THE EFFECTS OF CASE STUDIES ON HIGH SCHOOL CHEMISTRY STUDENTS' CRITICAL THINKING SKILLS, CONTENT KNOWLEDGE AND PERCEPTION OF RELEVANCE

by

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ABSTRACT

This research implemented case study learning in high school chemistry classes and measured how they affected student content knowledge, critical thinking skills, and perception of relevance. The case studies were based on specific chemistry content and utilized cooperative group work and lab exercises. Students collected and analyzed data both in the lab and from written cases, proposed solutions and drew conclusions about problems identified within the cases.

INTRODUCTION AND BACKGROUND

La Crescent High School is located in La Crescent, Minnesota. The city of 5114 residents is situated along the Mississippi River and is five miles from the city of La Crosse, WI that has a population 55,000. There are 1272 students enrolled in the La Crescent School District, with 481 students in grades 9-12 at the high school. The student population is 93% Caucasian, 21% of which qualifies for free and reduced lunch. The district has a 97.2% graduation rate (La Crescent-Hokah School District Report, 2012).

I have been teaching science at La Crescent High School for eight years. During this time I have taught chemistry, physics, and physical science. During the 2012-2013 school year I taught 2 sections of chemistry, 2 sections of 9th grade physical science, and 1 section of 6th grade general science; all classes met daily and had an average class size of 28 students. The chemistry and physical science classes met for 47 minute periods and were in a classroom that had both desk space and separate lab space. Students were seated in pairs while in the classroom environment and were encouraged to work together, solve problems and share ideas many times throughout each period. In a given week we were usually in lab for two periods and in seated work for three.

Lab work and problem solving are two areas of focus in my high school science classes. The National Science Standards promote learning science by using, "…a hands-on, problem-based approach that allows students to integrate new knowledge and skills into their existing cognitive structure" (Doran, Chan, & Tamir, 2002, p. 7). This idea aligns with my personal teaching goals of helping students develop higher-order thinking skills and learning to apply what they know to new problems that have multiple solutions.

I try to create lab activities and problems for students to solve in an inquiry format that require them to interpret, analyze, draw substantiated conclusions and communicate their reasoning to the class. Yet, students often lack the skills necessary to initiate and maintain problem solving strategies that will successfully guide them through the lab or problem. In addition, students often have difficulty connecting their previous knowledge and experiences to a specific lab or activity and further transferring what they learn to new situations or problems.

I conducted this research in an effort to further create a classroom in which students not only learn content with a high level of understanding, but who also become more proficient problem solvers and connect what they learn in chemistry to their daily lives. Eighty percent of the students are juniors and 20% are sophomores. Most of the students in chemistry are academically focused, high achieving and intrinsically motivated, as it is an elective course. My primary focus for this study was to determine how implementing content-specific case studies affected high school chemistry students' critical thinking skills. In addition, two sub-questions were further addressed: what were the effects of case studies on students' content knowledge, and what effects did case studies have on students' perception of content relevance.

CONCEPTUAL FRAMEWORK

There is a current trend in science education focused on helping students develop scientific skills and understanding that more closely align with how science is conducted in real world settings. Often referred to as skills for the 21st century, this curriculum approach integrates content knowledge with the critical thinking practices that will transfer to daily life and ensure successful participation in a technological, global society

(Cornell et al., 2011; Ghaith, 2010). As many problems facing societies today are associated with developments and applications of science or scientific processes, it is essential for students to understand the role science has in developing solutions which impact the problems they face in society and that will affect how they live (National Research Council, 2011). Most of these at-large problems, such as environmental issues surrounding energy use, food shortages, medical advancements and carbon emissions, are ill-defined and do not have predetermined paths to follow to arrive at successful solutions (Fortus, Krajcik, Dershimer, Marx, & Mamlock-Naaman, 2005; National Research Council, 2011). Consequently, developing solutions to such problems requires students to define their own processes and approaches; the successful outcome of which will be determined by students' abilities to identify, use and apply appropriate information (Hume & Coll, 2010).

The concept of developing critical thinking skills and practices in science education is historically rooted and has taken on various titles. Critical thinking can vary in its meaning, yet it often includes the following habits of mind: to be inquisitive, open-minded, creative, and able to solve problems by integrating knowledge. Students who are critical thinkers are able to design and evaluate information for usefulness and applicability and can communicate and collaborate on ideas (Cornell et al., 2011; Gabel, 1999; Herreid, 2004). John Dewey was an early proponent of active, inquiry-based curriculums where students constructed meaning by engaging in thinking and doing (Criswell, 2012). Inquiry learning has been defined multiple ways but consistently includes providing open-ended problems through which students uncover meaning. This type of learning involves designing, implementing, evaluating, and communicating

possible solutions for such problems (Cornell et al., 2011; Criswell, 2012; Fortus et al., 2005; Hume & Coll, 2010). The necessary skill set extends beyond factual content knowledge and requires the transfer and integration of knowledge from multiple sources and disciplines when applied to new situations. Similar curriculum approaches depend on engineering and technology to be the vehicle by which science is embedded in real world applications. Technology and engineering are naturally linked to science education because they directly apply scientific concepts and practices to improve the quality of society; consequently, integrating technology and engineering principles helps build relevance for students when learning science (Fensham, 2009; National Research Council, 2009). The Science/Technology/Society (STS) movement of the 1990s is re-emerging with the current focus on 21st century skill development because of the presence technology and engineering have in current society, and because it engages students through connections to their everyday lives (Fensham, 2009).

Problem-based learning (PBL) is another approach to science education that requires integration of multi-disciplinary concepts and cooperative group work to solve problems in real world contexts (Yadav et al., 2007). A specific type of this approach to teaching and learning is the case study method. Used extensively in medical, law, and business education at the post-secondary level, case studies are realistic or true subject-based stories that often include social, ethical, or humanistic dilemmas (Herreid, 1997; Yadav et al., 2007). Case study learning is intended to engage students through relevant applications of content and to further develop the critical thinking skills of inquiry, analysis, evaluation, and creativity when solving content-specific problems (Herreid, 2004). There is evidence that case based learning has positive impacts on students'

critical thinking abilities, their ability to make multidisciplinary connections, and on the depth of their content knowledge (Yadav at al., 2007). Although known to be an effective learning strategy, this type of PBL is not often practiced at the K-12 level. One reason teachers state as to why they do not actively teach with case studies is lack of time and inadequate training on the method (Yadav et al., 2007). This hesitance is supported by evidence that when teachers do not use the proper delivery or do not lay the proper foundation for active, inquiry, contextual learning, students do not develop deeper understanding of the concepts or further their critical thinking abilities (Criswell, 2012; Vos, Taconis, Jochems, & Pilot, 2010).

The traditional science lecture and lab style of teaching does not require students to be fully invested in their learning and does little to develop critical thinking skills. Case based learning is an alternative to cookbook style lab and lecture where students are required to be active learners and can be applied in both lab and classroom environments to actively engage students (Dinan, 2005; Vos et al., 2010). Case study teaching and learning requires planning to introduce the methods to students and is most effective when initially modeled for students. Once the necessary problem solving strategies have been modeled, the lesson transitions into student-directed learning where the teacher acts as facilitator (Gabel, 1999; Herreid, 2004).

Educating for the acquisition of both content knowledge and critical thinking abilities has many implications for K-12 science curriculum design. The National Research Council (2011) has outlined suggestions for a national curriculum and has provided a set of expectations for science education that emphasizes both critical thinking skills and core scientific knowledge. This integrated approach is a shift from the

standards-based education that addresses science as a set of discrete facts. Such an approach seems more accepted by post-secondary instructors than high school teachers. There is evidence that high school science teachers are more focused on content learning goals than on developing process or inquiry skills and feel that college-readiness is measured by student success on state standards-based assessments (ACT, 2009). This is the opposite for post-secondary instructors, who indicate that critical thinking skills are a more accurate gauge of college-readiness and college success than content-based standards (Cornell et al., 2011). This suggests a need for a focused commitment on developing more continuity and assessment of learning goals in science education as applied to both high school and college level learning (Ghaith, 2010).

Case study learning could be the approach that encourages K-12 science education to find a better balance between facts and process skills that will help students be successful outside of the school environment and understand how science is integrated into society. Effectively using case studies creates relevance for students, which could increase student interest and their election to take additional science courses (Yadav et al., 2007). Such an approach to learning may motivate them to engage in scientific endeavors and careers that will improve the quality of their own lives as well as others.

METHODOLOGY

This research was conducted with high school chemistry students from January through April of the 2012-2013 school year (N = 45). Each student and his or her parents signed an informed consent to participate in this research (Appendix A). 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.

The treatment for this study was to imbed content-specific case studies within two different units of study and monitor their effective on student learning. There were two separate treatment units followed by one non-treatment unit. Common teaching strategies for both treatment and non-treatment units included individual and group work, lab work, traditional lecture, and computer simulations. The treatment units had a reduction in the individual work, relied less on traditional lecture strategies, and included two case studies in each unit. The non-treatment unit did not use any case studies, was conducted after the two treatment units, and addressed the content concepts mostly through lecture, lab, and individual homework assignments.

The first treatment unit began in January 2013 and addressed the concepts of chemical quantities and chemical reactions. The first case, *Avogadro Goes to Court*, was an inquiry, lab-based case study modeled after an actual case in which two students successfully sued Pace University over an assignment given by a computer science professor (Bieron & Dinan, 2003). The assignment, as replicated from the case, was to calculate the cost of one aluminum atom in a roll of standard aluminum foil. Students were given the case to read as homework and had one class period the following day to conduct the lab work. The inquiry-style lab was presented to students with minimal guidance, and student groups worked to design and conduct experiments to solve the problem identified in the case. This case addressed concepts of experimental design, Avogadro's number, moles, significant digits, and dimensional analysis. I chose to start with this case because it was the first day of second semester, and although the case

format was new, students were familiar with the chemistry concepts from first semester. I felt they would be able to better focus on the problem solving and acclimate more comfortably to the case study format as well as to the new grouping of students that accompanied the change of semesters.

The second case in this unit, *The Case of the Missing Bees: High Fructose Corn Syrup and Colony Collapse Disorder*, was delivered using the interrupted case study method (Bohlscheid & Dinan, 2011). This method introduced students to the problem of colony collapse disorder (CCD) through a whole-class narrative, after which students worked in groups to answer a series of questions addressing chemical structures and reactions as well as the social implications of genetic modification and categorizing food as natural. Upon completion of the questions, student groups were given additional sections of narrative that successively introduced more information about the problem and that included more complex discussion questions. Through three narratives, student groups purposed possible experiments that could specify causes of CCD and identified the data they would need to collect, analyze, and evaluate.

The second treatment unit of this study was conducted in February 2013 and included two case studies related to the concepts of states of matter and the behavior of gases according to the gas laws. The first of the two cases in this unit, *Cooking Under Pressure: Applying the Ideal Gas Law in the Kitchen*, was a dilemma-type case in which students attempted to resolve a hypothetical problem without conducting any experiments (Chen, Anderson, & Wang, 2009). Students were given the case to read in class and were encouraged to read the dialogue format aloud in groups. After reading the case, students worked collectively in their groups to answer questions related to external pressure,

boiling point, and the ideal gas law and how the concepts applied to cooking, altitude, hypothermia, and steam burns. Students were provided resources and guidance as they asked for them but were otherwise given minimal directives. The last case in this unit, *Got gas? It May Save Your Life,* was another lab-based case study in which students designed, conducted, analyzed, and evaluated their own data (Sidaras & Smith, 2010). Students were introduced to the case through a BBC article that explained a malfunction in motorcycle air bag jackets (Whitworth, 2009). The following day, students conducted mock air bag experiments using the concepts of writing and balancing chemical reactions, making stoichiometric calculations, and applying the ideal gas law. Students delivered all results from cases in reports that were informally peer reviewed and presented.

Data were collected both quantitatively and qualitatively. Other than student interviews, data were collected for all student participants. Some of the data collection instruments were anonymous, such as student surveys, and others were confidential, such as pre- and post-tests and summative assessments. Data collection instruments were triangulated to ensure both reliability and validity (Table 1). The data were analyzed to show changes in thinking and content knowledge from pre to post-tests and for changes in student perception of the relevance chemistry has to their daily lives.

Table 1
Data Triangulation Matrix

	Data source 1	Data source 2	Data source 3	Data source 4
Primary Question 1. What effects do case studies have on students' critical thinking skills?	Pre- and post-test	Student surveys	Teacher field notes and observation	Formative assessment techniques: • Application cards • Documented problem solving
Secondary Question 2. What effects do case studies have on students' content knowledge in chemistry?	Pre- and post-test	Student self-assessment	Summative assessments	Formative assessment techniques: • Application cards • Documented problem solving
3. What effects do case studies have on student perception of content relevance to their daily lives?	Student surveys	Student interviews	Teacher field notes	Formative assessment technique: • Application Cards

Pre- and post-tests were given in each of the three units and were designed to measure both content knowledge and critical thinking skills. The *Chemical Quantities and Reactions Test* (Appendix B) was given before and after the first case study unit, the *States of Matter and Gas Laws Test* (Appendix C) was given before and after the second case study unit, and the *Water and Aqueous Systems Test* (Appendix D) was given before and after the non case study unit. The critical thinking skills assessed were *application,*

analysis, *synthesis* and *evaluation*, which are aligned with the higher order cognitive domains in Bloom's Taxonomy (Table 2). The pre-tests were given at the start of each unit in a stand-alone format with the same questions being incorporated into each unit summative exam as the post-test.

Table 2
Bloom's Cognitive Domains (adapted from Brookhart, 2010)

Bloom's Cognitive Domain	Criteria for categorizing
Application	Applying knowledge to actual situations through illustrations, applications, computations and demonstrations.
Analysis	Breaking down objects or ideas into simpler parts and finding evidence to support generalizations through diagraming, comparing and contrasting, differentiating and categorizing.
Synthesis	Compiling component ideas into a new whole or proposing alternative solutions through creating, summarizing, and explaining.
Evaluation	Making and defending judgments based on internal evidence or external criteria through evaluating, interpreting, and predicting.

All pre- and post-test questions were scored separately for thinking skills and content knowledge using the Content and Thinking Rubric (Appendix E). The rubric assessed student answers according to a three point scale with three representing *complete*, two representing *mostly complete*, and one representing *incomplete* levels of content knowledge and critical thinking skills. In addition to the pre-test questions, each unit summative exam included multiple choice, calculations, and short answer content questions (Appendices F-H). Summative exams were analyzed for depth of student

content learning according to a traditional percentage/letter grade scale. Pre- and post-test scores as well as summative assessment scores were used to compare the treatment units and non-treatment unit.

Prior to taking each unit summative exam, students were given content-based self-assessments to measure their perceptions of their own learning and evaluative thinking. The *Chemical Quantities and Reactions Self-Assessment* (Appendix I) was given after treatment unit one, the *States of Matter and Gas Laws Self-Assessment* (Appendix J) after treatment unit two, and the *Water and Aqueous Systems Self-Assessment* (Appendix K) was given after the non-treatment unit. Students rated their level of understanding for specific learning targets as *N* for *no skills or knowledge*, *B* for *basic skills and knowledge*, *F* for *functionally adequate skills and knowledge*, or *A* for *advanced skills and knowledge*. These ratings were cross-analyzed with scores from the unit summative assessments to identify how accurate students were in their perception of personal learning.

Students were also asked to assess the effectiveness of case study learning on their individual critical thinking abilities through the Critical Thinking and Relevance Survey (Appendix L). These surveys incorporated the secondary question of how relevant students perceived their science learning was and asked students to rate statements according to a Likert scale of *strongly disagree, disagree, neutral, agree, and strongly agree*, which corresponded to numbers one through five respectively. The survey concluded with open-ended response questions that addressed problem solving skills and transferability of these skills to problems outside of chemistry class.

To synthesize and monitor learning of both content and critical thinking skills, formative assessments were used regularly. Throughout each unit, students filled out application cards (Appendix M), which were notecards where they articulated original and specific real world applications of the unit content. Student responses were categorized according to how acceptable the suggested application was and grouped according to a three-point scale: one point being *not acceptable*, two points being *somewhat acceptable*, and three points being *acceptable*. Another formative assessment used in each unit was documented problem solving (Angelo & Cross, 1994). This assessment was intended to help students become more aware of their problem solving skills and how they could adapt them to less well-defined problems. Students were given problems to work out and were asked to document in sequential order the steps they took to solve the problems.

Another form of qualitative data was student interviews. The interviews were conducted with different ability students based upon current class grades using the *Student Thoughts Interview Questions* (Appendix N). Interviews were conducted with three individual students at the end of unit one and with four students each at the end of units two and three. The interview was comprised of open-ended questions related to their perception of relevance of science learning and the effectiveness of case studies. Interviews were assessed qualitatively for students' preferred method of learning chemistry, their perceptions of the applications of their science learning, and for their opinions regarding case study learning.

Finally, throughout the study I recorded field notes of student learning and how students interacted with class content. I noted when students demonstrated evidence of

critical thinking, asked relevant and higher level questions, and my perception of how students reacted to the case study strategy. I also recorded weekly reflections of my own ability to guide students through case study learning, the associated challenges, and any professional growth I was experiencing.

DATA AND ANALYSIS

The pre- and post-test data revealed that student content knowledge increased an average of 23.4% during treatment one, 26.8% during treatment two, and 12.7% during the non-treatment unit (*N =45*). Pre-test data showed students started each of the three units with different levels of preexisting knowledge, with treatment unit two being the lowest average pre-test score for content knowledge at 34.83% compared to the other two units with pre-test scores of 48.48% in treatment one and 42.05% in the non treatment unit (Figure 1).

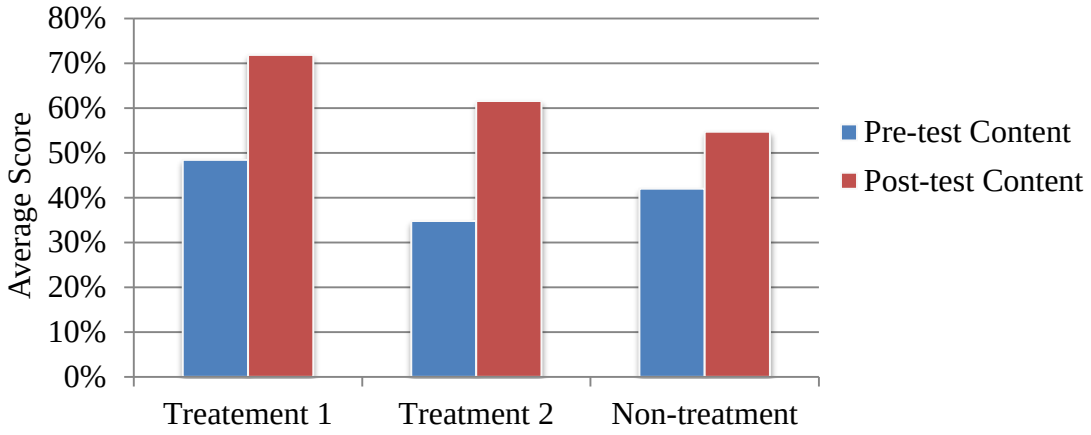

Figure 1. Content knowledge growth from pre- to post-tests, (*N* = 45).

Each of the summative assessments for the three units revealed similar average scores. The summative assessment included additional, usually lower level questions

than did the post-test and had a point value approximately twice that of the post-tests. The average score on the summative assessment for each of the three units was 75.6% for treatment one, 77.9% for treatment two, and 77.0% for the non-treatment unit. The summative assessment scores students earned in each unit, both treatment and non-treatment units, are notably higher than their corresponding post-test scores. The post-test and summative scores for treatment unit one showed a difference of 3.8%, which was the smallest difference between the two assessments in the three units. Treatment unit two revealed a difference of 16.3%, and the non-treatment unit showed a difference of 22.2% (Figure 2). All students interviewed stated that they learned academic content best when they were actively engaged and problem solving in a hands-on way. After one of the lab-based case studies in treatment unit two, one student stated, "real life applications like this are the key to my learning." Another student stated that she enjoyed the case study articles because they presented the content so much differently than the textbook and explained that reading from the text was "not the way for me to learn" because she didn't have the patience to for it.

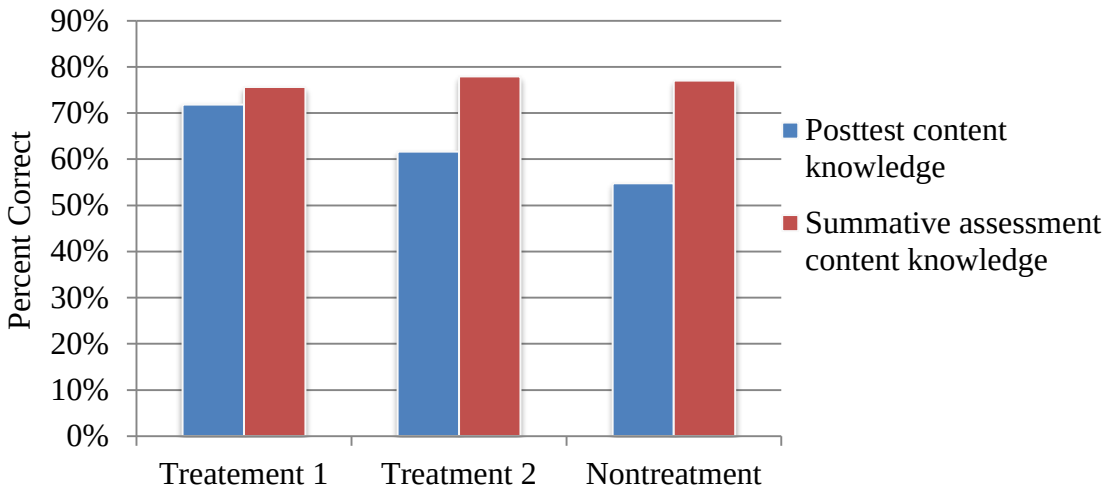

Figure 2. Post-test and summative assessment comparisons, (*N* = 45).

The Content Self-Assessments completed at the end of each unit showed that students scored their own level of comprehension similarly in all three units. The average score on the student content self-assessment was between *basic skills/knowledge* and *functional-proficient skills/knowledge* for all three units, although closer to the functional-proficient level. The average self-assessment score in treatment unit one was 2.72, in treatment unit two was 2.78, and in the non-treatment unit was 2.61, each of which had a maximum score of 4.0. Separating out questions from each of the self-assessments according to the taxonomic thinking skills of *application, analysis, synthesis,* and *evaluation*, revealed that students scored themselves generally lower as the level of cognition increased. Several students indicated throughout the unit that they felt like they understood the material in class, but, "if it isn't in my notes it is hard to study," and that some of the post-test questions were tough to decide if they had, "answered the question enough." There are two exceptions to this trend, the first being found in the *evaluative* thinking scores reported on the self-assessment in both treatment one and the non-treatment unit. Students reported a 13.7% higher level of *evaluative* thinking in treatment one and a 7.3% higher level in the non-treatment unit as compared to the lower-cognition *synthesis* level of understanding. The second exception is found in treatment unit two in which students reported an 8.5% increase in their *analysis* level of understanding as compared to the lower-cognition *application* level of understanding (Figure 3).

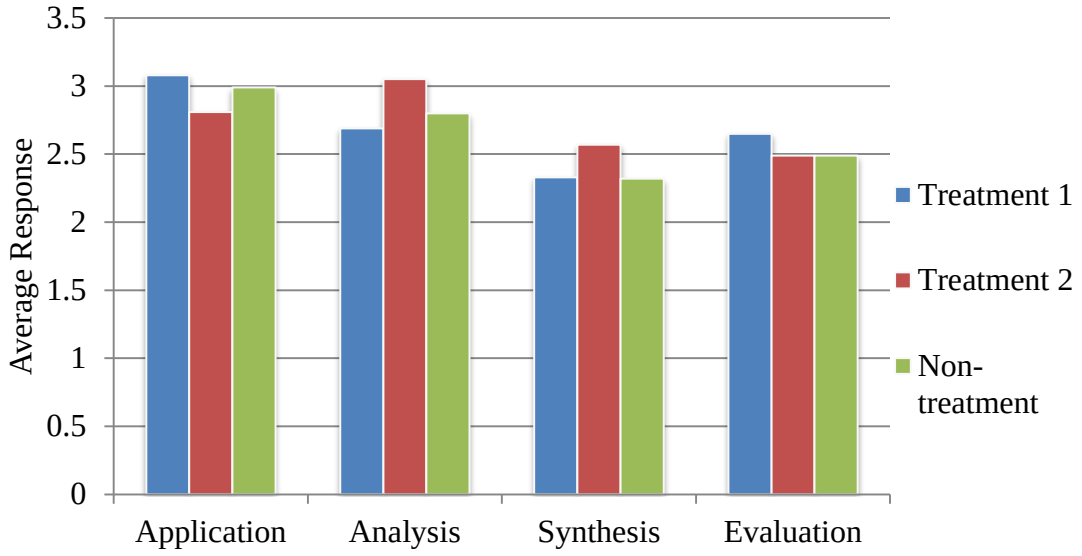

Figure 3. Content Self-Assessment scores, (*N* = 45). 1 = *no knowledge*, 2 = *basic skills and knowledge*, 3 = *functional=proficient knowledge*, 4 = *advanced skills and knowledge*

The content assessments data revealed a trend in treatment unit one not seen in the other two units. In this first treatment unit, students self-assessed their content knowledge an average of 3.9% lower than the scores they earned on the post-test, whereas in treatment unit two and the non-treatment unit, students self assessed their content knowledge higher than the scores they earned on the post-tests by 7.9% and 10.2% respectively. Commonly, students self-scored their content knowledge lower than the scores they earned on the summative assessments in all three units, specifically by 7.6% in treatment unit one, by 8.4% in treatment unit two, and by 12.0% in the non-treatment unit (Figure 4).

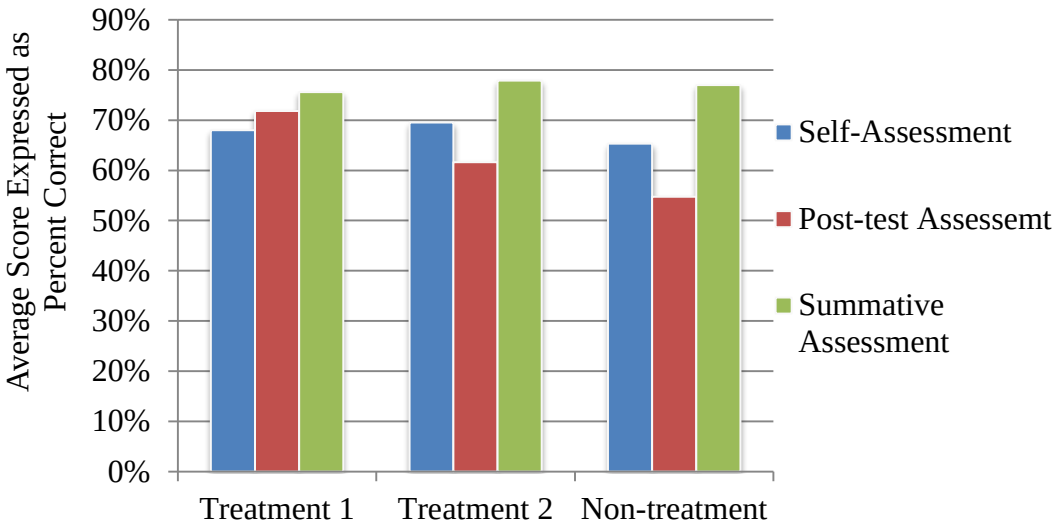

Figure 4. Comparison of content assessment scores, (*N* = 45).

Critical thinking skills as measured by pre- and post-tests in each unit increased an average of 36.9% in treatment unit one, 37.5% in treatment unit two, and 22.4% in the non-treatment unit. In addition, students displayed in increase in their critical thinking abilities as this project progressed. Treatment unit one showed a 29.5% starting score for thinking skills, treatment unit two showed a 33.5% starting score, and the non-treatment unit revealed a 37.6% starting score for thinking skills (Figure 5). During the first case study lesson in treatment unit one, students had a very difficult time figuring out where to start to solve the problem presented in the case. Students asked many clarifying questions before they proposed solutions or procedures that could solve the problem and were often frustrated at the lack of explicit directives on how to find answers. One group of students even asked, “how do we know if we are right?”

During the second case study in unit one, students were more actively engaged in discussing the problems with peers from the very beginning, sought out resources on their own, and started sharing personal connections to the material. One group commented

that they were surprised they understood the chemistry because the formulas and structures of the compounds were, “big and confusing.” Yet, many of them had direct connections with the case material and expressed a genuine interest in trying to explain and provide possible solutions for the case-identified problem.

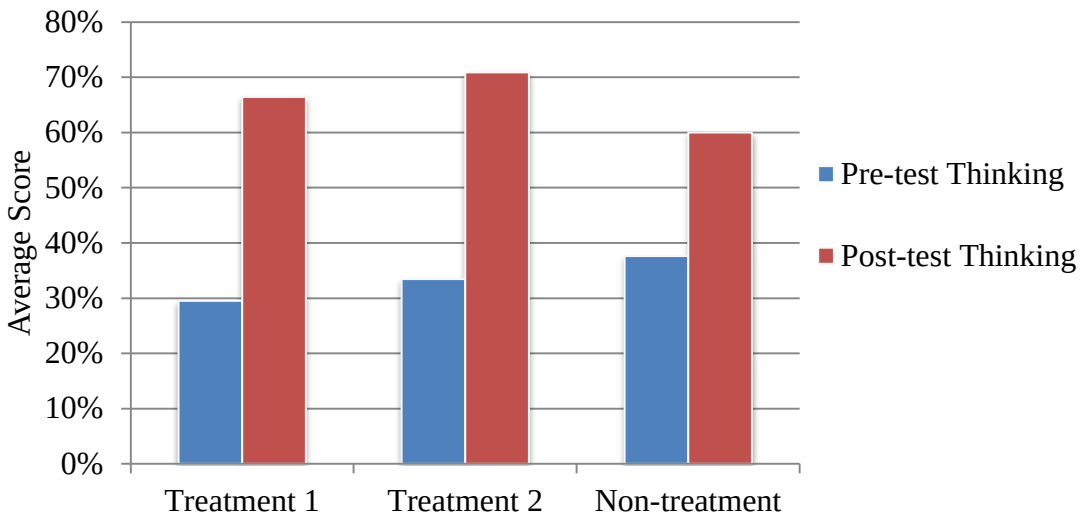

Figure 5. Critical thinking skills, as measured by pre- and post-tests, (*N =45*).

Conversely, the Critical Thinking Skills Survey showed a less positive trend moving from the two treatment units to the non-treatment unit. In 82% of the questions on the survey, students reported *agree* and *strongly agree* 8-38% less often in the non-treatment unit that came at the end of this study compared to treatment unit one, with responses moving to *neutral* and *disagree*. Treatment two, which was between treatment one and the non-treatment unit, also showed a decrease in the average response value from treatment one in 73% of the questions (Figure 6).

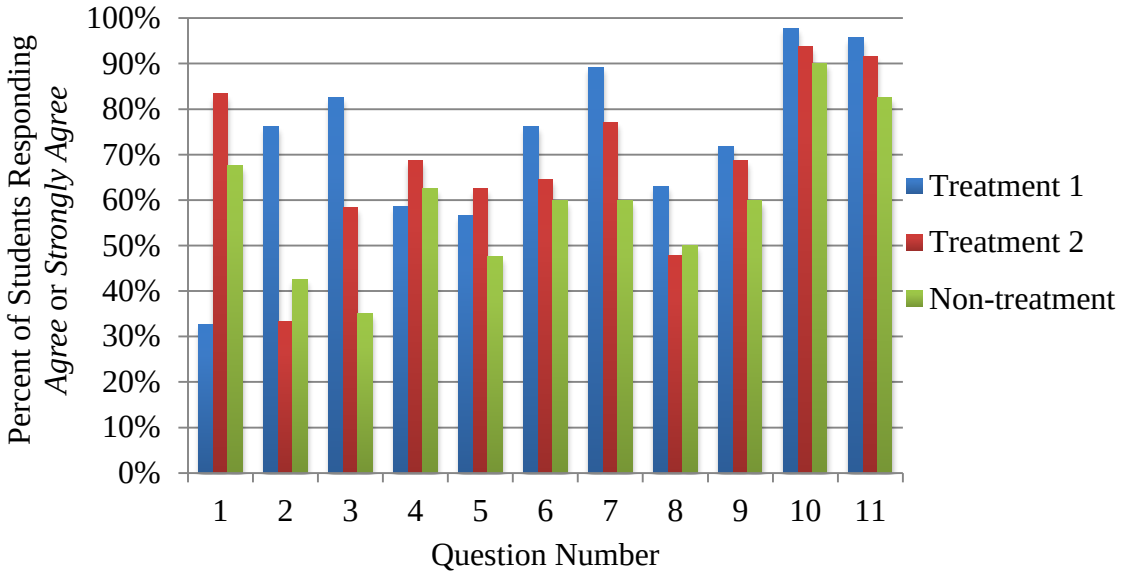

Figure 6. Critical Thinking Skills and Relevance Survey *Agree* and *Strongly Agree* responses, (N = 45).

In terms of general problem solving, the open response questions on the survey revealed that approximately 40% of students in each of the three units approached problem solving outside of science the same as they do in science. Although students stated varied approaches to problem solving, 20.3% of students in treatment unit one and 25.4% in treatment unit two reported systematic and clearly defined strategies they had employed throughout the unit as compared to 9.8% of students reporting similar approaches in the non-treatment unit. In addition, 19.5% of students reported asking for help from the teacher as a strategy in the non-treatment unit compared with 14.1% and 13.4% of students who reported this strategy in treatment units one and two. From a qualitative perspective, the types of questions students were asking in the non-treatment unit were very specific content questions and were generally not higher order thinking questions. In addition, 23.1% of students reported that the labs were the least helpful component of the non-treatment unit, with one student explaining that, “the labs where

none of us really knew what was going on and we just did what the sheet told us to do" as the reason they were the least effective part of the unit.

Various trends were evident when survey questions were grouped according to the individual thinking skills of *application*, *analysis*, *synthesis*, and *evaluation*. The first skill assessed was application, with two specific questions on the survey. The most common response students gave to the statement, *I can apply what I have learned in this unit to other chemistry units* was *neutral* in treatment unit one and improved to *agree* in both treatment unit two and the non-treatment unit. Conversely, students most often responded to the statement, *I can apply what I have learned in this unit to classes other than chemistry* with *agree* in treatment unit one yet shifted to report *disagree* and *strongly disagree* 33.1% more often in treatment unit two and 13.5% more often in the non-treatment unit (Figure 7). Although no student specifically identified using case studies as an effective strategy for learning the applications of chemistry, one student stated the, "article on pressure cookers really helped me understand the quantitative applications of the gas laws," which was used during treatment unit two. Another student commented that the cases were "really enjoyable and interesting to read, and I don't even like to read" and that he never knew of the applications before the case studies. When students were specifically asked during interviews about how they thought case studies affected their learning, 81.8% clearly stated that the case studies helped them understand how chemistry applies to life outside of the classroom.

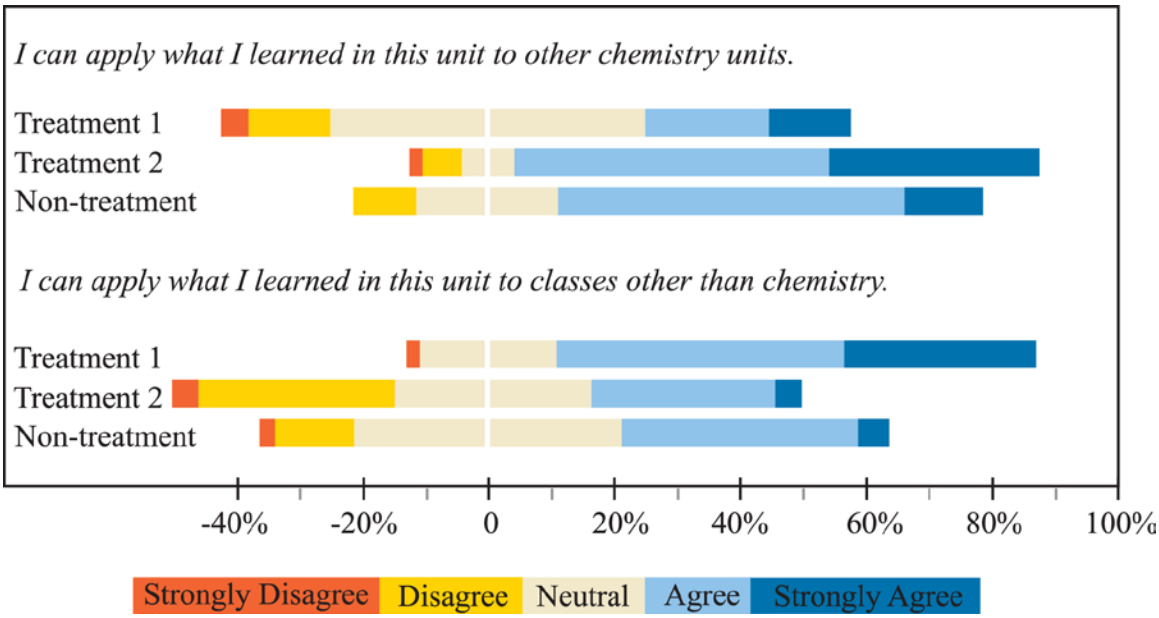

Figure 7. Application skills, as measured by the critical thinking skills and relevance survey, (N = 45).

The survey questions addressing analysis showed more students answered *agree* and *strongly agree* to statements about analyzing and solving problems in treatment units one and two as compared to the non-treatment unit. In response to the question, *I am able to solve problems for this unit is a systematic way*, 35% of students in the non-treatment unit responded with *agree* or *strongly agree* as compared to 82% of students in treatment unit one and 58% of students in treatment unit. The most common response students reported to analysis questions in treatment units one and two was *agree* and decreased to *neutral* in the non-treatment unit. Results for the two analysis questions combined showed the number of students who reported *disagree* and *strongly disagree* increased an average of 2.9% from treatment unit one to treatment unit two and an additional 4.6% from treatment unit two to the non-treatment unit (Figure 8).

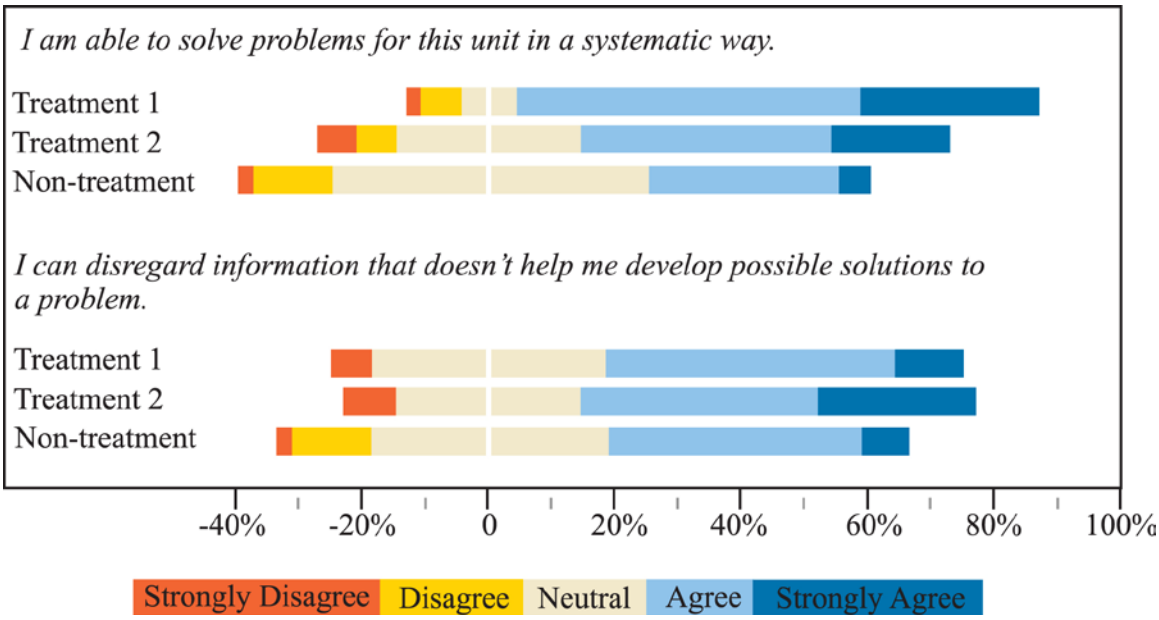

Figure 8. Analysis skills, as measured by the critical thinking skills and relevance survey, (*N* = 45).

Analysis skills were also addressed through the use of the *Documented Problem Solving* formative assessment. Qualitatively, the majority of students had a very difficult time getting started with documenting the steps they had taken to solve a particular problem during both treatment units one and two. Several students asked why they needed to write the steps if they had the correct answer, and many left out important steps they had used to arrive at correct responses. By the non-treatment unit, students were less resistant and more articulate, although many did not seemingly see value in the assessment. Yet, on one specific occasion during the non-treatment unit, a particular problem solving approach outlined by a student and not previously mentioned by me, brought clarity for several other students. A student listening to the approach said, "I did the exact same thing but couldn't really figure out why." The documentation in this assessment was so varied that it was not assessed quantitatively.

There was less measureable difference in the responses for synthesis-level thinking when the treatment units were compared to the non-treatment unit. The most common response to each of the two synthesis-level question was a*gree* in all three units, with the percentage of students who reported *agree* or *strongly agree* ranging from 57.5% in response to the question, *I am able to formulate relevant questions about a problem, lab, or concept that could affect the solution*, during the non-treatment unit to 71.7% on the same question during treatment unit one. Treatment unit two revealed that students reported *disagree* or *strongly disagree* to synthesis skills questions an average of 13.6% of the time as compared to 8.8% in treatment one and 11.3% in the non-treatment unit (Figure 9).

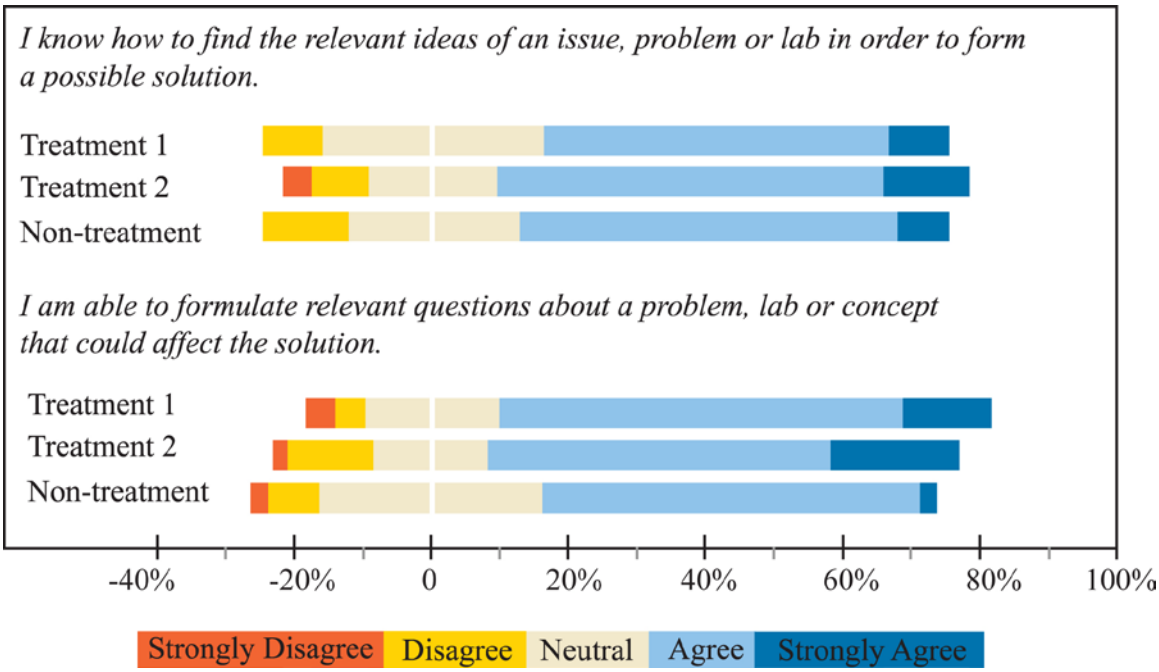

Figure 9. Synthesis skills, as measured by the critical thinking skills and relevance survey, (*N* = 45).

The highest cognition questions on the survey measured evaluation skills. Students responded to the question, *I can explain how material is supported by data and/or lab work* with *agree* or *strongly agree* 89% of the time in treatment unit one, 77% in treatment two, and 60% of the time in the non-treatment unit. Although the percentage of students who reported *agree* showed little change, the percentage who reported *strongly agree* dropped from 35% in treatment one to 31% in treatment two and to 10% in the non-treatment unit. The most common response to the question, *I am able to formulate my own opinion on the validity of the data related to this material,* was *agree* in treatment unit one and the non-treatment unit, whereas *neutral* was the most common response in treatment unit two (Figure 10).

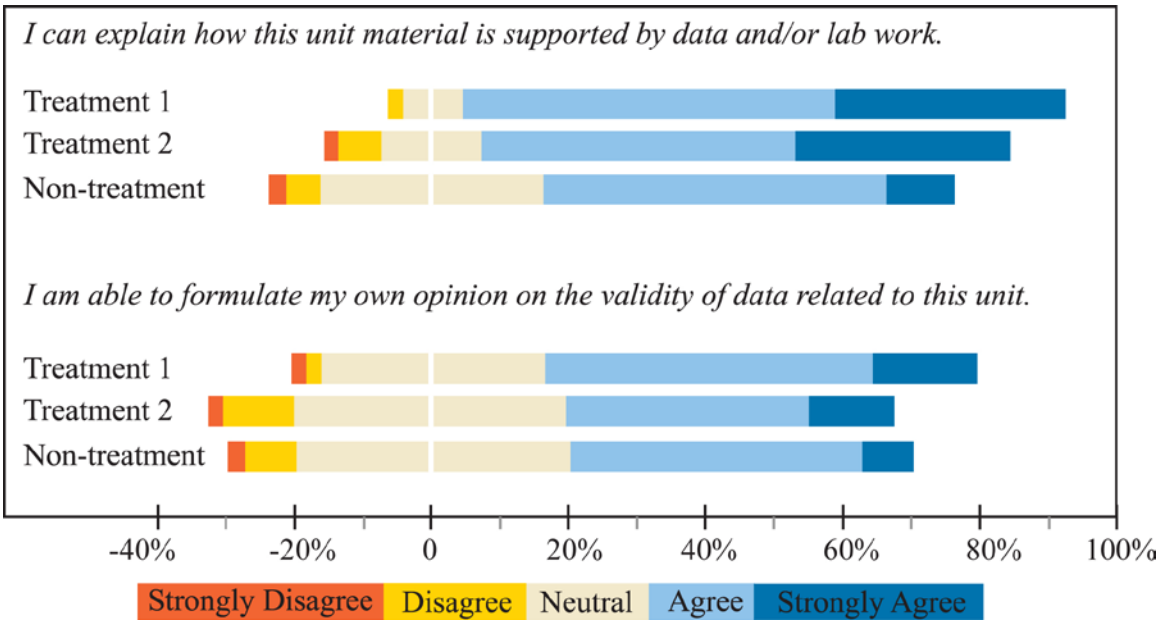

Figure 10. Evaluation skills, as measured by the critical thinking skills and relevance survey, (N = 45).

One numeric response question on the survey, *I understand why it is important for me to learn this material,* most directly measured students' perceptions of relevance. In

treatment unit one, 76.1% of students replied *agree* or *strongly agree* to the above statement, which subsequently decreased to 64.6% in treatment unit two and to 60.0% in the non-treatment unit. In addition, 17.5% of students reported that they *disagreed* or *strongly disagreed* with this statement in the non-treatment unit as compared to 10.9% and 8.3% of students who responded with *disagree* or *strongly disagree* in treatment units one and two respectively.

The *Application Cards* formative assessment also addressed relevance and showed that the 60.5% of students in treatment unit one who were unable to cite *acceptable* or *somewhat acceptable* examples of original or specific real world applications of the unit content decreased by 12.7% to 47.8% in treatment unit two and decreased by an additional 3.4% to 44.4% in the non-treatment unit. The most significant change in responses was the increase in acceptable responses from treatment unit one to two, which showed a 10.4% increase in the number of acceptable responses (Figure 11).

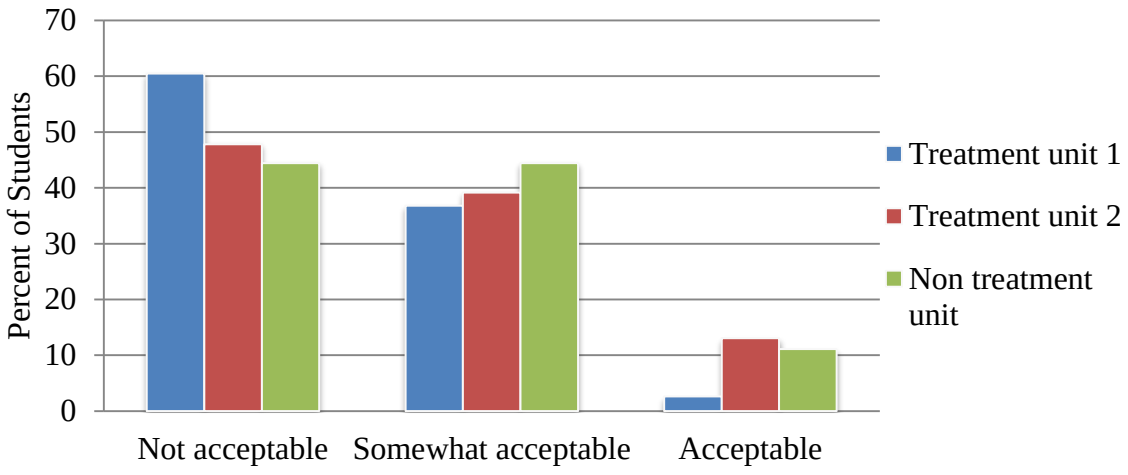

Figure 11. Application cards formative assessment grouped according to level of acceptability, (*N* = 45).

Application and student perception of relevance was further revealed through responses students gave to interview questions. Seventy-three percent of students stated that chemistry was relevant to their other classes, with 50% citing applications specifically to math classes. Other responses included that it helped with general problem solving, working with peers in group work, and that it has made doing research for other classes easier. When asked *how does what you learn in science impact your life outside of school*, 45.5% of students made general statements such as, "it gives me a better understanding of what goes on around me." An additional 18.2% cited specific chemistry applications similar to those in the case studies, another 18.2% stated they were unsure, and the other responses included applications to diesel mechanics and biology. All students interviewed said they thought they would use science after high school, although in different capacities. Eighty-two percent of students indicated they thought they would use science in college, with 55% stating specific STEM careers as possible majors. Another nine percent of students stated they planned to go into a trade where they would have to understand basic science, and another nine percent reported that they thought science would help them simply make, "better arguments" or be more persuasive.

INTERPRETATION AND CONCLUSION

The use of chemistry-based case studies appears to have a positive effect on students' overall critical thinking abilities. It is important to recognize the different content addressed in each of the units was not factored into this project, and the nature and difficulty could have contributed to the results. The two treatment units that used

case studies showed greater gains in students' thinking abilities than did the non-treatment unit, although the non-treatment unit also showed improvement. Students started each subsequent unit with higher critical thinking pre-test scores which suggests that students were developing higher level thinking skills throughout units one and two, both of which used case studies, and continued to develop them during the non-treatment unit but to a lesser degree. The data further support this in the specific area of *application.* Students were able to cite more specific examples of how chemistry connected to their lives outside of class after having worked through the case studies. Not only were students able to write about such applications, but many willingly shared personal connections with the material specific to the cases both during and after the cases. Interestingly, students' critical thinking skills scores were the lowest on the post-test after the non-treatment unit, which could suggest that the methods used were not as effective in helping them develop higher order thinking skills as compared to using the case study method.

There was very little difference in the content summative scores between treatment and non-treatment units, which indicates that this research is inconclusive on how case studies affect overall chemistry content knowledge. Considering the content summative assessments included lower cognitive domain questions as compared with the post-tests, further research could be conducted to see if the case studies have any effects on lower-level *knowledge* and *comprehension* type questions. The content post-tests measured only the higher cognitive domains and showed a marked decline in average scores in all units, which may suggest that case studies impact lower-cognition questions more than higher cognition level questions. Although the summative test scores showed

comparable student averages, the decrease in post-assessment scores from treatment one through the non-treatment unit indicated that students had less academic success with the higher cognition question-only format that was present on the post-assessment as compared to the summative assessment in which higher cognition questions were balanced by lower ones.

Use of the case studies appears to have improved how students relate to chemistry. During the case studies, most students were actively engaged in dialogue about the content as well as about the social implications, with conversations that seemed qualitatively more dynamic than those during more traditional lab and group work activities. Students themselves reported that working with peers helped them more during the case study units as compared to the non case study unit, which supports the idea that collaboration is an essential characteristic of critical thinking (Cornell et al., 2011; Gabel, 1999; Herreid, 2004). Furthermore, students were candid in their conversations in both formal and informal interviews about how they had been unaware of the connections brought forth in the case studies and in how much they enjoyed learning of the applications. It was interesting to note that no student ever mentioned the case studies when asked in the interviews what had been most helpful to them in learning the chemistry material.

There are two areas I would develop further going forward. It would be valuable to conduct a non-treatment unit at the beginning of the study as well as at the end to make comparisons before having used any case studies. This could provide more data about the extent of how case studies impacted student learning. In addition, because students showed little to no growth in the synthesis level questions, it would be advised to include

data rich case studies from which students need to work with large and more complex data sets in order to draw conclusions.

VALUE AND CLAIMS

This research has made it more evident to me that students develop critical thinking skills with practice and patience. Implementing the case study strategies were challenging at first, but it became evident very quickly that students appreciated the content connection to ideas beyond the classroom. In addition, I found myself more engaged in the case study applications than in the more traditional lab and lecture because the cases added value to why I was teaching the content and students were able to understand how the material related to their lives through complex yet tangible examples. Furthermore, the data collection tools were constant reminders that students need multiple exposures and modeling to understand both content and process skills. It was motivating for me to hear the active problem solving students were engaged in during the case studies and to deliver the content with a more humanistic perspective than how I have in the past.

Delivering the cases caused me to think differently about my role as a teacher, as one who is present to guide and scaffold learning to a higher level that is driven by both content and process. It was clear that students were often seeking the “right answer” and that the cases proved challenging for them because they needed to think at higher levels. One student even specifically stated that one of the lab-based case studies was the least helpful strategy because there was, “no way to end the lab knowing you had done it correctly.” In addition, there was no one right way to approach the problems, so groups

worked differently than others which caused internal conflict for many students. I found that students were asking more open-ended questions that displayed their natural curiosities about how chemistry related to life events as well as an obvious level of frustration from some students because of the lack of defined directions.

The nature of this research and the overall process increased my connection with students in a way I had not expected. I believe students felt they were more actively valued when they were asked for their opinions and ideas about the material and how well they were learning. I learned more about them as whole people than I have with classes in the past. Not only did the research tools reveal how they learn, but it also gave me insight as to who they are, what their interests are, and what they want to do after high school. This connection changed the dynamic in my classroom to one that displayed an obvious mutual investment in the learning process.

This action research has given me an understanding of how and why I will continue to conduct it in my classes. As a high school science teacher, it has been easy for me to be mostly content-driven and not particularly reflective in the past. Researching strategies for critical thinking helped me become aware of the differences between how high school teachers and college professors define college readiness and what they see as the goals of high school science. I learned more about my students' understanding from the formative assessments and the pre- and post-tests than I have ever known from their scores on summative assessments. As a teacher of both content and process, a constant awareness of student understanding is critical for me to help them further develop higher order thinking faculties and solve more ill defined scientific problems. In addition, I have found sharing my data and strategies with my colleagues

has evolved our professional development on a very genuine level. I am convinced that students learn more about why chemistry content matters when they are able to directly connect it to their own lives, and I believe this research has provided me enough evidence that case studies can be an effective strategy to help make this connection. Going further, I would like to develop my own cases that connect directly to our community and involve local people and resources so students can relate on an even more genuine level.

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APPENDICES

APPENDIX A

INFORMED CONSENT AND ASSENT

Informed Consent and Assent Form for Students in the Study

The purpose of this research project entitled "The Effects of Case Studies on High School Chemistry Students' Cognitive Skills, Content Understanding, and Perceived Relevance," examines how implementing chemistry-based case studies affects students' understanding of chemistry and related skills as delivered through problem-based learning. For this project, students will be asked to complete short surveys, take pre and post assessments of content knowledge and critical thinking skills, participate in interviews, and design and conduct lab experiments relative to the issues presented in cases. All of these data collection instruments fall within the area of common classroom assessment practices.

Identification of all students involved will be kept strictly confidential. Students involved in the research will remain unidentified in any way. Student environmental (lab and classroom) interactions, content knowledge, and cognitive growth will be assessed and noted, although not documented by student name. At the end of each unit, six students will be selected randomly for interviews. These interviews will be focused on their perceptions of the effectiveness of the case studies used in the unit and on their content knowledge. Nowhere in any report or listing will students' names or any other identifying information be listed.

There are no foreseeable risks or ill effects from participating in this study. All treatment and data collection falls within what is considered normal classroom instructional practice. Furthermore, participation in the study can in no way affect grades for this or any course, nor can it affect academic or personal standing in any fashion whatsoever.

There are broad expected benefits from participation in this study. Case studies have been shown to increase students' depth of content knowledge as well as further develop critical thinking skills, problem solving ability, and understanding of how science contributes to and advances society. In addition, case study learning promotes transferability of science to technology and engineering because it incorporates real world applications of chemistry concepts. Participation in this study is voluntary, and students are free to withdraw consent and to discontinue participation in this study at any time without prejudice from the investigator.

Please feel free to ask any questions of Suzanna Barnhart via e-mail, phone, or in person before signing the Informed Consent form and beginning the study, and at any time during the study.

Parent signature: _____

Student signature: _____

Date: _____

Phone: (507)-895-5031 email: suzanna.barnhart@isd300.k12.mn.us

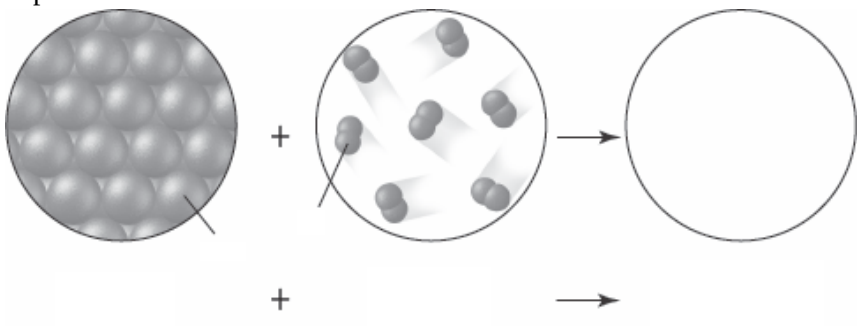
APPENDIX B

CHEMICAL QUANTITIES AND REACTIONS TEST

Chemical Quantities and Reactions Test

1. As you are doing your chemistry homework, your friend makes the statement, "mass is always conserved in a chemical reaction but moles are not." Do you agree or disagree with this statement? Explain your answer.

2. Using the picture, explain what kind of change is taking place and draw what you would expect to find in the final circle.



3. One way geologists identify rocks that contain the carbonate ion is to place acid on them; if the rock is a carbonate, then H_2O, bubbles of CO_2, and another compound form. This reaction is not a single reaction, but is a series of two reactions, one occurring immediately after the other. Limestone is made of predominately of $CaCO_3$, while sandstone is predominately SiO_2.

   a. Which type of rock will react with HCl? How do you know?

   b. The first step is double replacement between HCl and the predominate chemical in the rock. Write the reaction here.

   c. The second step is the decomposition of one of the products. Write the decomposition of one of the products of the previous reaction here.

   d. Write a balanced equation that shows the initial reactants and the final products
   of the reaction.

Use the following table to answer the questions below:

Before reaction	2 molecules O_2	3 molecules H_2	0 molecules H_2O

4. Write and balance the chemical reaction that will occur.

5. Starting with the amount of reactants in the table, how much product will be produced? How do you know?

6. Which substance will be in excess? Explain your answer.

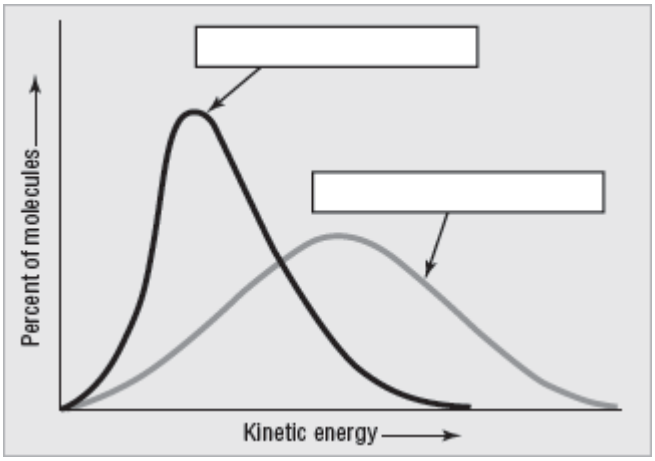
7. Which substance will limit the reaction? What does this mean?

APPENDIX C

STATES OF MATTER AND GAS LAWS TEST

States of Matter and Gas Laws Test

1. On the graph below, write the labels *lower temperature* and *higher temperature* to identify the curve that depicts the kinetic energy distribution of particles in a liquid at a lower temperature and at a higher temperature. Explain your answer.



2. How do air bags work (generally)?

	Reactants	Products
Initial Reaction	NaN_3	Na N_2 (g)
Second Reaction	Na KNO_3	K_2O Na_2O N_2 (g)

a. Explain the chemistry involved using the table.

b. There is a third reaction, which is not shown in the table. Why so you think so many steps are involved?

3. Some types of bacteria are killed by being heated to a temperature of 150°C for 30 minutes. Explain why water heated under pressure can be used to kill these bacteria, although boiling water at atmospheric pressure does not kill them.

4. Fill in the following table wherever there are blanks.

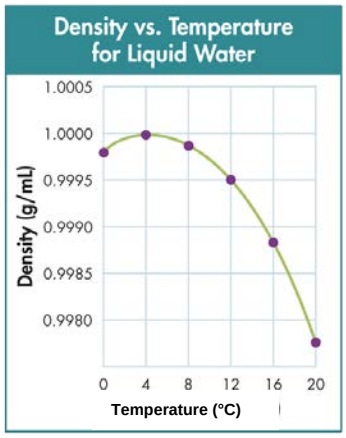
Effect of factor on gas pressure (use up and down arrows to show relationships)	**(*T*) temperature**	**(*V*) volume**	**(n) Number of molecules**	**(*P*) pressure**
If *(V)* and (n) are constant, show the relationship between (T) and (P).		constant	constant	
If *(T)* and (n) are constant, show the relationship between (V) and (P).	constant		constant	
If *(V)* and *(T)* are constant, show the relationship between (n) and (P).	constant	constant		

APPENDIX D

WATER AND AQUEOUS SYSTEMS TEST

Water and Aqueous Systems Test

1. Use the graph below to answer the following questions:



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a. At what temperature is the density of water the greatest?

b. Explain why this is atypical for most substances.

c. Why does water have this unique property?

d. Explain how this property of water is essential for aquatic organisms.

2. A problem for firefighters is that much of the water they spray on a fire doesn't soak in but runs off carrying debris and pollution into the environment. Explain how the addition of a surfactant to the water firefighters spray could help put out the fire more quickly and protect the environment.

3. Cobalt (II) chloride test paper is blue. This paper is made by soaking strips of paper in an aqueous solution of cobalt (II) chloride hexahydrate; when hydrated, the compound is pink. The paper strips are then dried in the oven.

   a. Write the equation for the dehydration of this hydrate.

   b. What color is the hydrate when dissolved in water?

   c. What is the color of the dry cobalt (II) chloride paper?

   d. What is the color of the wet cobalt (II) chloride paper?

   e. What does the paper test for? Explain how you know.

4. Calcium bromide soluble in water. Draw a picture and show the equation for how it dissolves.

   b. Identify a compound by chemical formula that will not dissolve in water. Explain the inter- and intra-molecular forces and the role they have in the compound's insolubility.

APPENDIX E

CONTENT AND THINKING RUBRIC

Content and Thinking Rubric

	3	2	1
Reasoning, clarity, and evidence	Evidence supports the answer and is clearly stated, is logical, and helps explain the answer.	Evidence supports the answer but is not completely clear or logical, or it is not entirely related.	Evidence is not stated clearly or is unrelated to the answer.
Content	Answer is accurate, complete and detailed	Answer is mostly accurate and complete, but missing details	Answer is mostly not accurate, incomplete, and lacks detail

APPENDIX F

SUMMATIVE ASSESSMENT: CHEMICAL QUANTITIES AND REACTIONS

Summative Assessment: Chemical Quantities and Reactions

Part I: Multiple Choice
Identify the choice that best completes the statement or answers the question.

____ 1. In the chemical equation $H_2O_2(aq) \rightarrow H_2O(l) + O_2(g)$, the O_2 is a ____.
a. catalyst
b. solid
c. product
d. reactant

____ 2. Which of the following is the correct skeleton equation for the reaction that takes place when solid phosphorus combines with oxygen gas to form diphosphorus pentoxide?
a. $P(s) + O_2(g) \rightarrow PO_2(g)$
b. $P(s) + O(g) \rightarrow P_5O_2(g)$
c. $P(s) + O_2(g) \rightarrow P_2O_5(s)$
d. $P_2O_5(s) \rightarrow P_2(s) + O_2(g)$

____ 3. What are the coefficients that will balance the skeleton equation below?
$AlCl_3 + NaOH \rightarrow Al(OH)_3 + NaCl$
a. 1, 3, 1, 3
b. 3, 1, 3, 1
c. 1, 1, 1, 3
d. 1, 3, 3, 1

____ 4. The product of a combination reaction is $Ba(OH)_2$. If one of the reactants is H_2O, what is the other reactant?
a. Ba_2O
b. BaO
c. BaH
d. BaO_2

____ 5. In order for the reaction $2Al + 6HCl \rightarrow 2AlCl_3 + 3H_2$ to occur, which of the following must be true?
a. Al must be above Cl on the activity series.
b. Al must be above H on the activity series.
c. Heat must be supplied for the reaction.
d. A precipitate must be formed.

____ 6. What is the balanced chemical equation for the reaction that takes place between bromine and sodium iodide?
a. $Br_2 + NaI \rightarrow NaBr_2 + I$
b. $Br_2 + 2NaI \rightarrow 2NaBr + I_2$
c. $Br + NaI_2 \rightarrow NaBrI_2$
d. $Br + NaI_2 \rightarrow NaBr + I_2$

____ 7. In the reaction $2CO(g) + O_2(g) \rightarrow 2CO_2(g)$, what is the ratio of moles of oxygen used to moles of CO_2 produced?
a. 1:1
b. 2:1
c. 1:2
d. 2:2

____ 8. Which of the following is an INCORRECT interpretation of the balanced equation shown below?
$2S(s) + 3O_2(g) \rightarrow 2SO_3(g)$
a. 2 atoms S + 3 molecules $O_2 \rightarrow$ 2 molecules SO_3
b. 2 g S + 3 g $O_2 \rightarrow$ 2 g SO_3
c. 2 mol S + 3 mol $O_2 \rightarrow$ 2 mol SO_3
d. 5 mol of reactants $\rightarrow$ 2 mol of products

____ 9. How many moles of aluminum are needed to react completely with 1.2 mol of FeO?
$2Al(s) + 3FeO(s) \rightarrow 3Fe(s) + Al_2O_3(s)$
a. 1.2 mol
b. 0.8 mol
c. 1.6 mol
d. 2.4 mol

____ 10. The equation below shows the decomposition of lead nitrate. How many grams of oxygen are produced when 11.5 g NO_2 is formed?
$2Pb(NO_3)_2(s) \rightarrow 2PbO(s) + 4NO_2(g) + O_2(g)$
a. 1.00 g
b. 2.00 g
c. 2.88 g
d. 32.0 g

____ 11. Which of the following statements about the reaction below is true ?
$3NaHCO_3(aq) + C_6H_8O_7(aq) \rightarrow 3CO_2(g) + 3H_2O(s) + Na_3C_6H_5O_7(aq)$
a. 22.4 L of $CO_2(g)$ are produced for every liter of $C_6H_8O_7(aq)$ reacted.
b. 1 mole of water is produced for every mole of carbon dioxide produced.
c. 6.02×10^{23} molecules of $Na_3C_6H_5O_7(aq)$ are produced for every mole of $NaHCO_3(aq)$ used.
d. 54 g of water are produced for every mole of $NaHCO_3(aq)$ produced.

____ 12. Which of the following is NOT a reason why actual yield is less than theoretical yield?
a. impure reactants present
b. competing side reactions
c. loss of product during purification
d. conservation of mass

Part II: Please answer the questions below fully; be sure to show your work.

13. One way geologists identify rocks that contain the carbonate ion is to place acid on them; if the rock is a carbonate, then H_2O, bubbles of CO_2, and another compound form. This reaction is not a single reaction, but is a series of two reactions, one occurring immediately after the other. Limestone is made of predominately of $CaCO_3$, while sandstone is predominately SiO_2.

    a. Which type of rock will react with HCl? How do you know?

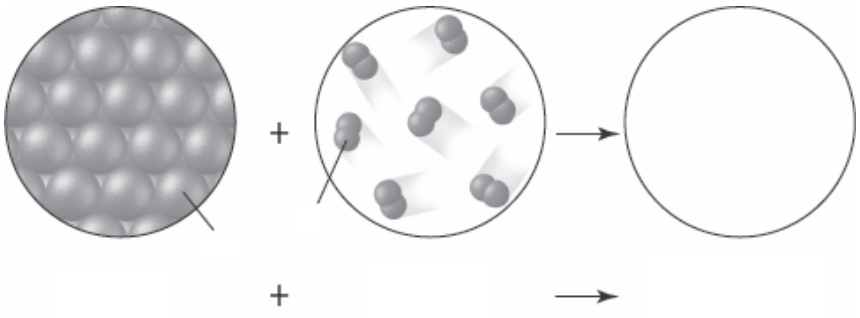
    b. The first step is double replacement between HCl and the predominate chemical in the rock. Write and balance the reaction here.

    c. The second step is the decomposition of one of the products. Write the decomposition of one of the products of the previous reaction here.

    d. Write a balanced equation that shows the initial reactants and the final products
    of the reaction.

14. As you are doing your chemistry homework, your friend makes the statement, "mass is always conserved in a chemical reaction but moles are not." Do you agree or disagree with this statement? Explain your answer.

15. Using the picture, explain what kind of change is taking place and draw what you would expect to find in the final circle. <u>Identify a type of reaction this could represent</u>



16. Methane (CH_4) is the major component of natural gas. Write and balance the combustion reaction.

b. How many grams of oxygen are needed to burn 175.85 grams of methane?

c. How many liters of oxygen do you need?

d. If you only had 250.0 g of oxygen, which reactant would be in excess?

17. Write and balance the reaction between aluminum metal and aqueous copper (II) chloride. What kind of reaction is this?

b. What is the mass of copper metal produced from 4.35 g of aluminum reacting with excess copper (II) chloride?

c. If in lab you only produce 12.6g of copper, what is your percent yield?

d. Give an example of a metal that won't react with aqueous copper (II) chloride. Explain your answer.

APPENDIX G

SUMMATIVE ASSESSMENT: STATES OF MATTER AND GAS LAWS

Summative Assessment: States of matter and gas laws

Part I: Please record your answers below in capital letters.

Match each item with the correct statement below.

a. melting point
b. boiling point
c. sublimation
d. evaporation
e. vaporization
f. normal boiling point

____ 1. vaporization at the surface of a liquid that is not boiling

____ 2. the conversion of a liquid to a gas below the boiling point

____ 3. the temperature at which the vapor pressure of a liquid is equal to the external pressure

____ 4. the temperature at which the vapor pressure of a liquid is equal to 1 atmosphere

____ 5. the temperature at which a solid changes into a liquid

____ 6. the change of a solid directly to a vapor

____ 7. The pressure of a gas in a container is 152 mm Hg. This is equivalent to
a. 0.2 atm.
b. 2 atm.
c. 0.3 atm.
d. 0.4 atm.

____ 8. If 4 moles of gas are added to a container that already holds 1 mole of gas, how will the pressure change inside the container?
a. The pressure will be five times higher.
b. The pressure will double.
c. The pressure will be four times higher.
d. The pressure will not change.

____ 9. When the Kelvin temperature of an enclosed gas doubles, the particles of the gas
a. move faster.
b. strike the walls of the container with less force.
c. decrease in average kinetic energy.
d. decrease in volume.

____ 10. The volume of a gas is reduced from 4.0 L to 0.5 L while the temperature is held constant. How does the gas pressure change?
a. It increases by a factor of four.

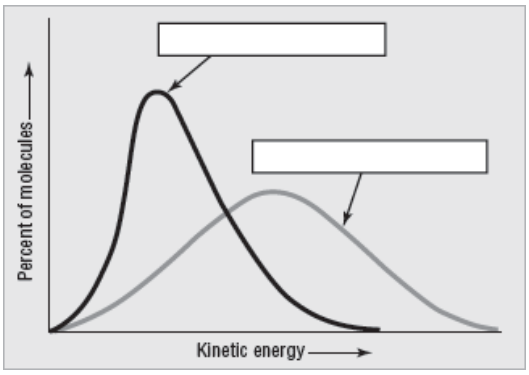
b. It decreases by a factor of eight.
c. It increases by a factor of eight.
d. It increases by a factor of two.

____ 11. A sample of gas occupies 17 mL at –112°C. Assuming the pressure is held constant, what volume does the sample occupy at 70°C?
a. 10.6 mL
b. 27 mL
c. 36mL
d. 8.0mL

____ 12. If the atmospheric pressure on Mt. Everest is one-third the atmospheric pressure at sea level, the partial pressure of oxygen on Everest is ____.
a. one-sixth its pressure at sea level
b. one-third its pressure at sea level
c. one-half its pressure at sea level
d. equal to its pressure at sea level

Part II: Please answer the questions below fully; be sure to show your work.

13. On the graph below, write the labels *lower temperature* and *higher temperature* to identify the curve that depicts the kinetic energy distribution of particles in a liquid at a lower temperature and at a higher temperature. **Explain your answer.**



14. Some types of bacteria are killed by being heated to a temperature of 150°C for 30 minutes. Explain why water heated under pressure can be used to kill these bacteria, although boiling water at atmospheric pressure does not kill them.

15. How do air bags work (generally)?

a. Explain the chemistry involved using the table.

b. There is a third reaction, which is not shown in the table. Why so you think so many steps are involved?

	Reactants	Products
Initial Reaction	NaN_3	Na N_2 (g)
Second Reaction	Na KNO_3	K_2O Na_2O N_2 (g)

16. Ammonium sulfate (the only product), an important fertilizer, can be prepared by the reaction of ammonia with sulfuric acid. Finish writing and balancing the equation below.

NH_3 (g) + $H_2SO_{4(aq)}$

Calculate the volume of NH_3 (in liters) needed at 20.0ºC and 25.0 atm to react with 150.0 g of H_2SO_4

17. In an experiment similar to the lab where you collected hydrogen gas over water, you gather the following data from the single replacement reaction of zinc with hydrochloric acid:

Mass of Zn	.657g
Volume of H_2 collected	315.55 mL
Water temp	23.0°C
Barometric pressure	740.0 mmHg
Partial pressure of water vapor	21.1 mm Hg

a. Write and balance the single replacement reaction

b. Using the mass of Zn, calculate the number of moles of Zn.

c. Calculate the volume of hydrogen gas at STP (using the combined gas law).

d. Calculate molar volume (remember: **Liters**/mole)

e. Calculate % error (accepted…22.4L/mol)

APPENDIX H

SUMMATIVE ASSESSMENT: WATER AND AQUEOUS SYSTEMS

Summative Assessment: Water and aqueous systems

Part I: Multiple Choice

____ 1. The solubility of potassium chloride is $\frac{34\text{ g KCl}}{100\text{ g H}_2\text{O}}$ at 20°C. What is the maximum amount of KCl that can dissolve in 200 g of water at 20°C?

a. 17 g
b. 34 g
c. 68 g
d. 6800 g

____ 2. Which of the following generally occurs as temperature increases?

a. Solubility of a solid solute decreases.
b. Solubility of a solid solute increases.
c. Solubility of a solid solute remains the same.
d. Molarity of a solid solute doubles.

____ 3. To increase the solubility of a gas at constant temperature from 1.20 g/L, at 1.4 atm, to 2.3 g/L, the pressure would have to be increased to ____.

a. 0.37 atm
b. 0.7 atm
c. 1.37 atm
d. 2.7 atm

____ 4. In which of the following is the solution concentration expressed in terms of molarity?

a. $\frac{\text{10 g of solute}}{\text{1000 g of solution}}$
b. $\frac{\text{10 g of solute}}{\text{1000 mL of solution}}$
c. $\frac{\text{10 mL of solute}}{\text{1 L of solution}}$
d. $\frac{\text{10 mol of solute}}{\text{1 L of solution}}$

____ 5. Which of the following operations yields the number of moles of solute?

a. molarity $\times$ moles of solution
b. molarity $\times$ liters of solution
c. molarity $\times$ mass of solution
d. moles of solution $\div$ volume of solution

____ 6. What is the molarity of a solution containing 7.0 moles of solute in 569 mL of solution?

a. 81*M*
b. 0.081*M*
c. 12*M*
d. 4.0*M*

____ 7. What mass of Na_2SO_4 is needed to make 2.5 L of 2.0*M* solution? (Na = 23 g; S = 32 g; O = 16 g)

a. 178 g
b. 284 g
c. 356 g
d. 710 g

____ 8. Which of the following is unchanged when a solution is diluted by the addition of solvent?

a. volume of solvent
b. mass of solvent
c. number of moles of solute
d. molarity of solution

____ 9. How many mL of a 2.0*M* NaBr solution are needed to make 200.0 mL of 0.50*M* NaBr?

a. 25 mL
b. 50 mL
c. 100 mL
d. 150 mL

____ 10. If the percent by volume is 2.0% and the volume of solution is 250 mL, what is the volume of solute in solution?

a. 0.5 mL
b. 1.25 mL
c. 5.0 mL
d. 12.5 mL

____ 11. Which of the following is a colligative property of a solution?

a. boiling point elevation
b. melting point elevation
c. vapor pressure increase
d. freezing point increase

____ 12. Colligative properties depend upon the ____

a. nature of the solute.
b. nature of the solvent.
c. number of solute particles in a solution.
d. freezing point of a solute.

____ 13. A solute depresses the freezing point because the solute ____

a. is colder than the solvent.
b. disrupts crystal formation of the solvent.
c. tends to sink to the bottom of the solution.
d. has bigger molecules than the solvent.

____ 14. The molality of a solution containing 8.1 moles of solute in 4847 g of solvent is ____.

a. 39*m*
b. 1.7*m*
c. 0.17*m*
d. 598*m*

____ 15. What is the boiling point of a solution that contains 3 moles of KBr in 2000 g of water? (K_b = 0.512°C/*m*; molar mass of water = 18 g)

a. 97°C
b. 99.7°C
c. 101.4°C
d. 103°C

16. A problem for firefighters is that much of the water they spray on a fire doesn't soak in but runs off carrying debris and pollution into the environment. Explain how the addition of a surfactant to the water firefighters spray could help put out the fire more quickly and protect the environment.

17. Cobalt (II) chloride test paper is blue. This paper is made by soaking strips of paper in an aqueous solution of cobalt (II) chloride hexahydrate; when hydrated, the compound is pink. The paper strips are then dried in the oven.

a. Write the equation for the dehydration of this hydrate.

b. What color is the hydrate when dissolved in water?

c. What is the color of the dry cobalt (II) chloride paper?

d. What is the color of the wet cobalt (II) chloride paper?

e. What does the paper test for? Explain how you know.

18. Calcium bromide soluble in water. Draw a picture and show the equation for how it dissolves.

b. Identify a compound by chemical formula that will not dissolve in water. Explain the inter- and intra-molecular forces and the role they have in the compound's insolubility.

19. Aqueous sodium hydroxide reacts with aqueous iron (II) chloride to form two products.

a. Please write, balance, and predict the products for this double replacement reaction. Be sure to identify the precipitate.

b. Write the net ionic equation for the reaction.

20. Arrange the following solutes in order of increasing effect on elevating the boiling point of water (start with the solute that will change the bp the least)

a. $MgCl_2$
b. $C_{12}H_{22}O_{11}$
c. KBr
d. $Ca_3(PO_4)_2$

APPENDIX I

SELF-ASSESSMENT: CHEMICAL QUANTITIES AND REACTION

Self-Assessment: Chemical Quantities and Reactions

Directions: Please Circle the letter after each item below that best represents your level of skill or knowledge in relation to the topic. The letters stand for the following responses:

N=No skills or knowledge
B=Basic skills and knowledge
F=Functional and proficient skills and knowledge
A= Advanced levels of skills and knowledge

1. I can describe chemical reactions.	N	B	F	A
2. I can write and balance chemical equations.	N	B	F	A
3. I can differentiate between the 5 different types of chemical reactions.	N	B	F	A
4. I can predict products of a chemical reaction if given the reactants.	N	B	F	A
5. I can describe what a net ionic equation is.	N	B	F	A
6. I can predict the formation of a precipitate in a double replacement reaction.	N	B	F	A
7. I can describe what a balanced chemical reaction means.	N	B	F	A
8. I can interpret balanced chemical reactions for mole ratios.	N	B	F	A
9. I can calculate quantities of reactants and products in a chemical reaction (stoichiometry).	N	B	F	A
10. I can explain what percent yield measures.	N	B	F	A
11. I can calculate percent yield given lab data.	N	B	F	A
12. I can explain the concept of limiting reactant.	N	B	F	A
13. I can verify that chemical reactions obey the law of conservation of mass	N	B	F	A

14. Which specific activities, classroom lessons/labs, and study strategies were the most helpful to you learning the material in this unit?

15. Which specific activities, classroom lessons/labs, and study strategies were the least helpful to you learning the material in this unit?

APPENDIX J

SELF-ASSESSMENT: STATES OF MATTER AND GAS LAWS

Self-Assessment: States of Matter and Gas Laws

Directions: Please Circle the letter after each item below that best represents your level of skill or knowledge in relation to the topic. The letters stand for the following responses:

N=No skills or knowledge
B=Basic skills and knowledge
F=Functional and proficient skills and knowledge
A= Advanced levels of skills and knowledge

1. I can explain the kinetic theory of matter and the model as it applies to gases.	N	B	F	A
2. I can interpret gas pressure according to kinetic theory.	N	B	F	A
3. I can explain the relationship between kelvin temperature and the average kinetic energy of particles.	N	B	F	A
4. I can describe properties that distinguish solids, liquids, and gases.	N	B	F	A
5. I can differentiate between evaporation and boiling in terms of kinetic energy.	N	B	F	A
6. I can explain differences in intermolecular forces for solids, liquids, and gases.	N	B	F	A
7. I can identify factors that determine the shape of a crystalline solid.	N	B	F	A
8. I can explain how the structure and properties of solids are related.	N	B	F	A
9. I can explain how temperature, volume, and number of particles affect gas pressure.	N	B	F	A
10. I can describe the relationship between temperature, volume, and pressure of gases.	N	B	F	A
11. I can use the gas laws to calculate changes in temperature, pressure, or volume of a gas.	N	B	F	A
12. I can explain how why we use the ideal gas law.	N	B	F	A
13. I can calculate the amount of a gas using the ideal gas law.	N	B	F	A
14. I can relate total pressure of gases to partial pressure.	N	B	F	A
15. I can explain changes in conditions that will cause substances to change states.	N	B	F	A

19. Which specific activities, classroom lessons/labs, and study strategies were the most helpful to you learning the material in this unit?

20. Which specific activities, classroom lessons/labs, and study strategies were the least helpful to you learning the material in this unit?

APPENDIX K

SELF-ASSESSMENT: WATER AQUEOUS SYSTEMS

Self-Assessment: Water and Aqueous Systems

Directions: Please Circle the letter after each item below that best represents your level of skill or knowledge in relation to the topic. The letters stand for the following responses:

N=No skills or knowledge
B=Basic skills and knowledge
F=Functional and proficient skills and knowledge
A= Advanced levels of skills and knowledge

1. I can explain why water has high surface tension, low vapor pressure, and a high boiling point.	N	B	F	A
2. I can explain the structure of ice.	N	B	F	A
3. I can explain which types of substances dissolve in water.	N	B	F	A
4. I can explain why all ionic substances are electrolytes.	N	B	F	A
5. I can distinguish between solutions, colloids, and suspensions.	N	B	F	A
6. I can describe the factors that affect the solubility of a substance.	N	B	F	A
7. I can describe the equilibrium in a saturated solution.	N	B	F	A
8. I can calculate molarity, molality, and percent solutions.	N	B	F	A
9. I can interpret solution concentrations in terms of solute and solvent.	N	B	F	A
10. I can explain the structure of a hydrate.	N	B	F	A
11. I can explain how colligative properties can be determined based on number of dissolved particles	N	B	F	A
12. I can calculate freezing point depressions and boiling point elevations.	N	B	F	A

13. Which specific activities, classroom lessons/labs, and study strategies were the most helpful to you learning the material in this unit?

14. Which specific activities, classroom lessons/labs, and study strategies were the least helpful to you learning the material in this unit?

APPENDIX L

CRITICAL THINKING AND RELEVANCE SURVEY

Critical Thinking and Relevance Survey

Please respond to the following questions honestly and accurately.

Part I Directions: Circle the number after each item that best represents how you feel.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1. I can apply what I have learned in this unit to other science units	1	2	3	4	5
2. I can apply what I have learned in this unit to classes other than science	1	2	3	4	5
3. I am able to solve problems for this unit in a systematic way	1	2	3	4	5
4. I know how to find the relevant ideas of an issue, problem, lab in order to form a possible solution	1	2	3	4	5
5. I can disregard information that doesn't help me develop possible solution to a problem	1	2	3	4	5
6. I understand why it is important for me to learn the material in this unit.	1	2	3	4	5
7. I understand how this unit material was developed from data	1	2	3	4	5
8. I am able to formulate my own opinion on the *validity* of data related to this unit material	1	2	3	4	5
9. I am able to develop relevant questions about a problem, lab, or concept that could affect the solution.	1	2	3	4	5
10. Working with peers and collaborating helped me solve problems in this unit	1	2	3	4	5
11. Communicating results or solutions with others helps me better understand the problem or content.	1	2	3	4	5

Part II Directions: Respond to the following questions in your own words.

10. How did you approach problem solving in this unit?

11. How does your approach to solving problems change outside of science?

12. What kinds of scientific problems affect you?

APPENDIX M

APPLICATION CARDS

Application Card Name_____

Chemical reactions occur around you constantly. Give one practical example of how understanding chemical reactions applies to you outside of class.

APPENDIX N

STUDENT THOUGHTS INTERVIEW QUESTIONS

Student Thoughts Interview Questions
Research Question: How does using case studies in science affect students' critical thinking skills?

1. How do you best learn academic content?

2. Does the way you learn best change for more complicated material? Please Explain.

3. What do you think some of the goals are for students taking science classes?

4. What is the most difficult part of learning science for you?

5. How does what you learn in science apply to other classes?

6. How does what you learn in science impact your life outside of school?

7. Do you think you will use science after you graduate from school? Explain.

8. According to the scale below, how well do you like hearing or reading stories?

1	2	3	4	5
Dislike greatly	Dislike somewhat	Neutral	Like somewhat	Like very much

9. What do you know about case studies?

10. If you have used case studies in classes, how do they affect what you learn?

11. Is there anything else you would like me to know?