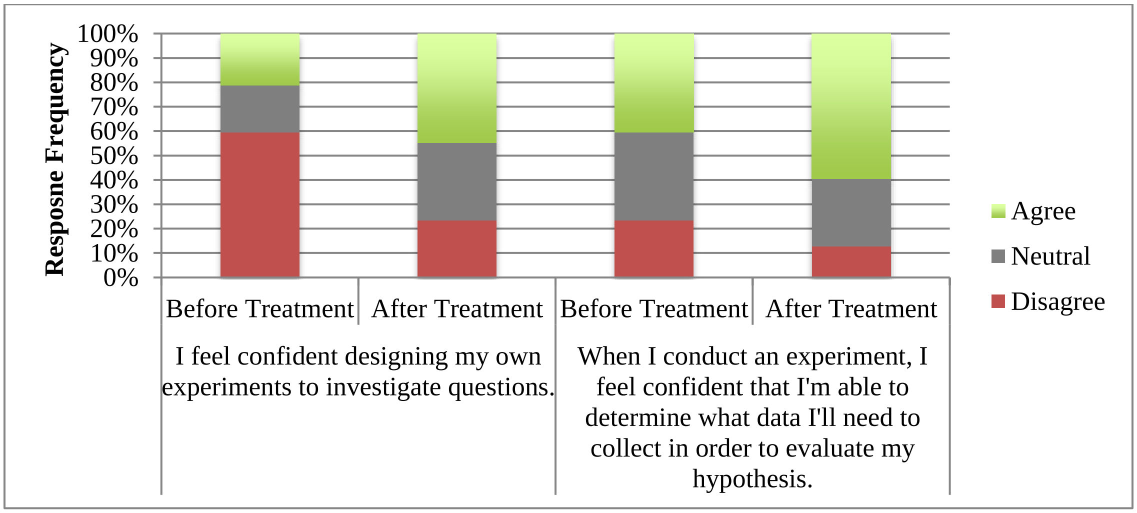

Figure 2. Comparison of confidence in lab skill survey responses, (N=47).

Similarly, responses to the statement, "When I conduct an experiment, I feel confident that I'm able to determine what data I'll need to collect in order to evaluate my hypothesis" also became more positive throughout the treatment. Average responses to this statement rose significantly, starting at 3.17 and ending at 3.51. Initially, 23.40% of responses to this statement were negative. At the end of the treatment, negative responses dropped by 45.45%, falling to only 12.77% of all responses. Positive responses grew from 40.43% to 59.57% of all responses. This represents a 47.37% increase in positive responses from the beginning to the end of the treatment (Figure 2).

In aggregate, confidence in lab skill response averages rose from 2.84 initially to 3.21 after the treatment (Figure 3). A Wilcoxon Signed Rank test was conducted on these aggregate responses. The test indicated that there was only a 1.5% chance that the distribution of lab skill confidence responses was the same before and after the treatment, as *p*=0.015. This *p*-value is well below the alpha level of 0.05, providing sufficient evidence to reject the null hypothesis. This result suggests that students had a statistically significant increase in terms of their confidence in lab skills after the treatment.

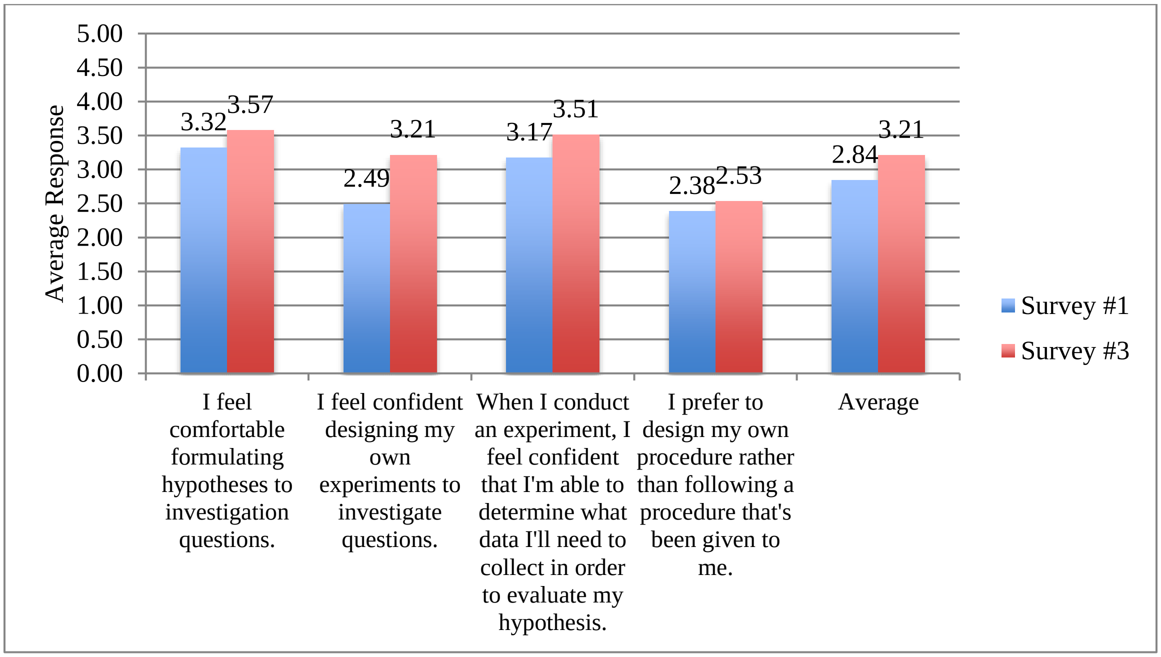

Figure 3. Comparison of mean pre- and post-treatment lab skill confidence responses, (*N*=47).

Negative responses to all statements about lab skill confidence dropped by 42% throughout the treatment. Initially, 40.43% of responses to lab skill confidence statements were negative. By the end of the treatment, only 23.40% of responses were negative. Positive responses, on the other hand, increased by 46.43% throughout the treatment. While only 29.79% of initial responses were positive, at the end of the treatment that number had increased to 43.62%.

Student interviews further supported this evidence. In response to whether she felt more comfortable in her ability to evaluate data after taking Science 2B, one student explained, “I do, because we practiced this a lot during lab reports and lab practicals. This was probably the most difficult aspect of the class for me, but I think that my ability to analyze and evaluate data did improve from the beginning of the term.” Another student added, “I believe that as a result of the final project and being given the opportunity to design my own systematic investigation, I feel more confident in myself if a similar task was to be presented to me in the future.”

Attitudes about student motivation for learning were evaluated through the Chemistry Attitudes and Motivation Survey. The mean initial response to all questions in the motivation for learning section of the survey was 3.61. The average response to the statement, “I enjoy conducting experiments to learn about chemistry” was particularly high, with an initial average of 3.85 and a post-treatment average of 3.81. Furthermore, 60.85% of students responded positively to statements that reflected their motivation for and enjoyment of learning. The number of favorable responses increased slightly throughout the treatment, rising to 65.11%. Overall, changes in student motivation for learning were minimal throughout the treatment.

Student interviews also reflected a positive feeling about learning science. One student explained, “I have enjoyed all the math we’ve been doing. It’s really satisfying to solve a complex problem that both requires you to apply your knowledge of science but also math.” She went on to add, “I think I’ve also enjoyed the amount of labs we’ve done because personally I like to learn through hands-on work, and with the labs, that’s the main way I’ve been able to understand a lot of the concepts from this term.”

Additionally, teacher surveys indicated that students felt engaged and motivated throughout the treatment. One teacher explained that students “had so many good questions.” She added that because environmental chemistry “is such a relevant topic today and is in the news all of the time,” students were “fascinated to learn about how an oyster farm works, to analyze the effectiveness of a camp stove, to think about how small marine organisms are affected by fossil fuels...every kid had a ‘this is cool’ moment.”

The analysis of data indicated positive changes in the development of students’ higher order thinking skills. The Chemistry Attitudes and Motivation survey statements on higher order thinking skills presented learning chemistry as a rote, memorization-oriented task. Negative responses to questions in this section increased throughout the treatment (Figure 4).

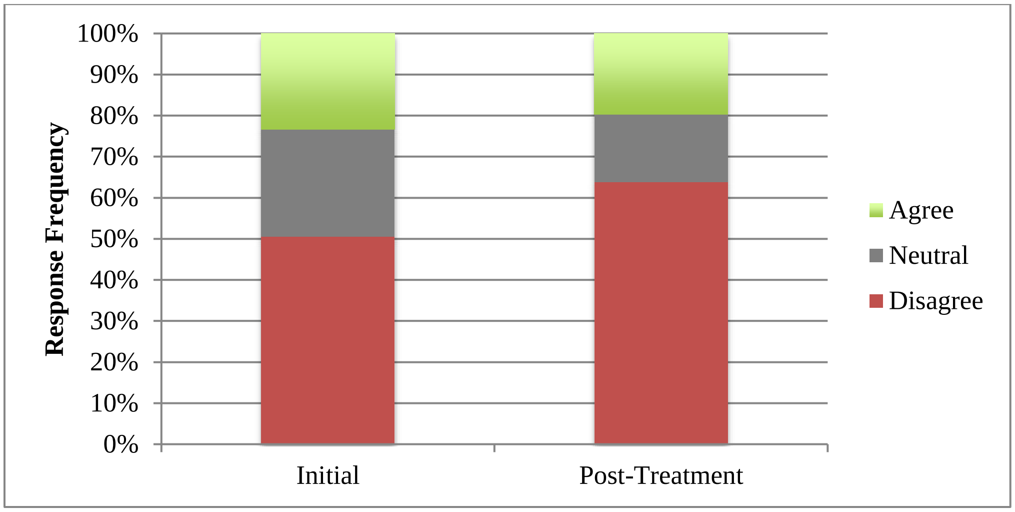

Figure 4. Student responses to negative higher order thinking skill questions, (*N*=47).

Overall, the mean response in the higher order thinking skill subsection of the survey fell from 2.68 to 2.44, a 9.84% decline. A Wilcoxon Signed Rank test was performed on the aggregate data in this subsection to evaluate whether the distribution of post-treatment responses differed significantly from pre-treatment responses. The *p*-value for this test, *p*=0.0820, was just above the 0.05 alpha-level threshold for statistical significance. While there was not sufficient evidence to reject the null hypothesis, the results of the test indicated that there was weak, inconclusive evidence that the post-treatment results differ significantly from the pre-treatment results.

At the end of the treatment, students were more likely to disagree with the statement, “Knowledge in chemistry consists of many disconnected topics.” While the average initial response to this question was 2.45, it fell to 2.13 post-treatment (Figure 5).

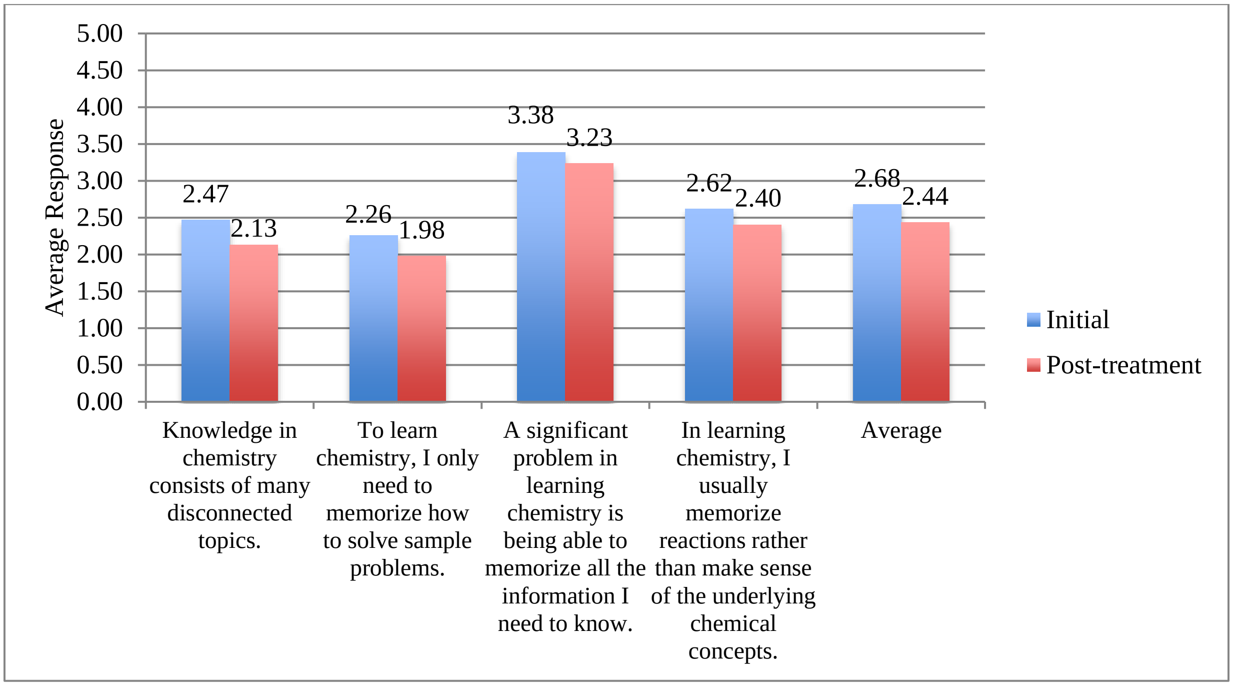

Figure 5. Comparison of mean pre- and post-treatment responses to higher order thinking skill questions, (*N*=47).

Similarly, student responses indicated that they believed relying on memorizing topics and equations was less useful to them throughout the term. Initially, the average response to the statement, “To learn chemistry, I only need to memorize how to solve sample problems” was 2.26. By the end of the treatment, the average response dropped to 1.98. Additionally, the number of students who *strongly disagreed* with this statement rose from 19.15% to 31.92%, a 66.67% increase throughout the treatment. While 10.64% of students *agreed* with this statement at the start of the treatment, no students *agreed* at the end of the treatment. Furthermore, positive responses to the statement, “In learning chemistry, I usually memorize reactions rather than make sense of the underlying chemical concepts,” dropped throughout the treatment. While 21.28% of students initially *agreed* that they tried to memorize reactions to understand, only 14.89% *agreed* at the end of the treatment. The number of students who responded *neutrally* dropped by 27.27% throughout the treatment. Students who *disagreed* with this statement rose from 34.04% to 44.68%, a 31.25% change throughout the treatment.

Teacher feedback indicated that a context-based approach to chemistry improved the quality of evaluation of student learning. One teacher explained, “I found it much easier to assess who understood and who was trying to memorize their way through the curriculum.” Asking students to communicate their understanding in the context of real-world phenomena provided more opportunities to differentiate understanding among students.

While survey responses indicated students were less likely to rely on memorization, interview responses indicated that students felt more comfortable with higher order thinking skills like evaluating data and applying their understanding in new contexts. When asked how comfortable she felt synthesizing information after the treatment, one student explained, “Because of all of the labs we did in which we conducted experiments that required the synthesis of data, I believe I have developed this skill throughout the term.” While some students felt more comfortable utilizing higher order thinking skills, other continued to find it challenging to do so. In response to the same question, another student explained, “Somewhat. I feel more confident making sense of my results, but at times I find it difficult to synthesize information across multiple chemical concepts.” She specifically stated that the unit on solubility, molarity, and stoichiometry was especially challenging because it required the integration of so many concepts.

The results of the lab practical assessments were evaluated to investigate whether a context-based approach to chemistry had an impact on the ability of students to apply their understanding of chemical concepts in new situations. A Wilcoxon Signed Rank test was performed to evaluate whether the distribution of end-of-treatment lab practical scores differed significantly from that of the mid-treatment practical scores. The results of the test suggest that the final practical scores did not differ significantly from the mid-treatment scores. The average of both scores was nearly identical, at 85.36% mid-treatment and 85.29% post-treatment.

Table 3
Comparison of Mid-treatment and End-of-treatment Lab Practical Scores.

	Average	Standard Deviation	Median	Range	*p*-value
Mid-treatment Practical	85.36	2.9	85.5	11	0.66
Final Practical	85.29	6.47	85.5	23	

During student interviews, one student brought up her experience with lab practicals when asked whether she was more comfortable applying her understanding of concepts in new situations. She explained, “Last year, going into lab practicals was quite scary. This year I felt very prepared based on what I learned, and I felt as though we were taught in such a way that enabled us to relate what we previously learned to what information was new.” She added that, the structure of the treatment helped her in “applying [her] knowledge in scenarios like lab practicals, when we weren’t explicitly told what themes to focus on and write-ups too.”

The results of the Chemistry Application and Higher Order Thinking Skills (CAHOTS) Assessments showed a slight increase in average student score from 67.09% to 70.90%, (*N*=12). A Wilcoxon Signed Rank test was performed on these assessments scores. The results indicated that there was not a statistically significant difference between the initial and final treatment results, as *p*=0.63 (Table 4).

Table 4
Comparison of Mid- and Post-treatment CAHOTS Assessment Scores

	Average	Standard Deviation	Median	Range	*p*-value
Mid-treatment	67.09	23.86	62.50	85.71	0.63
Post-treatment	70.90	20.84	71.80	65.40	

Notably, however, both the standard deviation and the range decreased from the initial to final CAHOTS Assessments. This is evident in Figure 6, which shows a much smaller spread of scores on the final assessment.

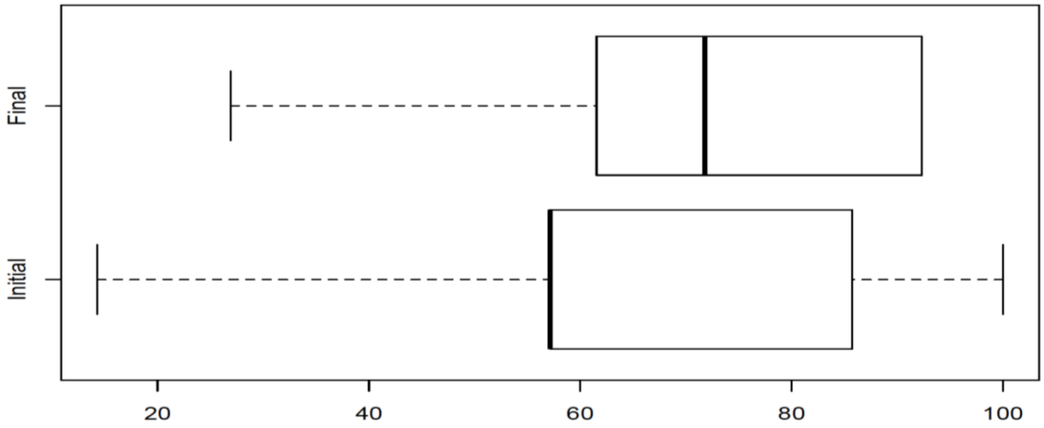

Figure 6. Comparison of initial and final CAHOTS assessment scores, (*N*=12).

Interview responses align with this trend. In response to a question about whether she felt comfortable applying her understanding in new situations, one student explained, "This has always been challenging for me, as it requires a lot more thought and a true conceptual understanding. Although it's still challenging, I definitely feel like I can apply my understanding to new situations more effectively and accurately now than I could at the beginning of the term."

Teachers also felt that a context-based approach to chemistry enabled them to evaluate student learning more effectively, as it provided more opportunities to challenge students to apply their understanding in new situations. One teacher commented, "From some of the new labs and practicals, I was able to read understanding and thinking more clearly because the students weren't simply replicating prior problems."

Despite being asked to draw upon higher order thinking skills more often during the treatment, students remained confident in their sense-making abilities. Students initially had positive attitudes about their ability to make sense of chemistry problems, starting the treatment with an average response of 3.72. At the end of the treatment, the mean response rose slightly to 3.84 (Figure 7). In particular, negative responses to these questions decreased throughout the survey, as students were less likely to *disagree* with these questions. Similarly, students *strongly agreed* with sense making questions more often throughout the survey, with responses increasing from 19.15% to 21.99%. Overall, changes in this category were minimal, yet positive.

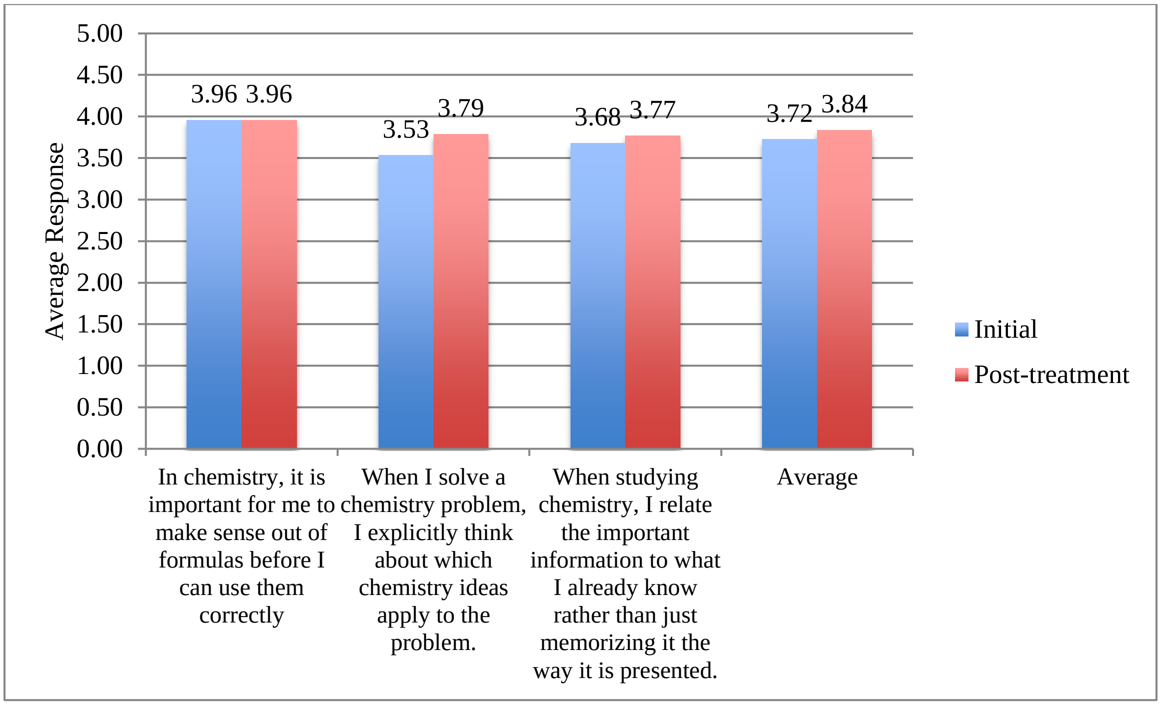

Figure 7. Student attitudes about their sense-making abilities, (*N*=47).

Results indicate that before the treatment, only 10.64% of students *strongly agreed* with the statement, “When I solve a chemistry problem, I explicitly think about which chemistry ideas apply to the problem.” At the end of the treatment, that number rose to 17.02%, representing a 60.00% increase. Similarly, the number of negative responses to this question also declined. At the beginning of the treatment, 4.26% of students *strongly disagreed* with the statement. By the end of the treatment, no students *strongly disagreed*. The number of *disagree* responses also fell by 25.00%.

Finally, the results of the survey indicated that a context-based approach to chemistry encouraged students to make real-world connections between new concepts and their everyday lives. Overall, there was an 8.56% increase in students’ opinions about the usefulness of chemistry in helping them understand the natural world, as the average responses across this category rose from 3.19 to 3.47. There was a 10.74%

increase in response to the question, “I regularly think about the chemistry I experience in everyday life,” as average responses increased from 2.57 to 2.85.

Additionally, there were statistically significant increases in students’ response to two questions in the real world connection section of the survey. Average student responses the question, “To understand chemistry, I sometimes think about my personal experiences and relate them to the topic being analyzed,” rose from 2.72 to 3.15. A Wilcoxon Signed Rank test was conducted on this question. The resulting *p*-value, 0.049, fell just below the 0.05 alpha level. There was also a statistically significant increase in responses to the question, “Understanding chemistry is important because it helps us in understanding the environment.” Average responses increased from 3.95 to 4.30, a 9.78% increase (Figure 8). The results of a Wilcoxon Signed Rank test on that statement indicated a statistically significant difference in the distribution of responses before and after the treatment, as $p=0.02$. Thus, these tests provided sufficient evidence to conclude that students more easily recognized the importance of understanding chemistry in real-world contexts following the treatment.

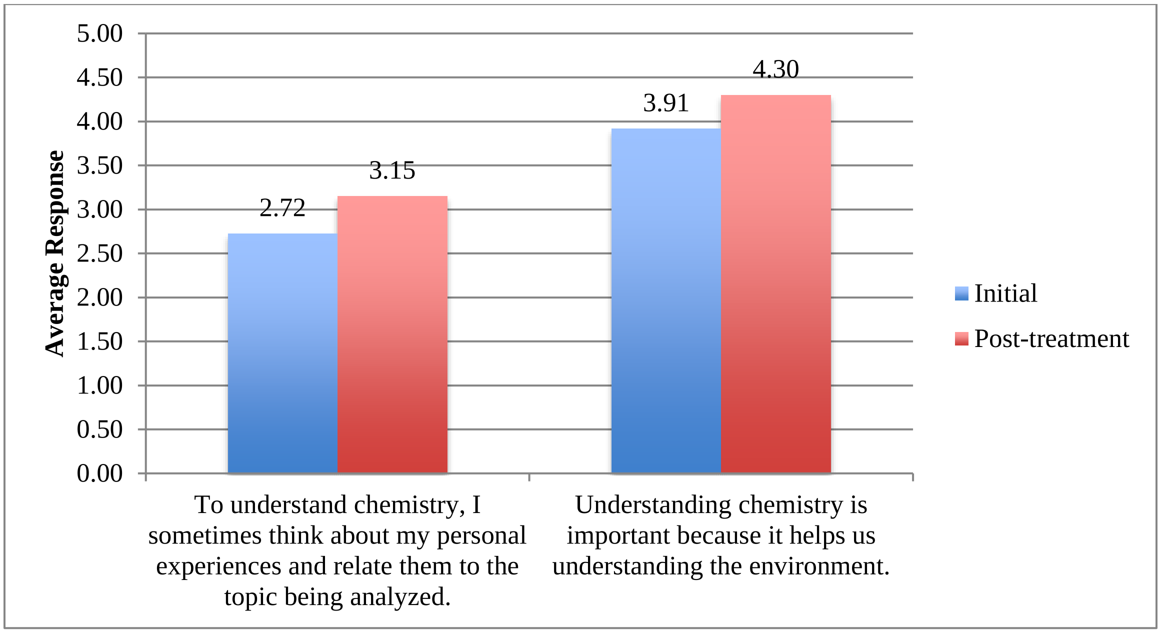

Figure 8. Comparison of mean pre- and post-treatment attitudes about real-world connections, (*N*=47).

Interview responses also supported this notion. When asked how often she thought about chemistry in the context of real-world applications, one student said, "This morning I was putting on my contacts and to clean them I use a solution that bubbles, so I actually began to think about what reactions were going on and if the gas released was soluble within the solution." She added that she believed "that after taking 2B [she has] thought the most about chemistry in the real-world." Additionally, teachers had positive opinions about teaching chemistry in the context of real-world applications. One teacher explained that she loved "that most, if not all, lessons had a connection to a real world context. The kids were invested, as was I. This invited really interesting questions and helped us use chemistry to solve and discuss problems rather than following algorithms." She then added, "I also liked how much I had to learn to teach it."

Overall, a context-based approach to chemistry did not significantly impact student understanding, which remained high throughout the treatment. This approach, however, did have a statistically significant impact student desire for inquiry. In particular, gains were made in terms of student confidence in their lab skills. Additionally, students maintained high levels of engagement in and enjoyment of learning. The opportunities to apply understanding in new situations that a context-based approach provides enabled students to develop higher order thinking skills. Finally, students invested in connections between new chemical concepts and real-world applications. Thus, a context-based approach to chemistry had positive impacts on student learning.

INTERPRETATION AND CONCLUSION

The results of the treatment revealed that a context-based approach to chemistry did not have a statistically significant impact on student understanding of content. Student understanding was not a significant issue going into the treatment. In the past, students have regularly demonstrated a strong understanding of chemical concepts on assessments. One of the challenging things about a context-based approach to chemistry is that rather than explicitly introducing new content by topic, content is synthesized and integrated to provide students with the knowledge needed to understand the chemistry behind the context. Because a context-based approach is less linear in terms of chemistry content, I wondered if students would find mastering the new material they were learning more challenging.

While results of the treatment showed no statistically significant change in understanding, students continued to demonstrate a strong understanding of chemical concepts on assessments. Additionally, attitudes about their conceptual understanding remained positive throughout the treatment. I found this result encouraging, because while the treatment required more synthesis and integration of new ideas, it did not negatively impact student understanding. Furthermore, the spiraling nature of a context-based curriculum highlighted connections among different chemical concepts. As a result, students were more likely to view chemical concepts as interwoven, rather than stand-alone at the end of the treatment.

Survey results indicated that students viewed lower order thinking skills as less beneficial to them as they learned chemistry. Students were less likely to rely on memorization to solve problems at the conclusion of the treatment. This suggests that students felt they needed to draw upon higher order thinking skills to understand chemistry. Additionally, responses to questions in the sense-making section of the Chemistry Attitudes and Motivation survey indicated that students became increasingly likely to identify and mentally articulate relevant concepts as they worked through questions. This indicates that students were developing strategies to help integrate their understanding of concepts more effectively. Thus, while a context-based approach to chemistry did not impact student understanding, it did support the development of higher order thinking skills in students.

The biggest benefit of the treatment was its impact on student desire for inquiry. Students already had a favorable opinion of active, inquiry-based learning prior to treatment. While the change in conceptual inquiry responses was not statistically significant, it began and remained positive throughout the treatment. The results did show a statistically significant improvement in lab skill confidence from the beginning to the end of the treatment. I found it surprising that while students initially had very positive attitudes about learning through experiments and demonstrations, as shown in their responses to conceptual inquiry questions, their confidence about lab skills was quite low at the start of the treatment. Given how often we complete laboratory investigations, this initial result was particularly surprising to me.

Throughout the treatment, new information was organized around four essential questions. These questions focused on relevant and current environmental issues like climate change and ocean acidification. I believe that these essential questions provided a model for students in terms of inquiry. At the beginning of each unit in the treatment, an environmental problem was presented. As each problem was introduced, teachers identified the information needed to evaluate and answer the environmental question at hand. Throughout the unit, new chemistry concepts were presented. The essential question would then be explored and evaluated in the context of this new chemical information. By modeling the inquiry process for students, I believe they became more comfortable developing the skills and practices that benefit them in scientific inquiry.

Furthermore, laboratory experiments in the treatment were intentionally more open-ended and anchored in real-world contexts. This allowed students to practice the skills of formulating hypotheses, designing procedures, and interpreting data. Because the labs were more open-ended, students had more freedom to analyze and interpret their experimental results. They were required to develop arguments from evidence and communicate their findings. One teacher articulated this at the end of the treatment, explaining that because Science 2B concludes the core science curriculum at our school, “It doesn't seem as critical to ensure high proficiency with specific concepts compared to larger questions around the methods, application, and key skills in science.” I felt that a context-based approach helped facilitate the development of science and engineering practices. Survey responses also captured an increased desire for inquiry among students. In particular, survey data indicated that students felt increasingly fluent formulating hypotheses and designing experiments after the treatment.

As I examined the confidence in lab skill data more closely, I noticed that female students initially held particularly negative views about their lab skill confidence when compared to their male peers. I was curious about this difference, so I conducted a Chi-Square Independence Test to investigate whether this difference in lab skill confidence was statistically significant. The results of the Chi-Square Independence Test revealed a statistically significant initial difference in lab skill confidence between female and male students, as $p=0.001$. This suggests female students were less confident in their lab skills than their male peers at the start of the treatment. I also ran a Chi-Square Independence Test on the post-treatment survey results to compare the lab skill confidence results by gender. The post-treatment results no longer indicated a statistically significant difference in lab skill confidence, as $p=0.320$. This suggested that female students became increasingly confident in their ability to conduct and evaluate experiments throughout the treatment. As a female teacher who strives to get more women involved in science, this was a particularly encouraging finding for me.

A context-based approach also provided unique opportunities for students to develop higher order thinking skills. Because students were working to understand the essential questions guiding each unit, students had many opportunities to practice applying their understanding in novel situations. One teacher explained that a context-based approach “forces kids to ask ‘why.’ And in doing so, they have to look at data. Understanding data and trying to tease out trends is such a key skill for any science class.”

An unexpected benefit of this treatment was the rich information it provided teachers about student learning. When asked how a context-based approach supported student learning, one teacher explained, “The breadth and depth of information I received from assessment as a teacher made differentiation easier which I think indirectly improves learning.” The context-based approach naturally provided more opportunities for assessments that evaluated higher order thinking skills. Rather than traditional, algorithmic chemistry problems, teachers found that they were able to ask more meaningful and substantive assessment questions.

Finally, this treatment had a positive impact on student motivation for learning. While survey data did not reveal significant changes in the motivation for learning section of the Chemistry Attitudes and Motivation Assessment, results showed that students became much more interested in making connections between new chemical concepts and their everyday experiences. Students felt more strongly that understanding chemistry allowed them to understand the environment. Additionally, there was a statistically significant improvement in students' willingness to relate their own experiences to chemistry topics being studied in class. Other teachers also noted this increased enthusiasm and engagement. A colleague commented that students "could see themselves in the curriculum and therefore could invest. Some kids like to snorkel and are worried about coral reefs. Some kids have a hybrid car and want to know how it affects emissions." As a result, "Every student in the room could connect some part of the curriculum to their own personal experience." Teaching chemistry in the context of real world phenomena encouraged students to think more critically about their own experiences and relate those experiences to their understanding of chemistry.

A context-based approach to chemistry benefitted student learning by fostering a desire for inquiry in students. Students were more confident in their ability to formulate hypotheses, design and execute experimental procedures, and evaluate and interpret experimental evidence. Additionally, this approach encouraged students to connect chemical concepts to real-world phenomena. Finally, while a context-based approach to chemistry encouraged the development of higher order thinking skills, it did not have a statistically significant impact on student understanding.

VALUE

While this treatment required a significant shift in our chemistry curriculum, the results of this study indicated that a context-based approach to teaching chemistry had strong, positive impacts on student learning. It encouraged students to think more deeply about the connection between chemical content and natural phenomena and, as a result, helped facilitate the development of higher order thinking skills in students. By anchoring new scientific information in relevant and exciting real-world phenomena, students developed a genuine curiosity about science. A context-based approach seemed to diminish a common flaw of chemical curricula. As Ültay & Çalik (2012) explain, too often chemistry classes emphasize rote memorization of facts and ideas. As a result, students work to memorize concepts rather than truly understand them. This study indicated that students were less likely to believe that chemistry consists of many disconnected topics at the conclusion of the treatment. Additionally, students found memorization less useful to them throughout the treatment. Instead, students' increasingly believed that chemical concepts were interwoven, rather than stand-alone.

A context-based approach to chemistry also increased students' desire for inquiry. It built excitement and curiosity, not only among students but also among teachers. In many ways, this treatment thoroughly integrated many of the Next Generation Science Standards science and engineering practices (Next Generation Science Standards, 2013). Centering the treatment on essential questions allowed students to observe what it looks like to ask questions and define problems through laboratory investigations. Open-ended laboratory experiments provided students with opportunities to plan and execute investigations. Throughout the treatment, students were required to analyze data, draw upon mathematical thinking, and construct explanations. In order to sufficiently answer essential questions, students were asked to engage in argument from evidence and communicate information. Learning chemistry in the context of a guiding question provided students ample opportunities to practice these skills.

In the future, I would like to further investigate my findings about initial lab skill confidence. Given how frequently our students complete laboratory experiments, I was very surprised to see how negatively they viewed their confidence with lab skills. Next year, I hope to administer the desire for inquiry survey questions to students in all core classes. I am curious about how lab confidence changes as students navigate the core sequence of science classes at Urban School. I'm also particularly interested in the statistically significant difference in initial lab skill confidence between female and male students. I'd like to see if this gap exists in students when they enter The Urban School or if it becomes more pronounced throughout the core sequence. I hope to use the results of this extended investigation to continue to refine the curriculum throughout the core sequence.

Finally, teaching chemistry through a context-based approach was rewarding and inspiring as an educator. A colleague articulated this, explaining, "I also liked how much I had to learn to teach it. This was taxing but it led to an increase in my own personal knowledge of environmentally related chemistry." This was a particularly interesting element of the study. In order to teach chemistry in the context of environmentally relevant concepts, teachers needed to possess an understanding not only of the chemistry they were teaching, but also of the environmental context for this chemistry. As a result, a context-based approach required teachers to put themselves in the position of learners. It was both challenging and rewarding to integrate traditional chemistry content with environmental applications. Collaboration among teachers was especially helpful throughout the treatment, as it enabled teachers to learn from and support one another.

At the end of the treatment, all three Science 2B teachers supported continuing to anchor the curriculum in real-world contexts in the future. This is a positive finding, as it suggests that teachers saw substantial benefits in a context-based approach to chemistry. One teacher added, “This gives kids a lot more room to explore and to find ways to make sense of data.” In reflecting on his experience teaching in a context-based curriculum, another colleague concluded, “I really liked how much more information I had about student learning, how much more buy-in and student-driven learning there was, and how there was more room for students to push themselves to think creatively and do more substantive analysis.”

I personally found a tremendous amount of value in shifting to a context-based approach. At times, I have felt uninspired by teaching the same chemical content year after year. While humanities teachers can easily change the theme of their courses by adjusting readings and books, science teachers can become stuck in teaching a set body of traditional chemical content. A context-based approach allowed for a more dynamic chemistry curriculum. The context for learning chemistry could be varied from year to year. Another teacher commented that this approach “also creates space to pull pieces that aren't working and put in something else because it's thematically based rather than a linear progression.” I found teaching chemistry through an environmental lens to be exciting and engaging. In the future, I’d be curious about other contexts through which chemical content can be taught.

Finally, I loved seeing the enthusiasm my students brought to class as they learned about current environmental issues. They eagerly dove into chemical concepts because they were motivated to understand pressing issues like fossil fuel use, climate change, and ocean acidification. Watching my students' curiosity and passion for learning grow throughout the treatment was highly rewarding.

The opportunity to systematically evaluate changes in student understanding, engagement, and motivation for learning helped me reflect on how I can be a stronger science educator. The results of this project indicated that a context-based approach to chemistry positively impacted student learning. This project also benefitted me as an educator by encouraging me to reflect on my own practices and modify them to more effectively support student learning.

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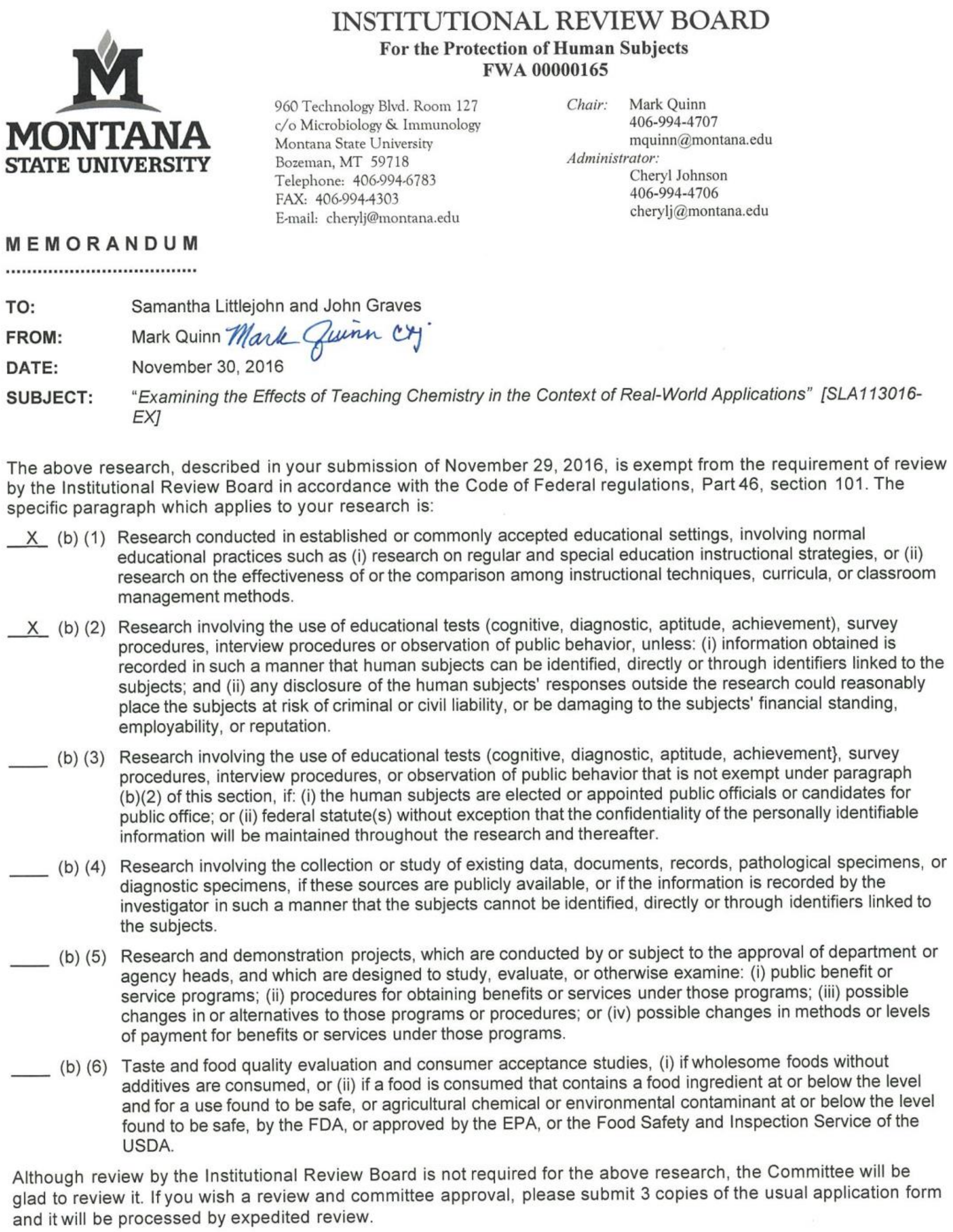
APPENDICES

APPENDIX A

INSTITUTIONAL REVIEW BOARD EXEMPTION



MONTANA
STATE UNIVERSITY

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MEMORANDUM

TO: Samantha Littlejohn and John Graves
FROM: Mark Quinn Mark Quinn cj
DATE: November 30, 2016
SUBJECT: "*Examining the Effects of Teaching Chemistry in the Context of Real-World Applications" [SLA113016-EX]*

The above research, described in your submission of November 29, 2016, 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 the comparison 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 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

CHEMISTRY ATTITUDES AND MOTIVATION SURVEY

This Likert Survey will be given as a Google Form. Each question will have the responses associated with the question. This Survey was adapted from the CLASS-Chemistry (Colorado Learning Attitudes about Science Survey): http://www.colorado.edu/sei/surveys/Faculty/CLASS-CHEM-faculty.html

1. What is your student ID number.
2. I identify as…(gender)

Introduction

Here are a number of statements that may or may not describe your beliefs about learning chemistry. You are asked to rate each statement by selecting a number between 1 and 5 where the numbers mean the following:

1. ***Strongly Disagree*** 2. ***Disagree*** 3. ***Neutral*** 4. ***Agree*** 5. ***Strongly Agree***

Choose one of the above five choices that **best expresses your feeling** about the statement. If you don't understand a statement, leave it blank. If you have no strong opinion, choose 3.

1. To understand a chemical reaction, I think about the interactions between atoms and molecules.
2. I think about how the atoms are arranged in a molecule to help my understanding of its behavior in chemical reactions.
3. Understanding how things work on an atomic level helps us understanding the world better.
4. Knowledge in chemistry consists of many disconnected topics.
5. To learn chemistry, I only need to memorize how to solve sample problems.
6. If I get stuck on a chemistry problem on my first try, I usually try to figure out a different way that works.
7. I can usually figure out a way to solve chemistry problems.
8. When I'm solving chemistry problems, I often don't really understand what I am doing.
9. In chemistry, it is important for me to make sense out of formulas before I can use them correctly.
10. When I solve a chemistry problem, I explicitly think about which chemistry ideas apply to the problem.
11. When studying chemistry, I relate the important information to what I already know rather than just memorizing it the way it is presented.
12. A significant problem in learning chemistry is being able to memorize all the information I need to know.
13. In learning chemistry, I usually memorize reactions rather than make sense of the underlying chemical concepts.
14. I enjoy figuring out how concepts relate on my own, rather than being explicitly taught relationships.
15. I feel comfortable formulating hypotheses to investigation questions.
16. I enjoy the opportunity to learn concepts through demonstrations and experiments, rather than being taught concepts directly.
17. I feel confident designing my own experiments to investigate questions.
18. When I conduct an experiment, I feel confident that I'm able to determine what data I'll need to collect in order to evaluate my hypothesis.
19. I prefer to design my own procedure rather than following a procedure that's been given to me.
20. I enjoy solving chemistry problems.
21. I enjoy learning about chemical concepts.
22. I enjoy being able to explain the chemistry behind everyday phenomena to my friends and family.
23. I enjoy conducting experiments to learn more about chemistry.
24. I generally find learning about chemistry engaging.
25. Learning chemistry changes my ideas about how the world works.
26. I regularly think about the chemistry I experience in everyday life.
27. I study chemistry to learn knowledge that will be useful in my life outside of school.
28. Reasoning skills used to understand chemistry can be helpful to me in my everyday life.
29. To understand chemistry, I sometimes think about my personal experiences and relate them to the topic being analyzed.
30. Understanding chemistry is important because it helps us in understanding the environment.

APPENDIX C

STUDENT INTERVIEW QUESTIONS

All questions will be administered post-treatment.

1. What aspects of Science 2B have you enjoyed most?
2. What elements of Science 2B have been challenging for you?
3. What supported your learning in Science 2B?
4. What got in the way of your learning in Science 2B?
5. Did you feel Science 2B was different from other core science classes? If so, explain why.
6. How comfortable do you feel with your understanding of chemical concepts?
7. How comfortable do you feel with applying your understanding of chemical concepts in new situations?
8. How often do you think about chemistry in the context of real-world applications?
9. This term, we organized content into four bigger questions rather than by chemical topic. What was your experience learning chemistry in this manner?
10. Do you feel more comfortable in your ability to evaluate data after taking Science 2B?
11. Do you feel more comfortable in your ability to synthesize information after taking Science 2B?
12. Do you feel more comfortable in your ability to design systematic investigations after taking Science 2B?
13. Is there anything you’d like to add?

APPENDIX D

TEACHER SURVEY QUESTIONS

All questions will be administered post-treatment.

1. What was your experience teaching Science 2B in the new format? What did you like about it? What was challenging?
2. Did you find incorporating more real-world context for chemistry change student engagement or motivation? If so, how?
3. In what ways do you think the new Science 2B supported student learning?
4. Did you find that any aspects of the new 2B negatively impacted student learning? If so, explain.
5. Did the new Science 2B format impact your ability to assess student learning and understanding? How so?
6. Would you recommend organizing Science 2B around essential questions rather than explicit content topics in the future? Why or why not?

APPENDIX E

CHEMISTRY CONTENT ASSESSMENT

Quiz #3: Gas Laws **Name: ___________________**

________/16 points

R = 0.0821 L*atm/(mol*K) **1 mol of an ideal gas = 22.4 Liters at STP**

Multiple-choice section. Each question has just one correct answer. Circle the right answer. (1 point each)

1. If you only triple the temperature of a gas, the pressure will…
a. Increase by a factor of three
b. Decrease by a factor of three
c. Stay the same
d. Turn you into David Bowie

2. How will the volume of a balloon change, as it rises higher and higher into the sky? (Assume that no air enters or escapes from the balloon, and that the temperature of the balloon doesn't change.)
a. Its volume will increase.
b. Its volume will decrease.
c. Its volume will remain the same.
d. Its volume will first increase, then decrease.

3. If at a constant temperature the number of moles of gas doubles and its volume quadruples, the pressure will…
a. Increase by a factor of two
b. Decrease by a factor of two
c. Increase by a factor of four
d. Decrease by a factor of four

4. 8 grams of helium gas at STP would occupy
a. 11.2 L
b. 22.4 L
c. 44.8 L
d. Not enough information to answer the question

5. A capped syringe with 40 ml of gas is placed in a vacuum chamber. When air is pumped out of the chamber, the syringe will…
a. expand
b. stay the same
c. shrink
d. explode

Short answer questions: Use the factor-label method when appropriate. Identify all variables and show the manipulated equation before plugging in numbers. Make sure to include units.

6. At 210.0 ˚C, a gas has a volume of 8.00 L at 1 atm of pressure. What is the volume of this gas at -23.0 ˚C and the same pressure? (3 points)

7. You have a 4 L metal cylinder of carbon dioxide under 5 atm of pressure at room temperature (25.0 ˚C). What is the mass of the carbon dioxide inside the cylinder? (4 points)

8. Hydrogen peroxide, H_2O_2, decomposes into water and oxygen gas. If you start with 2 moles of hydrogen peroxide, what volume of oxygen gas will you create at STP? (4 points)

APPENDIX F

CHEMISTRY APPLICATION AND HIGHER ORDER THINKING SKILLS ASSESSMENTS

Chemistry in Context Assessment **Name:** ____________________

________ / 15 pt

Stoichiometry Challenge Problem of Champions

1. Nuclear power plants generate their energy from fission reactions. The fission 2.5 g of Uranium generates 20,1550,000 kJ of energy. What is the energy density of Uranium in kJ/g?

[__ / 2 pt]

b. The standard enthalpy of the combustion of methane, CH_4, is -51.6 kJ/mol. Calculate the mass of methane, CH_4, that must be burned in air to produce the same amount of energy that would be produced by the fission of 1.0 g of Uranium.

[__ / 5 pt]

Chemistry in Context Assessment **Name:** ____________________

________ / 13 pt

The Mighty Gas Challenge!

$R = 0.0821 \frac{L * atm}{mol * K}$

1 mol of an ideal gas = 22.4 Liters at STP

1. What is the density of CO_2 at STP? Imagine you walked into our classroom, which happened to be under standard conditions (STP), and found a balloon filled with CO_2. Where in the room would the balloon be found?

2. Geoff mines 30 kg of coal, CH, to use to generate electricity for the The Urban School. Geoff collects the carbon dioxide produced from the burning of coal in a special chamber, where the temperature is 25 °C and the pressure is held at 1 atm. What volume does the container need to be?

$$4\ CH\ (s) + 5\ O_2\ (g) \rightarrow 4\ CO_2\ (g) + 2\ H_2O\ (g)$$

c. Geoff wants to minimize the volume of his gas collecting chamber, as the Urban School doesn't have much extra space. Explain one way Geoff could collect the same amount of gas and decrease the volume of the gas.