

INQUIRY-BASED MODELING IN THE HIGH SCHOOL
CHEMISTRY CLASSROOM

by

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ABSTRACT

This project investigated the impact of intentionally integrated inquiry-based modeling impacted student attitudes and achievement towards chemistry in a high school Advanced Placement Chemistry classroom. For two chapters of instruction, student learning was coupled with inquiry-based model creating. Students performed modeling regularly throughout the two chapters. Data collection for this project included pre-tests, post-tests, modeling performance assessments, surveys, and interviews. The results indicated a slight improvement in student attitudes and achievement in chemistry.

INTRODUCTION AND BACKGROUND

Samuel Karlin (1983), an American mathematician, once said, “The purpose of models is not to fit the data but to sharpen the questions” (p. 13). As a teacher, I felt deeply responsible for my students’ understanding of information and their ability to use the knowledge that they gain in my class throughout their lives. Memorization or plug-and-chug calculations allow for momentary success, but do not truly reflect understanding. Memorization-based learning could also lead to a shallow grasp of chemical principles, resulting in a lack of ability to think beyond the textbook problems.

I have taught chemistry for five years, which was my major in college. All of my professional teaching experience has been at Artesia High School (AHS) in Lakewood, California. According to California School Ratings (2015), there were about 1,500 students attending AHS. The school’s ethnic demographics were 71% Hispanic/Latino, 11% African American, 6% Asian, 6% Filipino, 4% White, and 1% Pacific Islander. AHS was a Title I school with 77% of the students receiving free or reduced lunch. Many students may have possibly been the first in their family to graduate from college, since 30% of the students’ parents did not graduate from high school. About 50% of students’ parents did not receive any type of education since high school (California School Ratings, 2015). When compared to other schools of similar demographics, AHS was one of the top-rated schools. AHS was in a more dangerous location in the greater Los Angeles County. We had several students involved in gangs, but our racial tension has drastically decreased in the last eight years. Students were held to strict rules, and teacher-to-student relationships were highly emphasized.

Chemistry is a required class for students to take during their sophomore year. It is considered a laboratory class and is a demanding course. Chemistry requires students to understand concepts on subatomic, atomic, and molecular levels. Students need to grasp abstract ideas, which can be difficult to visualize and transfer into a real-life comprehension. Beyond their first year of Chemistry, students had the option of enrolling in Advanced Placement (AP) Chemistry, which is a college level course.

I have noticed that my own understanding of concepts in chemistry is very imaginative. I create a model in my head for the principles, concepts, and behaviors of atoms in chemistry. Trying to transfer this information to my students, however, had become alarmingly difficult. I tried to use models and drawings, but in reflection, the students weren't creating the models based on their own understanding, so it was not retained nor understood to a deeper level.

With the release of the Next Generation Science Standards (NGSS), modeling was an important concept in the new standards (NGSS Lead States, 2013). Also, with the release of revised AP Chemistry standards in 2014, there was a shift in focus from recall to enduring conceptual understanding (The College Board, 2014). Because of these shifts in standards, it became very apparent that inquiry-based modeling was something that I needed to help my students succeed with.

I discovered that after I had created visualizations, models, and manipulatives, that I had longer-lasting and transferable understanding of chemical concepts. When I tried to transfer my understanding to my students, however, information tended to get lost in the process. I found that when the students made their own models and visualized

concepts, they understood and retained information better. Also, models allowed for misconceptions to be drawn out so that we could correct misunderstandings efficiently and effectively. In order to encourage and facilitate my students in learning and achieving a model-based concept of chemistry, I modified my teaching to allow for inquiry-based modeling and discovery.

My reflections led to the creation of my focus statement: how did the implementation of inquiry-based modeling impact students in the chemistry classroom? In addition, I asked the following sub-questions: 1. What was the effect of inquiry-based modeling on student achievement in chemistry? 2. What is the effect of inquiry-based modeling on student attitudes about chemistry?

CONCEPTUAL FRAMEWORK

According to Kelvin (1884), when models can be successfully made, it shows that those models are then understood. Chemistry is a branch of science that deals with atoms and their interactions. Because chemistry is a physical science, it makes sense to teach a chemistry course by using a modeling approach of visual and spatial learning techniques. Science requires conceptual thinking in order to understand concepts. When a student observes a phenomenon occur before his or her eyes, the student should then be able to create a model and then use the model to explain their understanding of the phenomenon. Teachers should encourage conceptual thinking and modeling in students. Instead of showing pictures and explaining concepts, teachers should be guiding students to create a visual and spatial model for themselves (Ramadas, 2009).

Chemistry and other physical sciences are often taught in a traditional, teacher-dominated environment. In this type of learning environment, physical and chemical changes that occur are not illustrated using models and physical examples, but instead are taught from a perspective that requires students to create mental models. An effective way to have a student understand real-world experiences is to have the student model those phenomena (McNeil, Uttal, Jarvin & Sternberg, 2009). Using a three-dimensional environment to teach and visualize chemistry concepts helps increase understanding for students. Once the physical model is created, the student then must make use of it. When required to explain the model, it becomes apparent to a teacher if the student understands the concept being modeled. If a student's mental model can be transferred into a visual or physical model, it is shown to increase retention and minimize misconceptions (Trindade, Fiolhais & Almeida, 2002).

With the adoption and modification of the NGSS in California, modeling is a new requirement in the *science and engineering practices*. These new standards require students to transfer their mental models, or incomplete, imagined understandings, into a physical, conceptual model. This allows students to visualize and create an external presentation. Modeling is incorporated throughout the chemistry standards and students are expected to be able to use different media to communicate understanding. The media that can be used for modeling include mathematical and analogous diagrams, physical representations, and computer simulations (NGSS Lead States, 2013). In 2014, The College Board also made a shift towards requiring students to make connections between models and concepts (The College Board, 2014).

One study revealed that guided-inquiry based modeling was proven to increase student success and understanding of conceptual ideas. When teaching strategies were implemented to support student achievement in modeling, students were able to successfully express their understanding with the use of physical representations (Weiss, 2006). Another study revealed that analyzing the treated subjects' models drew out misconceptions of the subjects being treated. The subjects used modeling to visually present different types of matter, allowing for incorrect understanding to become apparent. Inquiry-based questioning was used to try to correct the subjects' understanding. It was found that using only a verbal transfer of information was not enough. Physical and spatial modeling was a critical factor in improving understanding (Yakmaci-Guzel & Adadan, 2012).

Ogan-Bekiroglu and Arslan (2014) conducted a study to determine the difference between the impact of cookbook-type lab experiments and model-based learning on student skills. The individuals studied were placed into two groups. The control group received experiments, which required them to follow the instructions similar to that of a cookbook. The experimental group constructed models and developed explanations based on the models they created. The results indicate that creating models impacts student development by increasing scientific processing skills. Evidence suggests that using models in science classes impact "student scientific inquiry skills compared to the traditional learning model, especially in the dimensions of process skills, comprehensive skills, learning attitude, communication skills, and reflection skills" (Wang, Guo, & Jou, 2015, p. 668).

Mental and physical models, however, can be difficult to understand and interpret. Individuals have different backgrounds, creativity, previous experiences, and conceptual understandings. Some research suggests that because of the complexity of evaluating an a student's mental understanding, having students create a physical representation of their mental model can cause disconnects and possibly even misconceptions (Greca & Moreira, 2000). Teacher interactions with students play a large role in the results of student understanding. With an open mindset and intentional, investigative questioning, models can be useful in a classroom setting (Weiss, 2006).

Research has shown that the incorporation of modeling into classroom lessons helps a variety of students of different cultures and backgrounds (Auberime, 2007). Having students draw on real-world knowledge when solving word problems is much more effective than when students try to solve problems by using memorized theories and concepts. When students relate the material that they learn to real-world experiences, the students are more likely to remember the information and also transfer their understanding to other problems (McNeil, Uttal, Jarvin & Sternberg, 2009).

Self-concept, specifically in a chemistry classroom, is a student's perception of his or her own abilities and identity. Self-concept is a large factor in a student's motivation, attitude, and performance. A study by Lewis, Shaw, and Heitz (2009) found that students who are actively involved and personalize their learning in chemistry experience an increase in self-concept. Students with a high self-concept are found to have a higher degree of success in chemistry than those with a low self-concept. The

integration of modeling lets students individualize and engage in the content in chemistry (Lewis, Shaw & Heitz, 2009).

The effect of implementing inquiry-based modeling is increased student understanding and improved attitude in the chemistry classroom. Inquiry-based models, when created by students, are used to explain real-life phenomena that occur. The explanation of concepts can draw out misconceptions or incorrect analyses of the chemical concepts taking place in a specific phenomenon. By creating a space for students to transfer their understanding and receive feedback, students better understand the science content and have a more positive attitude towards chemistry.

METHODOLOGY

The treatment of this study included intentional use of models for students throughout two units in the Advanced Placement (AP) Chemistry curriculum. Prior to treatment, there was modeling in the classroom, but this modeling was unplanned. This was because chemistry is a physical science, so some degree of modeling occurred by my students and myself. However, this unintentional modeling was not assessed nor directly prompted. For every topic covered within the two units, modeling was prompted by the teacher and completed by the students in the classroom. This treatment occurred from February 2017 to April 2017. These models were based on concepts in the NGSS and College Board's Course and Exam Description and were inquiry-based models. 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 collection began at the beginning of the 2016 school year, when students were asked to take the Modeling in Chemistry Survey (Appendix B). This survey was taken prior to the treatment of this action research-based classroom project. At the conclusion of the treatment plan, the students took the Modeling in Chemistry Survey a second time (Appendix B). This Likert-style survey was administered pre-treatment and post-treatment using Google Forms. The same six questions were given to the students, with the options *strongly agree*, *somewhat agree*, *somewhat disagree*, and *strongly disagree*. Students identified their understandings, benefits, and uses of models in chemistry through the survey. The Modeling in Chemistry Survey pre- and post-test scores were analyzed and compared using a stacked bar chart.

Treatment started with the unit on thermochemistry, which began on the first day of the second semester. Students started by taking the Chapter 6: Thermochemistry Pre-Test (Appendix C). Throughout the instructional time, students were engaged in creating models for the concepts that they learned. The Ice Cube Melting Model performance assessment was formally assessed and graded during the chapter (Appendix D). At the conclusion of the unit, students took the Chapter 6: Thermochemistry Post-Test (Appendix C). The data collected from the Thermochemistry Pre-Test and Thermochemistry Post-Test were analyzed using a normalized gain analysis. Hake (1998) determined that a normalized gain of less than 0.3 is a *low* gain, 0.3-0.7 is a *medium* gain, and greater than 0.7 is a *high* gain. The results were reported in box and whisker plot for the Pre-Test and Post-Test. Since the Thermochemistry Post-Test was also given the year prior as a summative test when classes had not received treatment, the

data collected between the 2015 school year and 2016 school year post-tests were analyzed and reported in box and whisker plot.

The second unit began immediately after the thermochemistry chapter. This chapter started with all students taking the Chapter 17: Spontaneity, Entropy, and Free Energy Pre-Test (Appendix E). Students were engaged in three weeks of instruction that included the integration of modeling regularly in class. The Enthalpy, Entropy, and Temperature Performance Assessment was implemented during this time (Appendix F). At the conclusion of the chapter, students took the Chapter 17: Spontaneity, Entropy, and Free Energy Post-Test (Appendix E). The data collected from the Pre-Test were compared to the Post-test using a normalized gain analysis. The results were reported in a box and whisker plot. Post-test data was also collected from the 2015 school year, which was prior to this treatment plan. The results of the post-tests were analyzed between the 2015 and 2016 school year and reported using a box and whisker plot. The results of the performance assessment data, for both performance assessments formally observed over the treatment plan, were analyzed and displayed as a histogram.

After the treatment, students were randomly selected to be interviewed about their feelings about science, their abilities in chemistry, and their overall experience when using modeling during the treatment (Appendix G). These interviews were used as qualitative evidence to support other data analysis claims and analyzed for common themes. Also, throughout the process, a teacher's journal was maintained regularly to document the process.

The data instruments and results collected, both qualitative and quantitative, were used to answer the focus questions (Table 1).

Table 1
Data Triangulation Matrix

Focus Question	Data Source 1	Data Source 2	Data Source 3	Data Source 4
<i>Primary Question:</i> 1. How will the implementation of inquiry-based modeling impact students in the chemistry classroom?	Modeling in Chemistry Survey	Interview Questions	Teacher's Journal	Both Performance Assessments
<i>Sub-Question 1:</i> What is the effect of inquiry-based modeling on student achievement in chemistry?	Thermochemistry Pre- and Post-Test	Spontaneity, Entropy, and Free Energy Pre- and Post-Test	Performance Assessment: Ice Cube Melting Model	Performance Assessment: Enthalpy, Entropy, and Temperature
<i>Sub-Question 2:</i> What is the effect of inquiry-based modeling on student attitudes about chemistry?	Modeling in Chemistry Survey	Interview Questions	Teacher's formal and informal observations	Teacher's Journal

DATA AND ANALYSIS

This pilot study was conducted in two periods of an Advanced Placement (AP) Chemistry course ($N=53$). The Modeling in Chemistry Survey was administered to the students pre-treatment and post-treatment (Appendix B). The results of the Modeling in Chemistry Survey indicated that students responded positively towards modeling in the chemistry classroom and that they used modeling more after the treatment than before. When asked if students regularly create mental models of the chemical concepts they learn, results indicated that 7.5% of students responded *strongly agree* prior to the

treatment. After the treatment, 32.1% of students responded *strongly agree*. One student stated, “I wish we had included more models in the beginning of the year because it would have been more beneficial.”

When asked if students better understand chemistry concepts when creating models, 37.7% of students responded *strongly agree* pre-treatment while 49% of students had the same response post-treatment. A student stated, “Modeling affected my learning in chemistry in the sense that I am better able to conceptually understand what is going on because it is easy to do the math portion but if I cannot conceptually understand it then what is the point?”

An increase from 15.1% to 37.7% of students responded *strongly agree* when asked if they enjoy making models of chemical concepts. One student stated, “I enjoy making models after learning the chemical concepts because it helps me understand what we just learned about and puts an image in my head of what is actually happening in chemistry.”

The percent of students who responded *strongly agree* increased from 9.4% to 15.1% between pre-treatment and post-treatment when asked if they are confident in their ability to create models. There was also an increase from 39.6% to 56.6% of students that responded that they *somewhat agree*.

Students who *strongly agree* that making models helped them better understand chemistry increased from 45.3% of students pre-treatment to 66% post-treatment. One student stated, “Before I would just be memorizing and then regurgitating. Modeling forced me to make the concept for myself rather than following a set concept that would

not contribute to my personal learning of the subject.” Another student responded, “Creating models has helped me better understand chemistry conceptually because I can not imagine how something would look during a reaction rather than just calculating a number.” Post-treatment, 1.9% of students responded *strongly disagree* when asked if making models helps them better understand chemistry. One student stated, “I need people to explain to me what is going on in order for me to understand a concept so trying to figure out what is happening on my own confuses me more.”

The percent of students who responded *strongly agree* to being good at chemistry increased from 13.2% to 18.9% from pre-treatment to post-treatment (Figure 1).

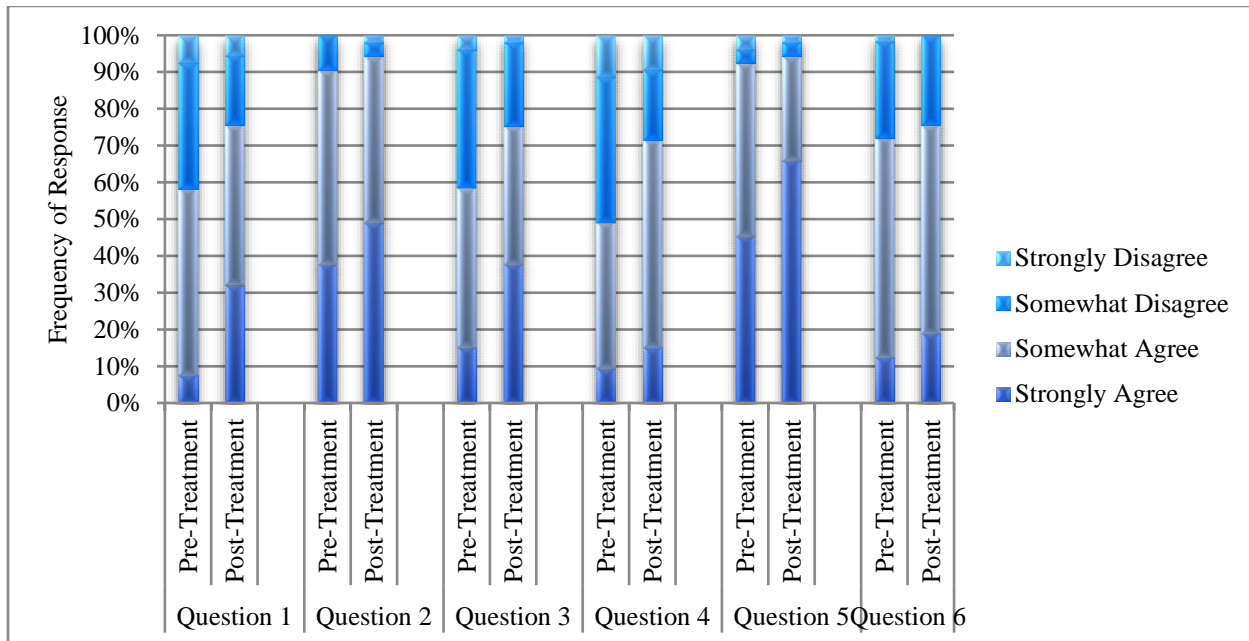


Figure 1. Modeling in Chemistry Survey results, (N=53).

Note. Question 1: I regularly create a mental model of the concepts I learn in chemistry. Question 2: I better understand chemistry problems after I create a model of the concept. Question 3: I enjoy making models of chemical concepts. Question 4: I am confident in my ability to create models in chemistry. Question 5: Making models helps me better understand chemistry. Question 6: I am good at chemistry.

During the treatment period, students were given performance assessments and were asked to create models that went along with concepts in the chapters. During the first chapter of the treatment plan, students watched an ice cube melt in a hand and were asked to construct a model based on what they saw along with their knowledge of thermochemistry (Appendix D). When students turned in their models, the teacher met one-on-one with each student individually. This meeting was for the student to explain their model and for the teacher to give feedback and address any misconceptions or missing concepts (Figure 2). For the second performance assessment, students were asked to create a model to explain the connection between enthalpy, entropy, temperature, and free energy (Appendix F). Students were allowed to use any medium and were asked to explain their models after the completion of the assignment (Figure 3).

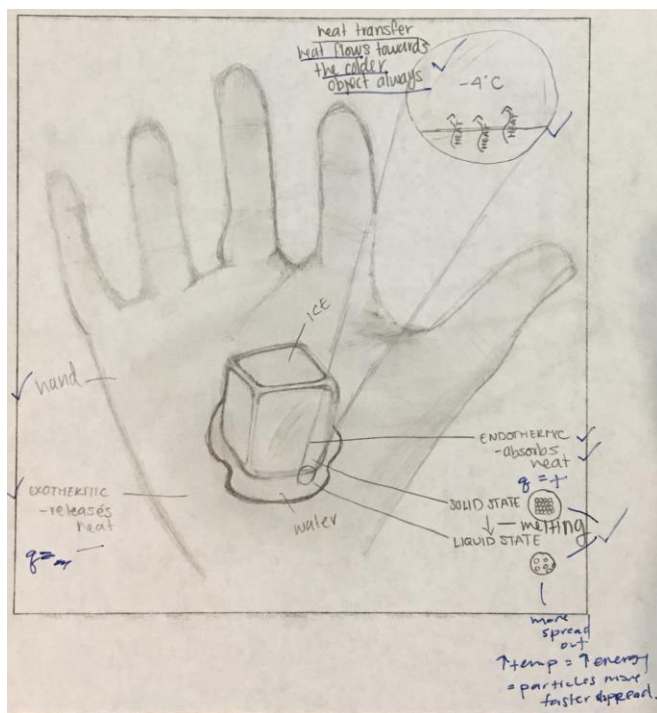


Figure 2. Ice Cube Melting Student model.

Note. The pencil writing was done by a student. The blue writing was done by the teacher.

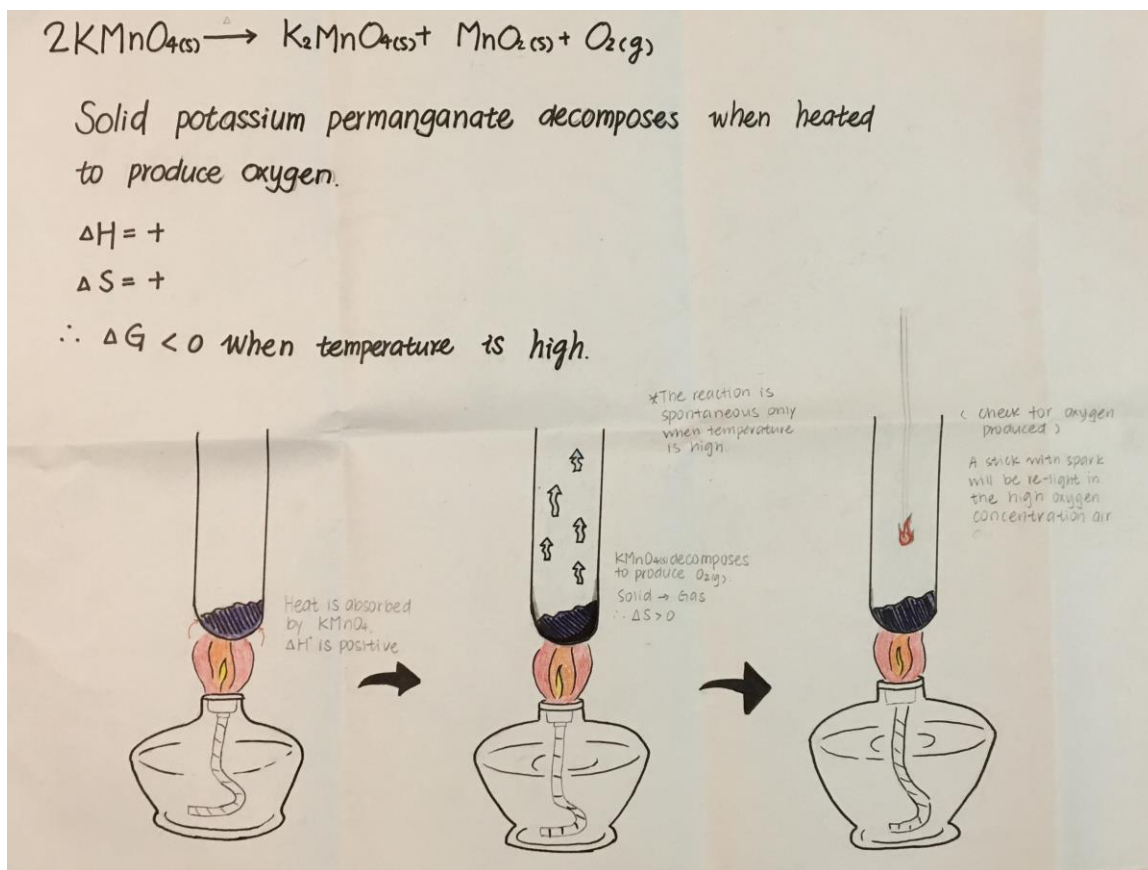


Figure 3. Student model of the relationship between enthalpy, entropy, temperature, and free energy.

The results of the Chapter 6 pre and post-tests from the treatment group of students showed a *medium* normalized gain of 0.53 (Appendix C). Hake (1998) states a normalized gain between 0.3 and 0.7 is considered to be medium. The average student score on the Chapter 6 pre-test was 18.06%, which increased to an average of 61.6% after the treatment was given. Results show there is a larger distribution range after the treatment than before (Figure 4).

The results of the Chapter 17 pre and post-tests from the treatment group of students showed a *medium* normalized gain of 0.58 (Appendix E). The average score on the Chapter 17 pre-test was 25.0%, which increased to an average of 68.4% on the post-

test. While the distribution range is larger on the post-test than the pre-test, there is an increase in student scores from pre to post-test (Figure 4). The data agrees with the interview responses from students. One student said, “I do think creating models has helped me conceptually understand because I noticed doing the problems at home and the classwork is better than what I did before, plus, I have been able to raise my test grade.”

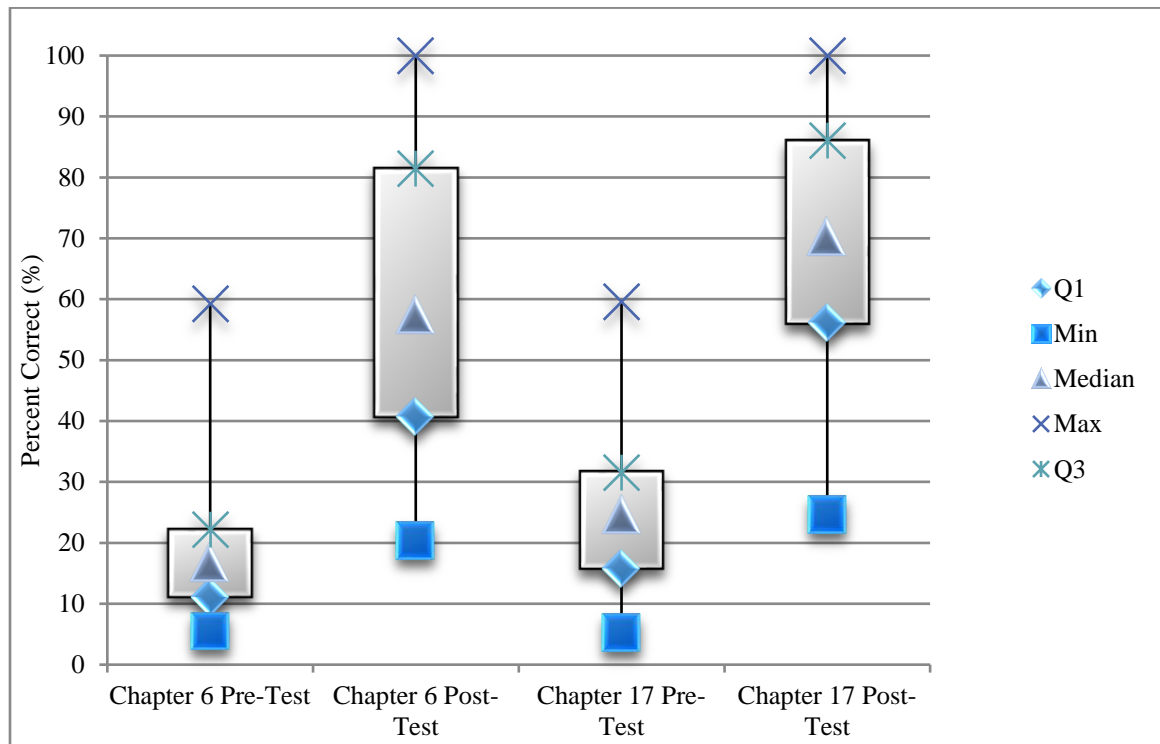


Figure 4. Score distributions of test percentages of Chapter 6 and 17 pre-test and post-test, ($N=53$).

The results of the Chapter 6 and Chapter 17 post-tests from the treatment group of students ($N=53$) was compared to the scores from my students the year prior, who did not receive any treatment ($N=76$). The average student score on the Chapter 6 exam from the previous no-treatment year was 58.7%. That average was slightly lower than the average for the students who received treatment, which was 61.6%. The average was 2.9% higher for the group of students who received treatment compared to the students who did not.

Results showed a larger distribution range for the group of students who received treatment compared to the students who did not receive treatment. There was a larger range in scores from the treatment group, but the median was 3.7% lower for the treatment group than the non-treatment group of students (Figure 5).

The results of the Chapter 17 test from the group of students who received treatment was an average score of 68.4%. The average student score for students who took the exam the year prior and did not have any treatment was 63.3%. The average increased by 5.1% from the non-treatment group to the treatment group of students. The results show a median of 70.2% for the treatment group and 63.2% for the non-treatment group (Figure 5). The median was 7% higher for the treatment group compared to the non-treatment group. The distribution range for the treatment group was larger, but the range was higher for the treatment group compared to the non-treatment group. The data agrees with the interview responses from students who were interviewed after the treatment. One student stated, “At first I did not have a conceptual understanding which prohibited me from creating a proper model and understanding the subject. However, as time progressed and more model making assignments and projects were instituted I was able to understand the concept and properly model what was going on.”

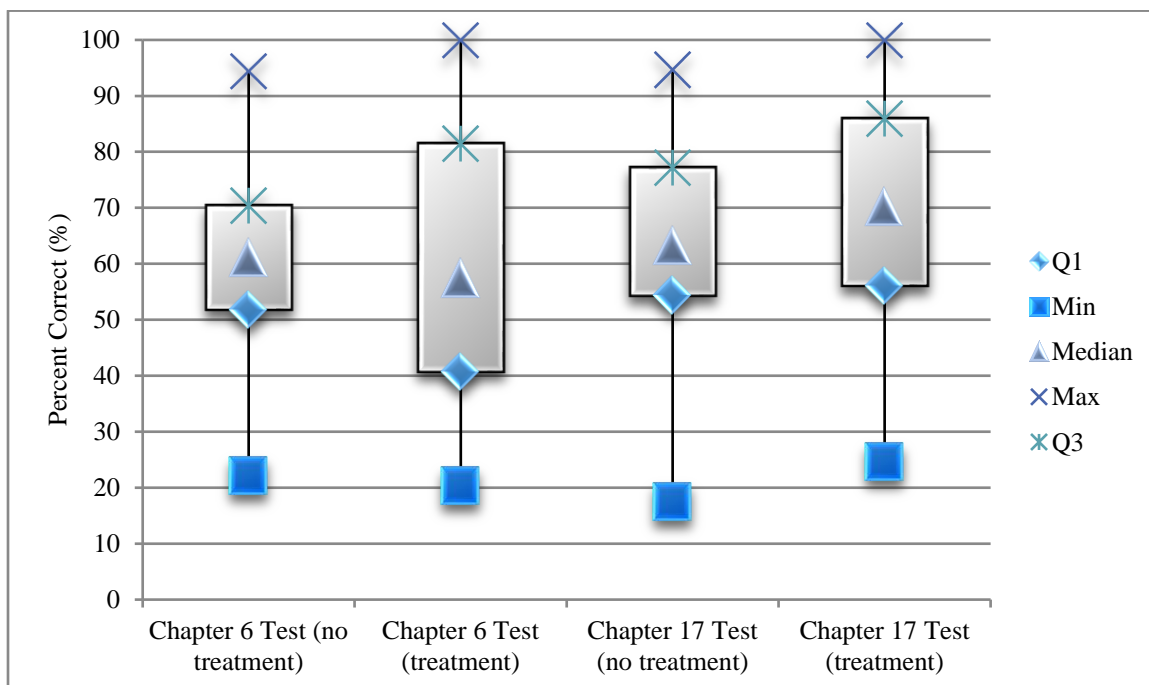


Figure 5. Score distributions of the non-treatment student groups compared to the treatment groups of students, ($N=76$) ($N=53$).

INTERPRETATION AND CONCLUSION

This study provided evidence that incorporating modeling into my classroom units positively affected student achievement and attitudes in chemistry. According to the data, students were impacted by the implementation of modeling in the chemistry classroom.

Student achievement in chemistry deviated only slightly from the previous year, which received no treatment, during the first chapter of treatment. It is evident, however, that there is a larger increase in achievement during the second chapter. When implementing modeling, I noticed that my students were not familiar with creating visuals and hadn't been challenged to contemplate conceptual concepts prior to the treatment. Because of this, I think the students took more time than I had expected to get comfortable with thinking conceptually, making mental models, and creating visual

representations of their understandings of chemistry concepts. By the time Chapter 17 was started, which was the second chapter in the treatment plan, students were beginning to be more comfortable with modeling and I noticed that students began making better models. As the data shows, the students have a slightly larger normalized gain in the second chapter compared to the first of the treatment. When comparing the scores on the same exams of my students from the previous year, who did not receive treatment, the group of students who received treatment showed higher scores comparatively as the treatment progressed. The achievement of my students who received treatment increased as they had more exposure and practice with creating their own models. Trindade, Fiolhais, and Almeida (2002) found that when students create models, misconceptions are reduced and understanding is increased. Based on the results of this action research, my findings show that student achievement increased when modeling was implemented.

I was very pleased and surprised by the positive attitudes that my students had towards modeling. I received a lot of positive feedback about a desire to keep incorporating modeling for the rest of the school year. Many students began to reflect that they were conceptually understanding instead of mathematically memorizing. I quickly realized that initially some students were not feeling confident with modeling and verbalized concerns that they were having. Most students who were not feeling positive about the treatment, I discovered, were embarrassed or not confident in their drawing abilities. I did have a small group of students who felt negatively about modeling for the entire duration of the treatment, but the general attitude of those students was a desire to memorize and not have to think through their own conceptual understanding of a topic.

For the students who were not feeling confident in their drawing abilities, I made sure to offer other mediums to create models, for which I received positive feedback.

When creating models, I gave time for students to share their models with each other, and also had students explain their models to me. I had students discuss their individually created models with each other. I also met individually with each student, where they explained their model to me. Research has shown that misconceptions are drawn out when students explain their models (Yakmaci-Guzel & Adadan, 2012). I found this to be true, and during the time I had students explaining their models, I identified misconceptions, corrected any errors, and gave feedback.

While my results do not show large gains, I do find them to have made a positive impact on student achievement and attitudes about chemistry. I believe that modeling will continue to help my students be better learners in the future, as they have been exposed to the importance of conceptual understanding and visual representations.

VALUE

My experience during this action research process has led me to realize the importance of inquiry-based modeling. There is a movement in education to increase the amount of modeling created and interpreted by students, and this study was done towards the beginning of that shift.

As a part of my data collection, I had students take a pre-test and post-test for both chapters during my treatment plan this year. I also used student post-test scores from the previous school year, to compare the scores of a treatment group to a non-treatment group. It would have been preferable to have last year's students take a pre-test

for both chapters. This would have allowed for a comparison of normalized gains between the non-treatment group and the treatment group.

One important change in my classroom that I plan to continue was that I created time to help each student individually. I observed each model and listened to or read the explanation with each individual student. This created a space for me to identify misconceptions and help students grasp concepts more effectively. I noticed that not only was I able to help each student effectively, but that my classroom culture improved when I talked with each student and had positive interactions with them. This performance task aspect, I realized, is important in my classroom. This led me to change my course to increase the amount of one-on-one performance tasks I do with the students. I can be a more effective teacher for all of my students when I meet with them separately and help them with any gaps they may have in their understanding.

This action research plan began because I realized that my students were mostly memorizing and regurgitating, especially with regards to the mathematical concepts in chemistry. I have noticed a positive change in my students' conceptual understanding. If the treatment duration had been longer, I believe I would have seen continued increase in student achievement, especially as they became more familiar with modeling. The more modeling the students experienced, the more they became accustomed to creating mental models. For the future, my second goal is to integrate modeling into my classroom on a regular basis.

I am still unsure of how large an impact the implementation of inquiry-based modeling can have on students in the chemistry classroom. I realize that it took time for

students to be familiar and confident with creating models. Because of this, I wonder if I will continue to see a greater impact as my students continue to create models. The next steps would include creating modeling assignments for my students over the entire curriculum.

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APPENDICES

APPENDIX A
IRB VERIFICATION



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MEMORANDUM

TO: Amelia Bagheri and John Graves
FROM: Mark Quinn *Mark Quinn*
DATE: December 7, 2016
SUBJECT: "The Effects of Inquiry-Based Modeling on Student Attitudes and Achievement in the Chemistry Classroom" [AB120716-EX]

The above research, described in your submission of December 7, 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:

- (b) (1) Research conducted in established or commonly accepted educational settings, involving normal educational practices such as (i) research on regular and special education instructional strategies, or (ii) research on the effectiveness of or the comparison among instructional techniques, curricula, or classroom management methods.
- (b) (2) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures or observation of public behavior, unless: (i) information obtained is recorded in such a manner that human subjects can be identified, directly or through identifiers linked to the subjects; and (ii) any disclosure of the human subjects' responses outside the research could reasonably place the subjects at risk of criminal or civil liability, or be damaging to the subjects' financial standing, employability, or reputation.
- (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
MODELING IN CHEMISTRY SURVEY

Name _____ Period _____ Date _____

MODELING IN CHEMISTRY SURVEY

Participation in this research is voluntary and participation or non-participation will not affect a student's grades in any way.

Instructions: Answer the following questions to the best of your ability. This assignment will not be graded, but will instead allow both of us to better help you in your educational endeavors.

1. I regularly create a mental model of the concepts I learn in chemistry.
 - a. Strongly agree
 - b. Somewhat agree
 - c. Somewhat disagree
 - d. Strongly disagree
2. I better understand chemistry problems after I create a model of the concept.
 - a. Strongly agree
 - b. Somewhat agree
 - c. Somewhat disagree
 - d. Strongly disagree
3. I enjoy making models of chemical concepts.
 - a. Strongly agree
 - b. Somewhat agree
 - c. Somewhat disagree
 - d. Strongly disagree
4. I am confident in my ability to create models in chemistry.
 - a. Strongly agree
 - b. Somewhat agree
 - c. Somewhat disagree
 - d. Strongly disagree
5. Making models helps me better understand chemistry.
 - a. Strongly agree
 - b. Somewhat agree
 - c. Somewhat disagree
 - d. Strongly disagree
6. I am good at chemistry
 - a. Strongly agree
 - b. Somewhat agree
 - c. Somewhat disagree
 - d. Strongly disagree

APPENDIX C

CHAPTER 6: THERMOCHEMISTRY PRE- AND POST-TEST

- e. 210.0 kJ/mol
4. For a particular process $q=-17$ J and $w=21$ J. Which is *false*?
- Heat flows from system to surroundings
 - The system does work on the surroundings
 - $E = +4$ J
 - The process is exothermic
 - All of the above are false
5. The reaction
- $$4\text{Al(s)} + 3\text{O}_2\text{(g)} \rightarrow 2\text{Al}_2\text{O}_3\text{(s)} \quad \Delta H = -3351 \text{ kJ}$$
- is _____, and therefore heat is _____ by the reaction.
- Exothermic, released
 - Exothermic, absorbed
 - Endothermic, released
 - Endothermic, absorbed
 - Thermoneutral, neither released nor absorbed

Free Response: Show your work to receive partial credit. Make sure you BOX YOUR ANSWERS for each section.

1. The standard enthalpies of formation are given below.

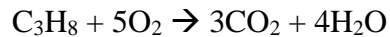
Substance	Standard Heat of Formation, ΔH_f° (kJ/mol)
C ₂ H ₂ , acetylene	+227
CH ₃ OH, methanol	-239
C ₂ H ₅ OH, ethanol	-278
CO (g)	-111
CO ₂ (g)	-394
H ₂ O(l)	-285
O ₂ (g)	0

- a. Balance the following equation:



- b. Calculate the heat of reaction, ΔH_{rxn} .
- c. Calculate the enthalpy change, ΔH , when 1.00 g of acetylene, C₂H₂, is completely burned.
- d. Is the enthalpy change in part (c) exothermic or endothermic? Justify your response.

2. What is the ΔH for the following reaction? Use the data table that follows.



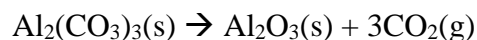
Bond	Bond energy (kJ/mol)
C-H	414
O=O	502
C=O	730
O-H	464
H-H	435
Cl-Cl	243
H-Cl	431
C-Cl	331
C-C	348

3. A 139 g sample of Al (specific heat: $0.89 \text{ J/g}\cdot^\circ\text{C}$) at 155°C is added to a 200. g sample of H_2O (specific heat: $4.184 \text{ J/g}\cdot^\circ\text{C}$) at 25°C .
- What is the final temperature of the water?

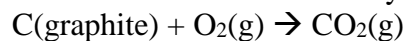
b. What is the change in temperature of the Aluminum?

c. How much total energy is transferred?

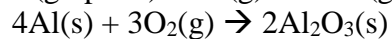
4. Calculate the enthalpy change for the following reaction given the information below.



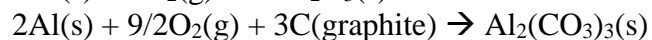
The information available to you is:



$$\Delta H = W \text{ kJ}$$



$$\Delta H = X \text{ kJ}$$



$$\Delta H = Y \text{ k}$$

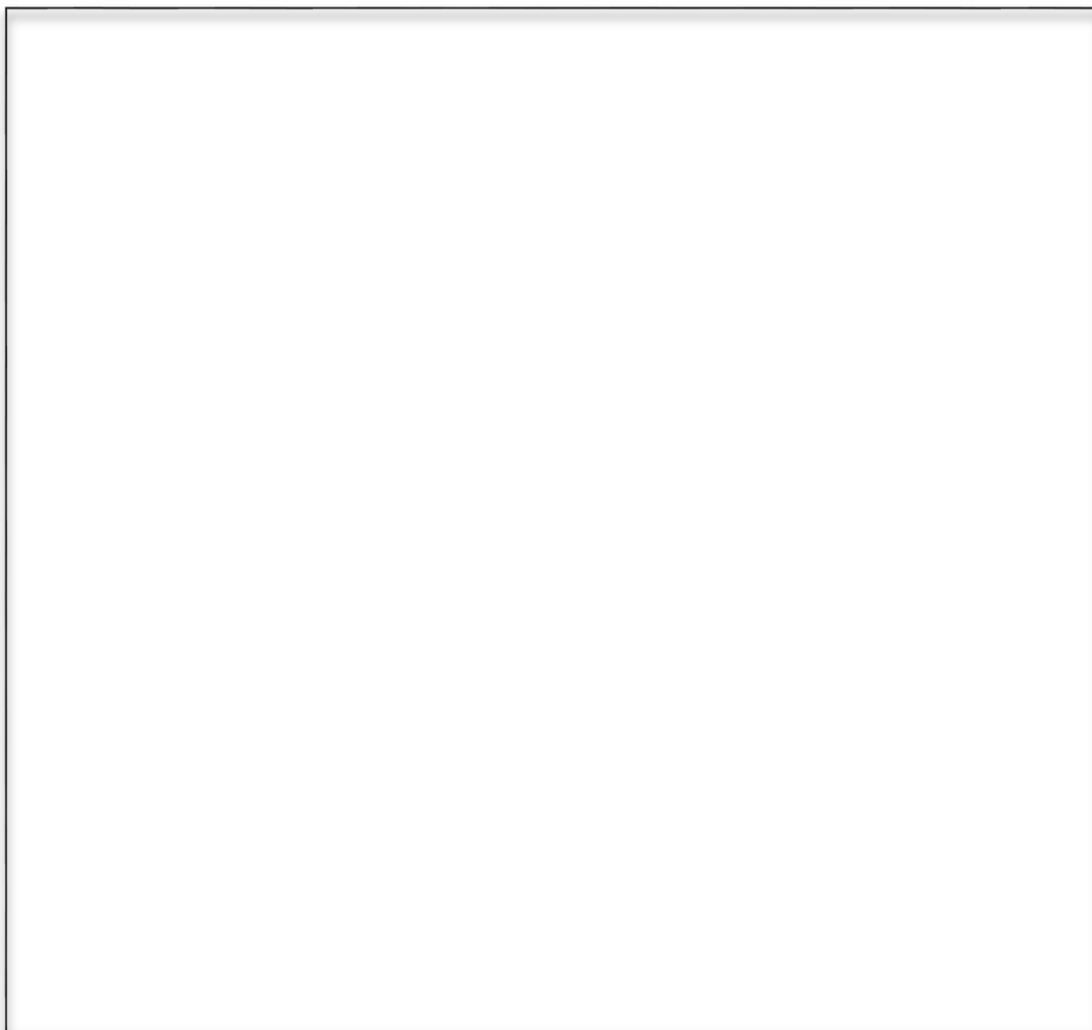
APPENDIX D
ICE CUBE MELTING MODEL

Name _____ Period _____ Date _____

PERFORMANCE ASSESSMENT: ICE CUBE MELTING

The following assignment will not be a part of your grade in this class. You will receive a score back that reflects your performance, but it will not be a part of your official class grade. You are scored so that we can better help you understand chemistry.

A person holds a cube of ice (solid water) in their hand. The cube of ice has an initial temperature of negative four degrees Celsius. Over time, the ice cube melts. Construct a model to explain the thermochemistry involved in this situation. Specifically, discuss the heat transfer involved. Make sure you label the parts of your model and explain what you are drawing.

A large empty rectangular box with a thin black border, intended for the student to draw a model explaining the thermochemistry of ice melting.

APPENDIX E

CHAPTER 17: SPONTANEITY, ENTROPY, AND FREE ENERGY PRE- AND
POST-TEST

CHAPTER 17 TEST: SPONTANEITY, ENTROPY, AND FREE ENERGY

Name _____ Period _____ Date _____

Multiple Choice: Circle the best answer for each question. Make sure to bubble your answer in the answer box provided.

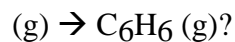
5. $\Delta_{\text{f}}^{\circ} \text{C}_2\text{H}_2 (\text{g})$

$= +230 \text{ kJ/mol}$

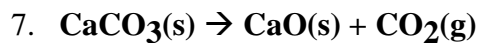
$\Delta_{\text{f}}^{\circ} \text{C}_6\text{H}_6 (\text{g}) = +83$

kJ/mol

What is the standard enthalpy change for this reaction: $3\text{C}_2\text{H}_2$



- 607 kJ
- 147 kJ
- 19 kJ
- +773 kJ



For the reaction shown above,

$\Delta H^{\circ} = +180 \text{ kJ/mol}$ and $\Delta S^{\circ} =$

$+160 \text{ J/K}\cdot\text{mol}$. The value of ΔG°

for this reaction at 27°C is

approximately

- 130 kJ
- 225 kJ
- 48 kJ
- 130 kJ

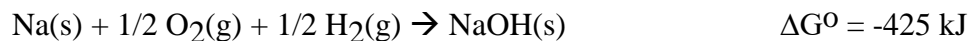
6. Under normal conditions, an iron nail rusts so slowly that the reaction is not easily observed.

What must be true?

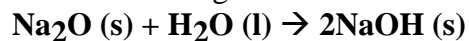
- The reaction occurs, but very slowly
- The product of the reaction is an invisible gas
- The reaction does not occur without a catalyst
- The reaction is not thermodynamically favorable

8. At what temperatures is the reaction shown in #7 spontaneous?

- $T > 298 \text{ K}$
- $T < 298 \text{ K}$
- $T > 1125 \text{ K}$
- $T < 1125 \text{ K}$



Based on the information above, what is the standard free energy change, ΔG° , for the following reaction?

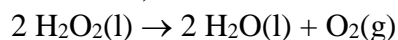


- +1125 kJ
- 1125 kJ
- +150 kJ
- 150 kJ

Continue to the following page to answer the Free Response Questions...

Free Response: Answer the questions in the blanks provided. Make sure to box your answer!

10. Given the following information, calculate ΔG° for the reaction below at 25°C:

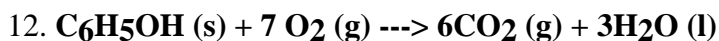


Compound	$\Delta H^\circ(\text{kJ/mol})$	$S^\circ(\text{J/K}\cdot\text{mol})$
$\text{H}_2\text{O}_2(\text{l})$	-187.8	109.6
$\text{H}_2\text{O}(\text{l})$	-285.8	69.9
$\text{O}_2(\text{g})$	0	205.1

- Calculate ΔH° .
- Calculate ΔS° .
- Calculate ΔG° .

11. When $\text{H}_2\text{SO}_4(l)$ is dissolved in water, the temperature of the mixture increases. Predict the sign of ΔH , ΔS and ΔG for this process (justify your answer).

	+/-	Justification
ΔH		
ΔS		
ΔG		



When the reaction above occurs, the result is a release of 3058 kJ of heat per mole.

Substance	Standard Heat of Formation ΔH_f° (kJ/mol) (25 °C)	Absolute Entropy, S° Joules/mole•K (25 °C)
C (s)		5.69
CO ₂ (g)	-393.5	213.6
H ₂ (g)		130.6
C ₆ H ₅ OH (s)		144.0
H ₂ O (l)	-285.85	69.9
O ₂ (g)	0	205.0

- A. Calculate the standard enthalpy of formation, ΔH° , of phenol at 25 °C.
- B. Calculate the standard change in entropy, ΔS° , for the combustion of phenol at 25 °C.
- C. Calculate the value of the standard free energy change, ΔG° , for the combustion of phenol at 25 °C.
- D. Explain how this value would change if the temperature of combustion was lowered to 0 °C.

APPENDIX F
ENTHALPY, ENTROPY, AND TEMPERATURE

PERFORMANCE ASSESSMENT: ENTHALPY, ENTROPY, AND TEMPERATURE

The following assignment will not be graded for correctness and included in your official grade. You will receive a score back that reflects your performance, but it will not be a part of your official class grade. You are scored so that we can better help you understand chemistry.

Create a MODEL to explain the connection between enthalpy, entropy, temperature, and those three factors' relations to free energy (spontaneity). You can choose any medium you like to present your visual understanding of the concepts. You must, however, be able to present it in class. This can include drawings, videos, stop motion films, cartoons, 3-dimensional creations, etc. You also need to include explanation of the visual representation you use when you model.

APPENDIX G
INTERVIEW QUESTIONS

INTERVIEW QUESTIONS:

Participation in this research is voluntary and participation or non-participation will not affect a student's grades in any way.

1. How has modeling affected your learning in chemistry?
2. Do you prefer or dislike creating models after learning chemical concepts? Why?
3. What was the most helpful part of making models during the past two chapters?
4. Have you noticed a change in your understanding of chemistry since we've started creating models of chemical concepts in class?
5. Do you think creating models helped you better understand chemistry conceptually? Why?
6. Do you find visualizing concepts in chemistry to help you be more successful in this class?
7. Is there anything else you want me to know?