

A STUDY OF THE EFFECTIVENESS OF USING MODELS
IN HIGH SCHOOL CHEMISTRY INSTRUCTION

by

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ABSTRACT

Scientific modeling in the high school chemistry classroom can help students visualize difficult concepts. This classroom research project used modeling activities to determine the effects on student achievement, engagement, and higher-order thinking skills. Test scores and student engagement observation data from the treatment and non-treatment portions of the study were compared. A rubric was also used to evaluate student-created models. The research project did not show significant improvement in test scores, but student engagement did increase. Students also showed improvement in higher-order thinking in the treatment phase of this study.

INTRODUCTION AND BACKGROUND

Chemistry involves phenomena that occur at the submicroscopic level. Many students can describe atoms and subatomic particles, but they struggle to make connections between these particles and how matter behaves in the macroscopic world. Chemistry students also see topics like stoichiometry and gas laws as just a bunch of equations to solve without an understanding of what is actually occurring. Teachers need to find ways to assist students in making connections between the macroscopic and particulate worlds.

I teach at Andrean High School, a college-preparatory parochial school in Merrillville, Indiana. Andrean High School has an enrollment of 414 students in grades 9-12, with 49% non-white minorities (Indiana Department of Education, 2018). Students come from the surrounding urban and suburban areas across northwest Indiana. Although Andrean is a parochial school, students of all backgrounds are welcome, and Indiana's voucher system allows public school students to attend a private school at a reduced cost ("Andrean High School," n.d.). Almost all students at Andrean plan to attend a four-year college or university. The leading employers in the area include the steel industry and health care providers, including hospitals and primary-care clinics ("Lake County IN Economic Alliance," n.d.). For my classroom research project, I am using two first-year chemistry classes made up of 10th and 11th grade students. These students have already taken biology, and some have also taken an integrated physical science course prior to enrolling in chemistry.

When the Next Generation Science Standards (NGSS) came out in 2013, I was not teaching chemistry, but rather advanced placement (AP) biology (NGSS Lead States, 2013). The science practices of the NGSS were incorporated into an updated AP biology curriculum. In this updated AP curriculum, students were being asked to use models to express their understanding of content knowledge. As I began to teach biology using models, I witnessed the ability of a model to help students take an abstract concept and make it concrete. Students could make more connections with an idea by manipulating parts of a model or by processing information that was presented in a graph or drawing.

In my current teaching position, I teach chemistry instead of AP biology. Compared to biology, chemistry is more mathematical and occurs at the submicroscopic level. Even though the content has changed, I believe that the science practice of using models is a valuable learning tool. Models, both physical and representational, can assist students in connecting their knowledge about the particulate level of matter with what they can observe at the macroscopic level and what they calculate with formulas and equations. This led to the creation of my focus statement: What were the effects of using models in a chemistry classroom? Besides the main focus question, sub-questions were created as follows:

1. What were the effects on student achievement?
2. What were the effects on higher-order thinking skills?
3. What were the effects on student engagement?

CONCEPTUAL FRAMEWORK

The Next Generation Science Standards (NGSS) describe models as diagrams, physical replicas, mathematical representations, analogies, and computer simulations (NGSS Lead States, 2013). The use of scientific models as instructional tools enables students to explain natural phenomena and predict what might happen in the future (Gouvea & Passmore, 2017). A model can be the link between the observed world and an explanation for what is observed (Passmore, Schwarz, & Mankowski, 2017). In general, scientific models are based upon evidence and are revised as additional evidence is uncovered (Bryce et al., 2016).

Within the last decade, science teachers have seen significant curricular revisions with the implementation of the NGSS and redesigned Advanced Placement (AP) science courses. Both of these curricular revisions emphasize using models as tools for science instruction (Edwards & Head, 2016). The classroom culture is shifting from one in which students are asked to restate knowledge stated by a teacher or in a textbook to a culture of exploration, modeling, and experimentation (Gouvea & Passmore, 2017). The NGSS highlight models as a central part of learning in science. Therefore, science teachers must intentionally incorporate scientific models into their instruction (Bryce et al., 2016).

Developing and using models is one of the eight science and engineering practices contained in the NGSS (NGSS Lead States, 2013). The National Research Council's *A Framework for K-12 Science Education* (2012) states "students cannot fully understand scientific and engineering ideas without engaging in the practices of inquiry and the

discourses by which such ideas are developed and refined” (p. 218). Scientists use models to describe, understand, and predict natural processes and as tools for inquiry (Bryce, et al., 2016; Gouvea & Passmore, 2017), so using models in the science classroom allows students to develop an understanding of content within the context of scientific practice. Students can test the accuracy of a model and use it to generate scientific questions (Bryce et al., 2016). They can use a model to represent a system or to generate data (NGSS Lead States, 2013). In addition to providing an understanding of natural processes, scientists use models to communicate their findings through the use of tables, diagrams, and graphs (Bell, Bricker, Tzou, Lee & Van Horne, 2012; Bryce et al., 2016). Models, therefore, are tools for describing, predicting, explaining and arguing scientific concepts (Campbell, Neilson, & Oh, 2013). Models are not just an art project or a representation that asks students to identify parts of a system without exploring the relationships among those parts (Passmore et al., 2017).

In addition to the use of models in scientific practice, models are useful in aiding student understanding of content. Using models can increase understanding of science concepts and the ability to explain natural processes (Campbell et al., 2013). Models can be a tool to develop students’ ability to use logic and reason and help students develop mental constructs that can explain natural phenomena (Bell & Smetana, 2008; Edwards & Head, 2016). This increased understanding is a result of using a model to determine the parts of a system and how those parts relate to one other (Passmore et al., 2017). A model can make a phenomenon easier to study by altering the scale, providing multiple representations, dispelling misconceptions, and making abstract ideas concrete (Bell &

Smetana, 2008; Edwards & Head, 2016; Kimberlin & Yeziarski, 2016). Student confusion can be reduced by allowing them to focus on one level of representation, such as the particulate level, and then apply that understanding to a different level of representation (Edwards & Head, 2016). Instruction using models can help students build their conceptual understanding of an idea before being asked to use that understanding to perform calculations (Dukerich, 2015). One final practical advantage of using models is that it allows students to investigate phenomena that might be too complex, time-consuming, or dangerous for a classroom experience (Bell & Smetana, 2008).

The process of constructing a scientific model usually begins with an anchoring phenomenon or observations, which is then used to develop the initial model (Campbell et al., 2013; Passmore et al., 2017). During the modeling process, students develop their models based on their observations and subsequently change the model as new observations are made (Dukerich, 2015; Krajcik & Merritt, 2012). Additional data can be used to evaluate the effectiveness of the model, which is then revised based on the evidence gathered (Neilson & Campbell, 2017). Revisions are made to improve accuracy and clarity of explanation (Schwarz et al., 2009). When students share their models with others, they might find that multiple models can be used to explain a phenomenon (Krajcik & Merritt, 2012). The cycle of creating, evaluating, and revising the model should continue over a period of time, making the modeling process more effective for student learning (Bryce et al., 2016; Passmore et al., 2017). Students also need to be able to identify both the limitations of a model and the differences between the model and

reality. Failure to understand a model's limitations can result in the formation of student misconceptions (Bell & Smetana, 2008). Teachers must assist students in identifying the strengths and limitations of the models they use (Edwards & Head, 2016).

Teachers can use models in their instruction to increase student engagement. Modeling can create a student-centered learning environment in which students can generate their own conceptual understanding and engage in scientific argumentation with their peers (Edwards & Head, 2016). Students who use modeling consider their peers, not the teacher, to be the audience for their explanations, and so the use of modeling can create a classroom in which the teacher is not the sole source of explanations (Schwarz et al., 2009). The models can take different forms for different cultures and students (Passmore et al., 2017). Dukerich (2015) describes modeling instruction as constructivist, student-centered, and active. The use of models in the classroom results in student enjoyment, feelings of empowerment in relation to the science practices, and overall positive emotions with regard to scientific inquiry. Students in one study indicated that the engagement they experienced with modeling was a new experience for them (Bouwma-Gearhart & Bouwma, 2015).

A student-centered environment, when combined with model building, can lead to the development of higher-order thinking skills (Edwards & Head, 2016). Higher-order thinking skills are those skills that are used at the upper levels of Bloom's taxonomy (Forawi, 2016). Bloom's taxonomy was originally grouped into these categories: knowledge, comprehension, application, analysis, synthesis, and evaluation. A newer version of this taxonomy uses the categories of remember, understand, apply, analyze,

evaluate, and create (Krathwohl, 2002). Within both of these taxonomies, applying, analyzing, evaluating, and creating are considered higher-order skills. Using models in the classroom involves creating a model, evaluating and refining that model, analyzing the models of others, and applying the model to new circumstances (Bryce et al., 2016; Edwards & Head, 2016; Neilson & Campbell, 2017; NGSS Lead States, 2013). As students evaluate their own models and engage in scientific argumentation to defend those models, they are engaged in higher-order thinking processes. Problem solving requires students to take knowledge gained from the model and use it in a different situation, thereby using the higher-order skill of applying (Dukerich, 2015). A study of national science standards ranked modeling as the third highest standard for critical thinking (Forawi, 2016).

Since models have been shown to increase student engagement and higher-order thinking, models can contribute to student achievement in science. The use of models has been shown to have a positive effect on learning in science (Neilson & Campbell, 2017). Student achievement gains have been reported across subject areas, with a deeper understanding of content (Bell & Smetana, 2008; Edwards & Head, 2016; Passmore et al., 2017). Researchers also reported gains in student competence and an increased understanding of the role of models in science practice (Bouwma-Gearhart & Bouwma, 2015). Active learning with physical objects, such as models, helps students analyze the parts of a system and allows them to use tactile senses to experience science content. The use of models has demonstrated increases in student achievement, particularly in English-language learners and other underrepresented populations (Bryce et al., 2008). In one

classroom study, students who used models were able to use microscopic explanations to explain a macroscopic phenomenon (Campbell et al., 2013). In chemistry courses, the exploration of macroscopic, particulate, and symbolic models is effective in developing student understanding of content. The effectiveness of the models is found to be similar for either student manipulation of the model or a teacher demonstration (Ryan & Herrington, 2014).

Models are used by scientists to explain phenomena, communicate ideas, and make predictions. The NGSS and AP science curricula include modeling as an important part of science instruction. As students create, evaluate, and refine models, they are using a process that takes their ideas about the world and makes those ideas concrete. Modeling has been shown to increase student engagement, higher-order thinking, and achievement.

METHODOLOGY

The focus of my classroom research project was to determine the effects of using models in the chemistry classroom. Specifically, I planned to measure how using models affected my students in three areas: achievement, higher-order thinking, and engagement. The participants in this study were students in my college-prep chemistry courses, 38 sophomores and 7 juniors ($N=45$). There were 26 males and 19 females in the group, with 44% of students classified as white, 31% African-American, 22% Hispanic, and 2% Asian. 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).

Intervention

This study had two parts, a non-treatment phase and a treatment phase. In the non-treatment part of the study, I wanted to establish a baseline for student achievement, higher-order thinking, and engagement in my classroom. Data collected during this phase was used for comparison with the data from the treatment phase. In the non-treatment phase, I taught content about molar quantities using a combination of lectures, practice problems, and laboratory experiences. The activities in this part of the study did not use any models.

In the treatment part of the study, I began with a phenomenon event related to stoichiometry. I used a demonstration in which different proportions of vinegar and baking soda were mixed together in a flask. This chemical reaction produced a gas, so each flask was attached to a balloon to capture the gas (Figure 1). The students made observations of how much gas was produced in each reaction and any unreacted substances in the flask. After introducing the phenomenon, I led a class discussion about what scientific models are and what they represent. Students were then asked to draw a model that explained what happened in the demonstration.

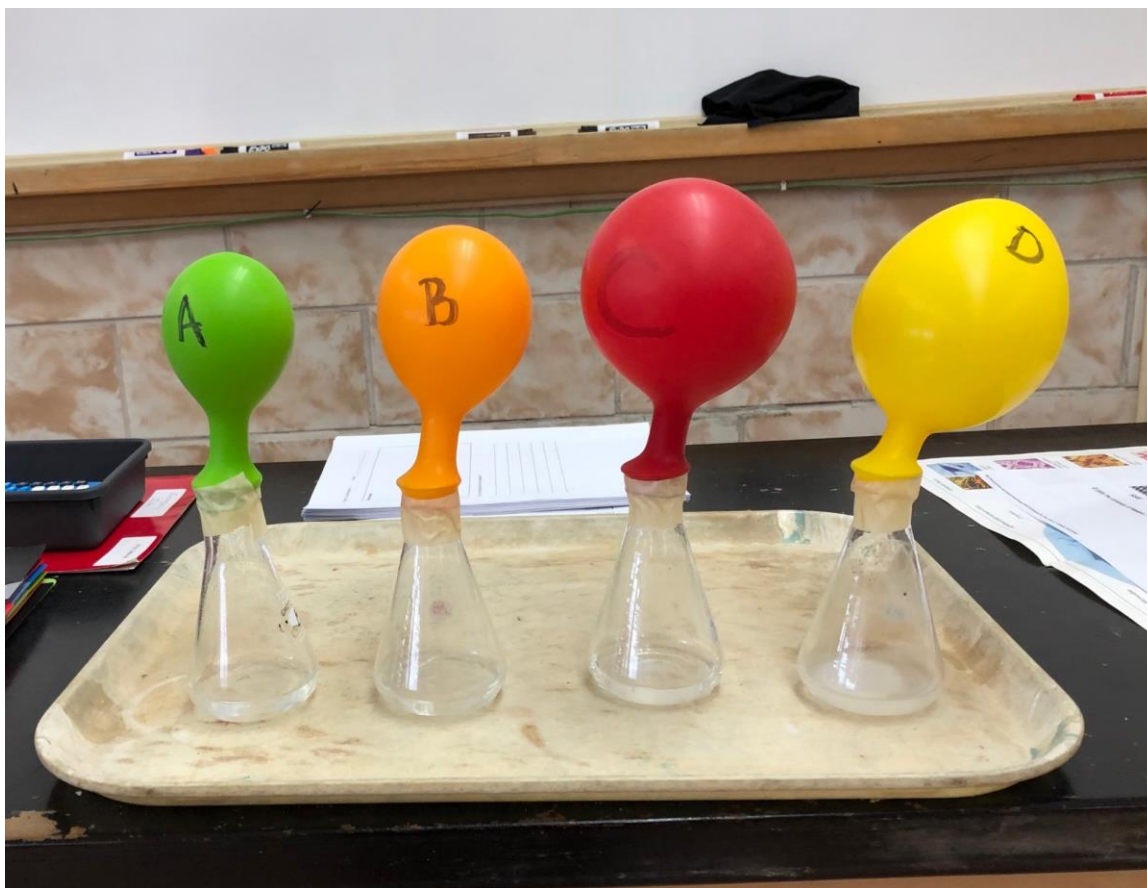


Figure 1. Balloon phenomenon.

In the following class periods, students received direct instruction on stoichiometry, participated in hands-on learning activities, and completed practice problems. Some of the hands-on activities involved particle models and computer simulations that represented the chemical substances in a reaction. Midway through the treatment phase, the students were shown examples of models that were drawn after the initial demonstration. The class was asked to evaluate the strengths and weaknesses of these models. Students were given a partner and were instructed to give each other feedback on their own models. After the period of peer feedback, each student revised their own model based on the peer feedback and new information they had learned since

the initial demonstration. Additional content was taught after the second round of modeling, using direct instruction and a laboratory experiment. At the end of the chapter, students produced a final model and explanation of the phenomenon event. In addition, students were asked to describe how their model had changed from the initial one and any limitations of their model.

Instrument Description

The Molar Quantities Pretest was given at the beginning of the non-treatment phase of the study to measure students' prior knowledge of moles and molar conversions and the Molar Quantities Posttest was given after this portion of the study (Appendix B). The scores on both of these tests were analyzed using the mean and normalized gain (Hake, 1996). In addition, selected questions from the Molar Quantities Posttest were used to measure students' higher-order thinking skills. One question asked students to evaluate the options and select the answer choice which had a correct combination of an empirical formula, molecular mass, and molecular formula. The second question used to measure higher-order thinking required students to apply problem-solving skills to determine the mass of a specific number of molecules of a substance. The final question used to measure higher-order thinking asked students to explain why one mole of carbon has a smaller mass than one mole of sulfur. Each of these questions was given a score of one to three based on the level of higher-order thinking that was demonstrated, with three being the highest. The mean and median of the scores were determined for each higher-order question.

The Engagement Observation Tool was used during both the treatment and non-treatment phases to gauge student engagement during a class period (Appendix C). During a class period, an adult observer would look around the classroom every five minutes and record how many students were on-task at that time. Before the class period, 12 students were selected using a random number generator for specific observation. At each time interval, the observer briefly described what two of the selected students were doing. The data from the Engagement Observation Tool was analyzed by calculating the percentage of students on task during the class period. The non-treatment and treatment data were also compared using a Wilcoxon signed rank test. The descriptions of student activity from the Engagement Observation Tool were analyzed for trends and patterns of behavior.

The Stoichiometry Pretest was a nine-item test given at the beginning of the treatment phase to assess student prior knowledge of this topic and the Stoichiometry Posttest was a more extensive test given at the end of the treatment phase (Appendix D). The scores on both of these tests were analyzed using the mean and normalized gain. Three questions from the Stoichiometry Posttest were further used to measure higher-order thinking skills. The first question asked students to solve a mole-to-mass stoichiometry problem. A second question asked students to describe a real-life situation in which the amounts of the necessary materials came in fixed ratios. The final higher-order thinking question that was used in this study asked students to describe the general procedure for solving a stoichiometric problem. Student responses on each of these questions were given a score of one to three based on the level of higher-order thinking

that was demonstrated. The data from these questions were analyzed by finding the mean and median for each higher-order thinking question.

The Modeling Rubric was used at the end of the treatment phase to evaluate the models the students created (Appendix E). The rubric had eight categories, which assessed both the scientific accuracy of the model and the process that students used to create, evaluate, and refine the model. Higher-order thinking skills were also assessed using some parts of the rubric. The category titled Generality addressed students' ability to apply the model to a new situation. Evaluation skills were addressed in the final three parts of the rubric: Considers alternate models, Revising the model, and Evaluating the limitations of the model. The ratings of Does Not Meet Expectations, Approaches Expectations, Meets Expectations, and Advanced were converted into numerical scores of one to four, respectively. Student scores from this rubric were analyzed using the mean and median.

At the end of the study, the Scientific Models Survey was given to all participants (Appendix F). This survey contained 13 Likert items asking students about how different instructional activities affected their engagement and understanding of chemistry content, as well as their thoughts about scientific modeling. The Likert items provided four choices: strongly agree, agree, disagree, and strongly disagree. The Scientific Models Survey also had four open-ended questions for students to provide feedback on the modeling activities and their learning in chemistry. The Likert data were analyzed by determining the frequencies of each response for each item. Both the Likert and open-ended survey items were analyzed for trends and themes as well.

Two sets of interview questions were asked of a randomly-selected sample of students ($N=5$). The Pre-Treatment Modeling Interview Questions consisted of five questions that asked students about their engagement in chemistry class and their ideas about scientific models (Appendix G). The Post-Treatment Modeling Interview Questions consisted of seven questions, asking for more in-depth information about scientific modeling and engagement in chemistry class (Appendix H). The interview responses were analyzed for themes and trends. Table 1 summarizes the data sources collected in the study.

Table 1
Data Triangulation Matrix

Focus Question	Source 1	Source 2	Source 3
What are the effects on student achievement?	Pretests and posttests	Modeling Rubric	Scientific Modeling Survey
What are the effects on students' higher-order thinking skills?	Posttests, selected questions	Modeling Rubric	Pre- and Post-Treatment Interview Questions
What are the effects on student engagement?	Engagement Observation Tool	Scientific Modeling Survey	Pre- and Post-Treatment Interview Questions

DATA AND ANALYSIS

Student engagement was measured using the Engagement Observation Tool. The classes were observed on two different class days, one during the treatment and one non-treatment. During direct instruction by the teacher in the non-treatment phase, an average of 85% of students were on task ($N=39$). When students were working on creating their models in the treatment phase, an average of 92% of students were on task. A Wilcoxon signed rank test of the data resulted in a W value of 36.5, which is beyond the critical

value of 9. Therefore, the differences in student engagement were not considered to be statistically significant.

The Scientific Models Survey asked students about their general level of engagement in chemistry class, their ability to focus when the teacher is lecturing, and their ability to focus when they are doing modeling activities. In regard to the general level of engagement, 73% of students selected Agree or Strongly Agree ($N=45$). Fifty-eight percent of students responded with Agree or Strongly Agree to the item about focus during lectures, while 87% responded with Agree or Strongly Agree to the item about focus during modeling (Figure 2). One student stated that they were more engaged when using models “because it is hands-on.”

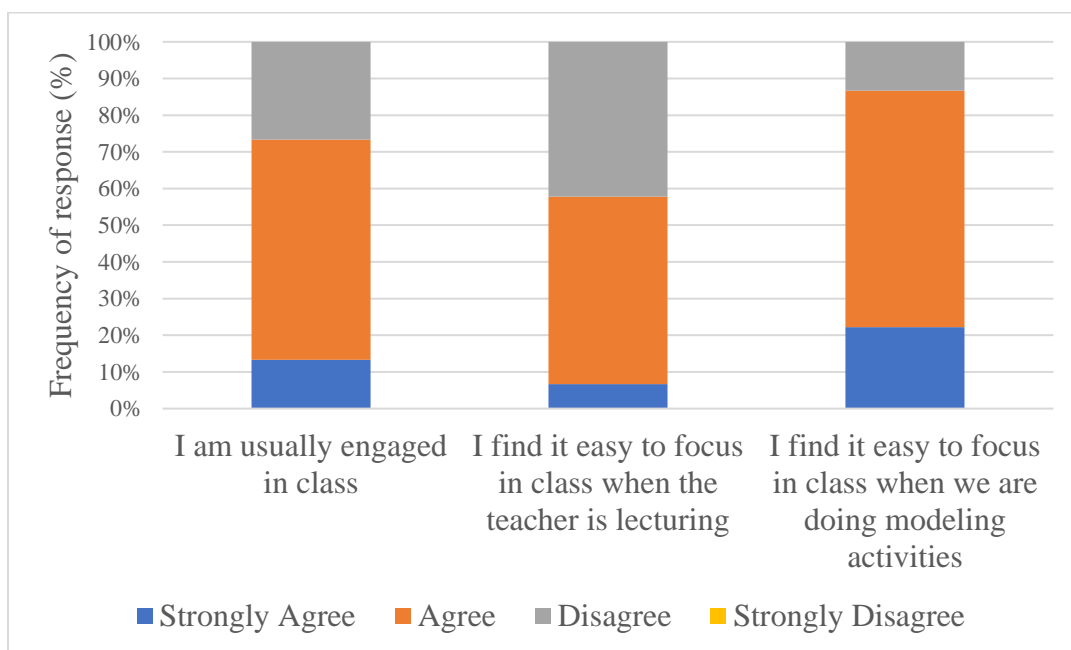


Figure 2. Scientific Modeling Survey engagement items, ($N=45$).

The Rubric for Scientific Modeling assessed student achievement in constructing a scientific model that could explain the stoichiometry-related phenomenon. The construction of the model was evaluated based on the following criteria: explains

phenomena, fits with evidence, builds on science ideas, and clarity of communication.

Each model was assessed and rated as Advanced, Meets Expectations, Approaches

Expectations, or Does Not Meet Expectations. Eighty-nine percent of students met or

exceeded expectations for the ability of the model to explain the phenomena ($N=45$). The

assessment of the models and their fit with the evidence had 71% of students meeting or

exceeding expectations. The criteria for building on science ideas was met or exceeded

by 36% of students, and clarity of communication was met or exceeded by 67% of the

models (Figure 3). The four ratings from the rubric were converted into numerical values

from one to four, with four being the highest. The mean and median for each item were

then calculated (Table 2).

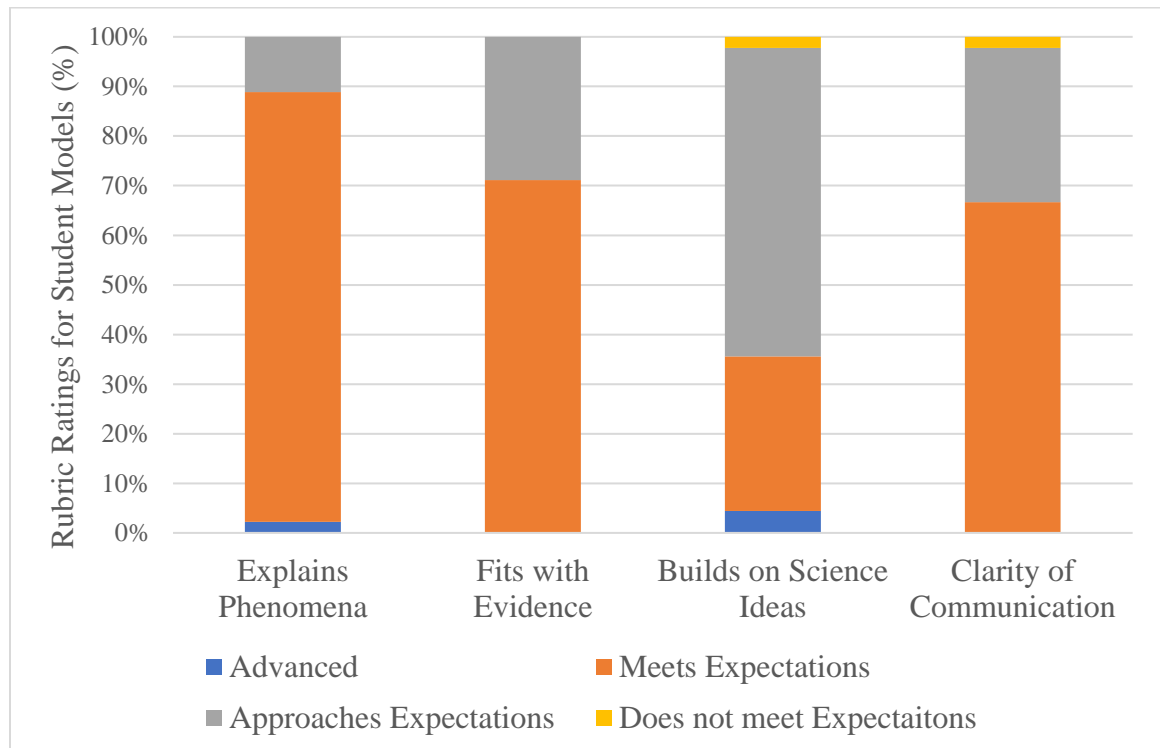


Figure 3. Model construction results from Rubric for Scientific Modeling, ($N=45$).

Table 2
Mean and Median for Construction of Model

Rubric Section	Mean (max= 4)	Median (max = 4)
Explains phenomena	2.9	3
Fits with evidence	2.7	3
Builds on science ideas	2.4	2
Clarity of communication	2.6	3

Note. ($N=45$).

The results of the Stoichiometry Pretest and Posttest show that the mean score improved from 31.8% on the pretest to 64.3% on the post-test ($N=45$). Box and whisker plots of the scores show an increase in the median, minimum and maximum scores (Figure 4). The normalized gain for the Stoichiometry Posttest is 0.47, which is considered a medium gain (Hake, 1996).

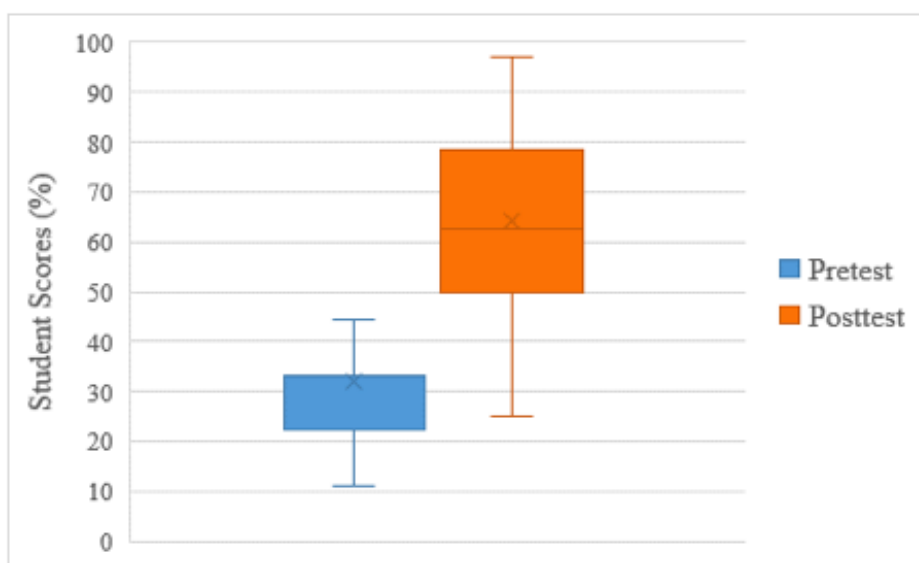


Figure 4. Stoichiometry Test (treatment) results, ($N=45$).

These test results were compared with the scores from the non-treatment Molar Quantities Pretest and Posttest. The mean score improved from 32.4% on the pretest to 70.8% on the posttest ($N=45$). Just like the Stoichiometry test, box and whisker plots of

the scores show an increase in the median, minimum and maximum scores (Figure 5). The normalized gain for the Molar Quantities Posttest is 0.55, which is considered a medium gain. While both treatment and non-treatment posttest scores showed improvement over the pretests, the non-treatment posttest had a higher mean.

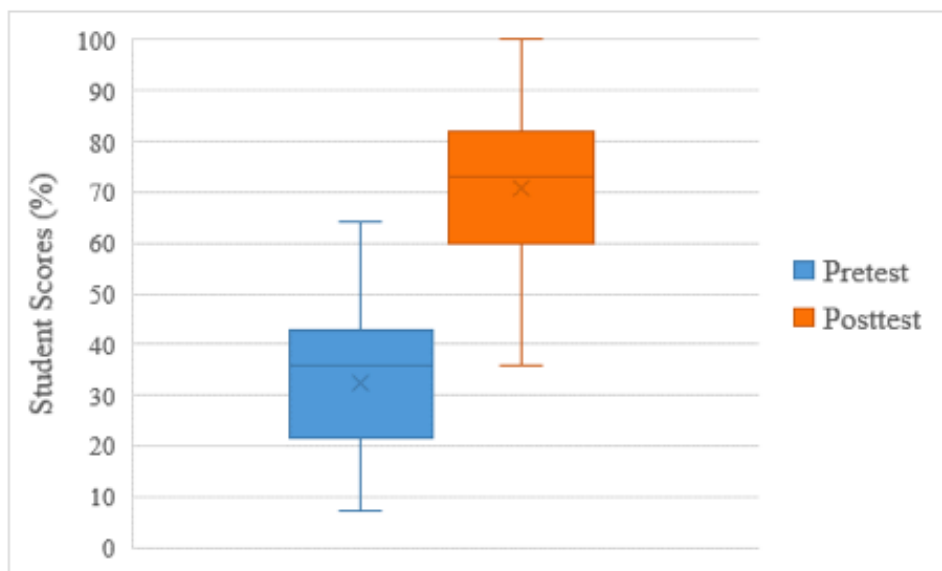


Figure 5. Molar Quantities Test (non-treatment) results, ($N=45$).

Items from the Scientific Modeling Survey that were related to student understanding asked students about whether different learning activities helped them learn chemistry. When asked if models helped them learn chemistry, 89% of students agreed. One student said that models “help me understand what’s going on because I have a visual.” Eighty-four percent indicated that diagrams helped them. One of the students stated that “the model on paper helped me organize what my equation was supposed to look like.” In comparison, 49% of students thought that lectures were helpful. Practice problems were also helpful, as indicated by 87% of students surveyed (Figure 6).

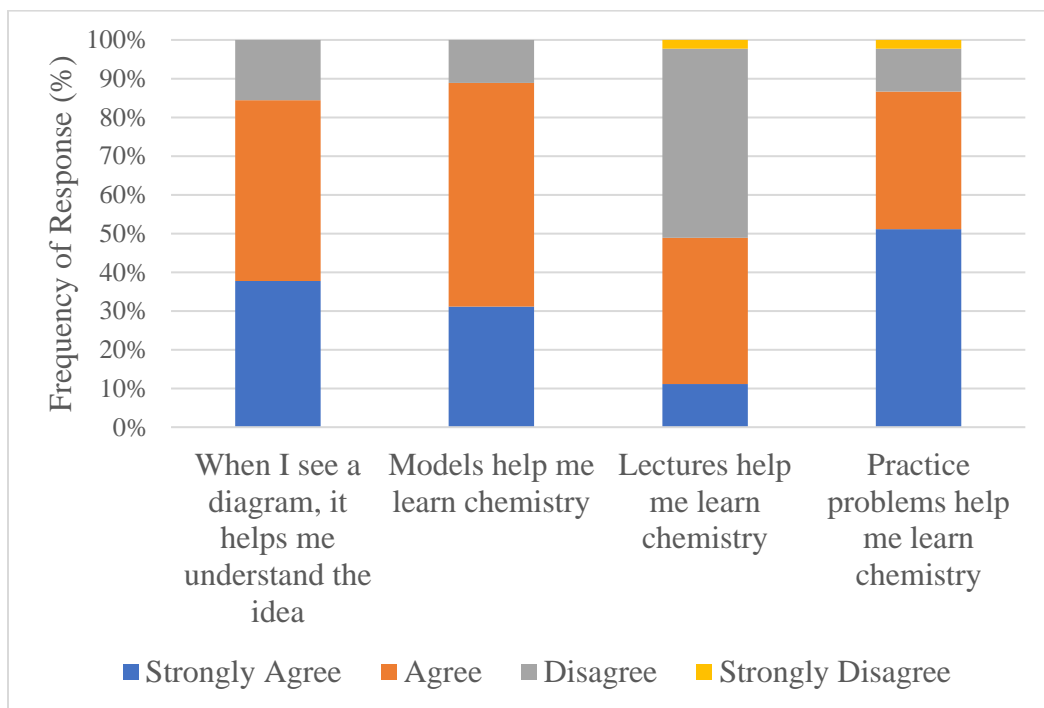


Figure 6. Scientific Modeling Survey student understanding items, ($N=45$).

For higher-order thinking, the Scientific Models Survey included items asking students about their ability to apply their knowledge to new situations and evaluate and refine ideas. Fifty-eight percent of students indicated that using models increased their ability to apply knowledge to new situations. In comparison, 80% of students agreed that using models increased their ability to evaluate an explanation and improve it (Figure 7). One student said that a model “lets you see how one thing affects another, the relationships between.”

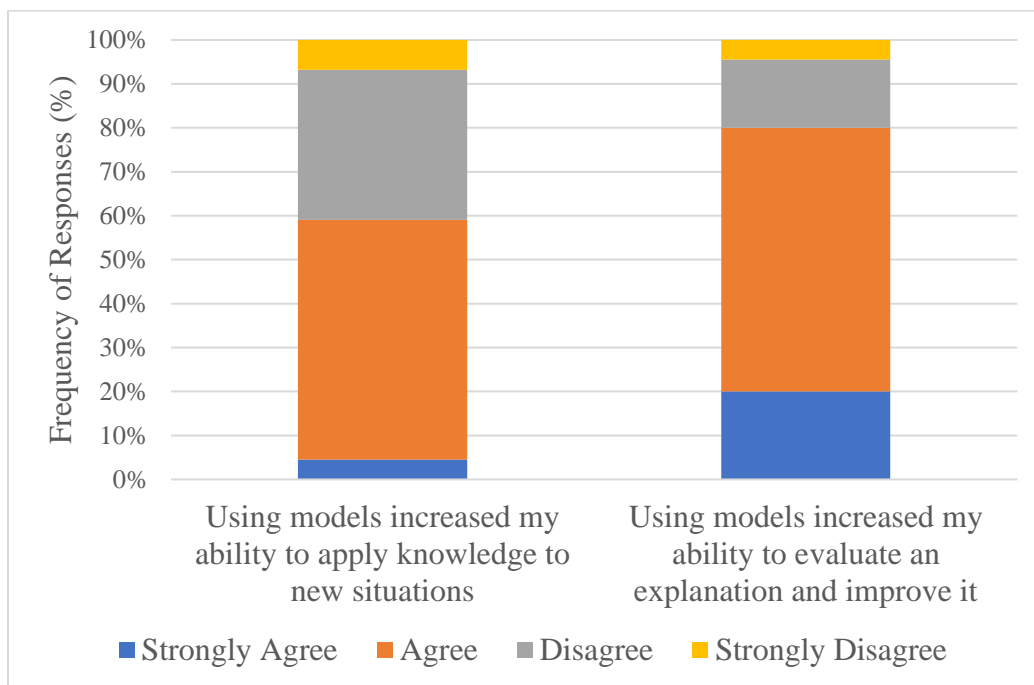


Figure 7. Scientific Modeling Survey higher-order thinking items, ($N=45$).

The higher-order thinking questions from the Stoichiometry Posttest and Molar Quantities Posttest were analyzed. Three higher-order thinking questions from each test were selected for analysis. Student responses were given a score from one to three, with three being the highest, based on the level of higher-order thinking that was demonstrated. For the Molar Quantities test, the mean score for the higher-order questions was 2.3, while the Stoichiometry test questions had a mean of 2.5 ($N=45$). The median score for the higher-order questions from the Molar Quantities test was 2 and the median for the Stoichiometry test was 3 (Table 3).

Table 3
Mean and Median for Higher-Order Test Questions

	Mean (max = 3)	Median (max = 3)
Molar Quantities Test	2.3	2
Stoichiometry Test	2.5	3

Note. ($N=45$). On the Stoichiometry test, more than half of the scores were 3, producing a median of 3.

The Rubric for Scientific Modeling was used to determine students' higher-order thinking skills in applying the model to other phenomena and revising the model based on ongoing learning. On the rubric, these skills were listed as: generality, considering alternate models, revising the model, and evaluating the limitations of the model. For both the categories of generality and considering alternate models, no student met or exceeded expectations. Forty-seven percent of students met or exceeded expectations for revising the model, and seven percent of students met expectations for evaluating the limitations of the model (Figure 8). The four ratings from the rubric were converted into numerical values from one to four, with four being the highest. The mean and median for each item were then calculated (Table 4).

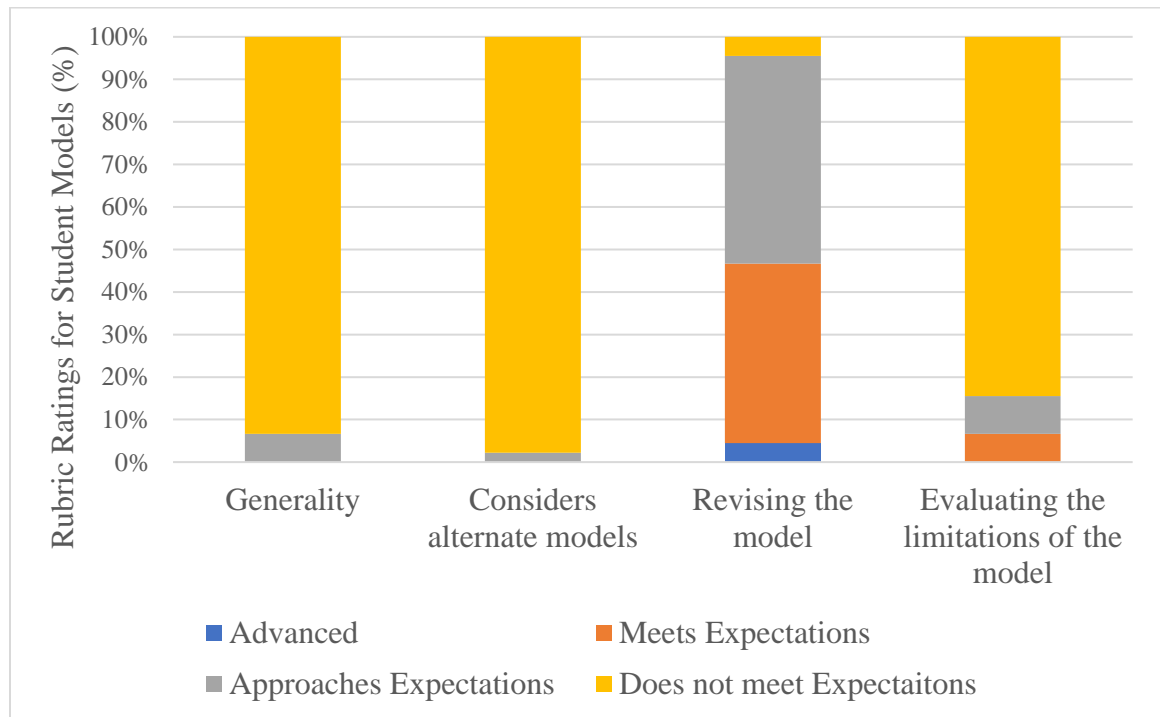


Figure 8. Higher-order thinking skills results from Rubric for Scientific Modeling, (N=45).

Table 4
Mean and Median for Higher-Order Thinking Skills in Model

Rubric Section	Mean (max = 4)	Median (max = 4)
Generality	1.1	1
Considers alternate models	1.0	1
Revising the model	2.5	2
Evaluating the limitations of the model	1.2	1

Note. (N=45).

INTERPRETATION AND CONCLUSION

This study was created to determine if using models in chemistry instruction would result in greater achievement, engagement, and higher-order thinking. This study did not show significant improvement in achievement, as measured by test scores, when students used modeling as part of their learning process. The use of models did increase student engagement during class time. Finally, students improved their use of higher-order thinking skills on test questions when they used models as a part of their classwork.

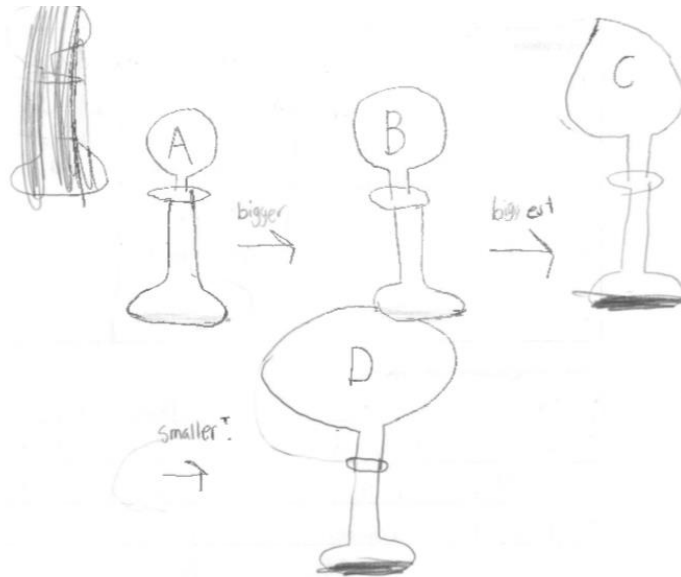
When evaluating the effect on student achievement, a comparison of the treatment and non-treatment pretest and posttest scores showed similar gains in both cases. In the survey and interviews, most students indicated that they thought models helped them learn chemistry more effectively. However, the students' perceptions of more effective learning did not result in higher test scores. During the treatment phase, four consecutive days of weather-related cancellations occurred between the time that students learned the content and when they were tested on it. This unexpected long break may have negatively affected the posttest scores. An area for further study would be to allow students to use physical model components during testing. This could help students

apply their knowledge from the models to the test questions, resulting in higher test scores.

During the treatment phase, students were more engaged in the class. This engagement was evident in the results of the observation tool, which showed an average of 92% of students being actively engaged during the class period. I also noticed that students asked more questions to clarify their understanding when they were using models. Student survey responses agreed with the observational data. There was a 14% increase in students responding positively regarding engagement when using models compared to a survey question about general engagement in chemistry class. Because models often are hands-on, students must be actively involved in order to complete the lesson. Interviewed students indicated that they enjoyed the modeling activities, which agrees with the research by Bouwma-Gearhart and Bouwma (2015). Because the students showed increased engagement and positive attitudes, I would continue to use models in my chemistry classes.


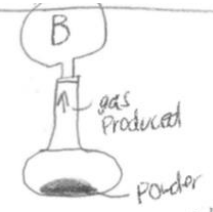


Using models in chemistry helped my students develop their higher-order thinking skills. On the posttest in the non-treatment phase, the median score on the higher-order thinking questions was two out of three, while the treatment posttest had a median score of three out of three. These questions asked students to apply their problem-solving skills, analyze the solutions to quantitative problems, and evaluate the process of solving the problems. The students' responses from the treatment part of the study were more detailed and showed greater evidence of scientific reasoning than those on the non-treatment posttest. This study also assessed higher-order thinking through the

designing and refining of a model that explained a phenomenon. Studies show that an effective way to use models in the classroom is to have the students create a model and then revise it over a period of time (Bryce et al., 2016). On the modeling rubric, 47% of students were able to show meaningful revisions to their models. When looking at the students' models, I could see how they had been changed to reflect what they were learning about stoichiometry and mole ratios (Figure 9). Some students also removed parts from their models as they realized those details were not necessary for explaining the phenomenon. Other aspects of the modeling process that related to higher-order thinking were being able to generalize the model to other phenomena and considering alternate models. My students did not demonstrate these thinking skills very well. When we talked about scientific models, I did not specifically bring up these ideas. This would explain why my students did not address the ideas of generality and alternate models when working on their own. In the future, I would make sure to include discussion of those aspects of modeling to make my students more aware of those ideas. I also would have the students write a reflection paragraph about the limitations of their model and the reasoning behind the edits they made to the model. I believe this would give me more insight into how my students worked through the modeling process.



There is only a certain amount of powder you can put in to make the balloon at its biggest size. 3.0 was too much and 1.0 was not enough.

Initial model

 <ul style="list-style-type: none"> 0.5 grams of powder makes the balloon fill up but it could fill up more. Because we didn't put a lot of powder in it is limiting reagent 	<p>A B</p>  <ul style="list-style-type: none"> 1.0 gram powder made the balloon fill up more than model A. More gas was produced in this model. The powder is still limiting reagent
<p>C D</p>  <ul style="list-style-type: none"> 2.0 grams of powder makes the balloon fill up with gas even more than model A and B. It was even. 	 <ul style="list-style-type: none"> 3.0 is the most amount of powder we used. But it is the same as model C. The ratio between acetic acid to powder was higher. The powder can not completely be used up. Model D was not completely clear.

Final model

Figure 9. Example of student model and revisions.

VALUE

This classroom research project has provided benefits for my students and for me as a teacher. One way this study benefited my students was that they learned how to visualize what was happening at the particle level in a chemical reaction. Many students commented in the survey and interviews that they felt more confident in solving the stoichiometry problems because they could think back to the visual models we used. My students learned that they could draw a simple diagram that illustrated processes that were too small to see. They also were able to focus on just one or two parts of a system in their models, instead of trying to observe everything at once. I think that the increased confidence that my students gained from using models and visual representations could help them be more successful throughout the chemistry course. If I use particulate drawings and modeling early in the school year, I feel that the students will have a strong foundation on which to build further knowledge.

My students were also more engaged when they were using models. This was of benefit to them because they were able to use the model to reason through their questions. I noticed an increase in the number of clarifying questions that students asked me when they used the models compared to when they were listening to my explanations. By working through their questions and creating their own models, I believe my students were able to reach a deeper understanding of the topic. During the modeling activities, I was very busy answering questions, but I was glad to see that my students were engaged. I was also able to observe how their ideas developed as we moved through the activities.

The modeling activities allowed the students to use and demonstrate higher-order thinking. Creating their own models required them to analyze the different parts of a system and the relationships among those parts. They were also expected to evaluate their models and make changes based on new information and seeing the models of others. These skills of analyzing, evaluating, and synthesizing are all part of higher-order thinking.

As a teacher, this classroom research project has given me the tools I need to measure the effectiveness of my teaching techniques. In the past, I have tried different teaching techniques, but my assessment of the effectiveness of these interventions has always been tied to my own informal observations. Now I have methods to use to objectively measure if a teaching technique is effective. As a result, I feel more confident in my ability to determine if a new strategy is helping my students learn more effectively or not. In addition, the surveys and rubrics also helped me identify areas that I need to work on in my instruction. For example, I thought my students would be able to explain the limitations of their models, but when I asked them to do that, most students had no idea where to begin. This told me that I need to teach them how to evaluate a model and determine what that model can and cannot tell you.

As a result of this classroom research, I am ready to expand my use of models in teaching chemistry. Because I have seen how the use of models has helped my students become more engaged and think through new concepts, I know that using models will improve learning in my classroom. Although the use of models did not show a significant improvement in test scores, I feel like the changes I observed in engagement

and student confidence are important pieces in increasing student success in chemistry. I have some new ideas about how to implement the use of models, including more specific instruction on identifying the limitations of a model and helping my students understand the value of editing the model. This project has shown me how to use modeling as a valuable part of my teaching strategies.

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APPENDICES

APPENDIX A
IRB EXEMPTION



INSTITUTIONAL REVIEW BOARD
For the Protection of Human Subjects
FWA 00000165

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 c/o Microbiology & Immunology
 Montana State University
 Bozeman, MT 59718
 Telephone: 406-994-6783
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Chair: Mark Quinn
 406-994-4707
 mquinn@montana.edu
Administrator:
 Cheryl Johnson
 406-994-4706
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MEMORANDUM

TO: Deborah Price and John Graves

FROM: Mark Quinn *Mark Quinn CJ*
 Chair, Institutional Review Board for the Protection of Human Subjects

DATE: November 1, 2018

RE: "A Study of the Effectiveness of Using Models in High School Chemistry Instruction" [DP110118-EX]

The above research, described in your submission of October 31, 2018, 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

MOLAR QUANTITIES PRETEST AND POSTTEST

Molar Quantities Pretest**Multiple Choice**

Identify the choice that best completes the statement or answers the question.

- _____ 1. If a dozen oranges have a mass of 744 g, what will be the mass of 15 oranges?
a. 11.16 kg
b. 595 g
c. 896 g
d. 930 g
- _____ 2. How many atoms are in 3.5 moles of arsenic atoms?
a. 5.8×10^{-24} atoms
b. 7.5×10^1 atoms
c. 2.1×10^{24} atoms
d. 1.7×10^{23} atoms
- _____ 3. What is true about the molar mass of chlorine gas?
a. The molar mass is 35.5 g.
b. The molar mass is 71.0 g.
c. The molar mass is equal to the mass of one mole of chlorine atoms.
d. None of the above
- _____ 4. What is the molar mass of $(\text{NH}_4)_2\text{CO}_3$?
a. 144 g/mol
b. 138 g/mol
c. 96 g/mol
d. 78 g/mol
- _____ 5. How many moles of CaBr_2 are in 5.0 grams of CaBr_2 ?
a. 2.5×10^{-2} mol
b. 4.2×10^{-2} mol
c. 4.0×10^1 mol
d. 1.0×10^3 mol
- _____ 6. What is the mass of silver in 3.4 g AgNO_3 ?
a. 0.025 g
b. 2.2 g
c. 0.64 g
d. 3.0 g
- _____ 7. What information is needed to calculate the percent composition of a compound?
a. the weight of the sample to be analyzed and its density
b. the weight of the sample to be analyzed and its molar volume
c. the formula of the compound and the atomic mass of its elements

- d. the formula of the compound and its density
- _____ 8. What is the percent composition of carbon in heptane, C_7H_{16} ?
- 12%
 - 19%
 - 68%
 - 84%
- _____ 9. The lowest whole-number ratio of the elements in a compound is called the _____.
- empirical formula
 - molecular formula
 - binary formula
 - representative formula
- _____ 10. Which of the following is an empirical formula?
- $C_2N_2H_8$
 - C_3H_8O
 - $Be_2(Cr_2O_7)_2$
 - Sb_4S_6
- _____ 11. What is the empirical formula of a substance that is 53.5% C, 15.5% H, and 31.1% N by weight?
- C_3HN_2
 - $C_4H_{14}N_2$
 - C_2H_7N
 - CH_4N_7
- _____ 12. How many moles of tungsten atoms are in 4.8×10^{25} atoms of tungsten?
- 8.0×10^2 mol
 - 8.0×10^1 mol
 - 1.3×10^{-1} mol
 - 1.3×10^{-2} mol
- _____ 13. The molar volume of a gas at STP occupies _____.
- 22.4 L
 - $0^\circ C$
 - 1 kilopascal
 - 12 grams
- _____ 14. What is the volume, in liters, of 0.500 mol of C_3H_8 gas at STP?
- 0.0335 L
 - 11.2 L
 - 16.8 L
 - 22.4 L

Molar Quantities Posttest**Multiple Choice**

Identify the choice that best completes the statement or answers the question.

- ____ 1. What SI unit is used to measure the number of representative particles in a substance?
- kilogram
 - ampere
 - kelvin
 - mole
- ____ 2. Which of the following elements exists as a diatomic molecule?
- neon
 - lithium
 - nitrogen
 - sulfur
- ____ 3. How many moles of tungsten atoms are in 4.8×10^{25} atoms of tungsten?
- 8.0×10^2 mol
 - 8.0×10^1 mol
 - 1.3×10^{-1} mol
 - 1.3×10^{-2} mol
- ____ 4. How many molecules are in 2.10 mol CO_2 ?
- 2.53×10^{24} molecules
 - 3.79×10^{24} molecules
 - 3.49×10^{-24} molecules
 - 1.26×10^{24} molecules
- ____ 5. What is true about the molar mass of chlorine gas?
- The molar mass is 35.5 g.
 - The molar mass is 71.0 g.
 - The molar mass is equal to the mass of one mole of chlorine atoms.
 - None of the above
- ____ 6. What is the molar mass of $(\text{NH}_4)_2\text{CO}_3$?
- 144 g/mol
 - 138 g/mol
 - 96 g/mol
 - 78 g/mol
- ____ 7. How many moles of CaBr_2 are in 5.0 grams of CaBr_2 ?
- 2.5×10^{-2} mol

- b. 4.2×10^{-2} mol
 - c. 4.0×10^1 mol
 - d. 1.0×10^3 mol
- _____ 8. What is the mass of silver in 3.4 g AgNO_3 ?
- a. 0.025 g
 - b. 0.64 g
 - c. 2.2 g
 - d. 3.0 g
- _____ 9. The molar volume of a gas at STP occupies _____ .
- a. 22.4 L
 - b. 0°C
 - c. 1 kilopascal
 - d. 12 grams
- _____ 10. Which combination of temperature and pressure correctly describes standard temperature and pressure (STP)?
- a. 100°C and 100 kPa
 - b. 1°C and 0 kPa
 - c. 0°C and 22.4 kPa
 - d. 0°C and 100 kPa
- _____ 11. What is the volume, in liters, of 0.300 mol of C_3H_8 gas at STP?
- a. 0.0335 L
 - b. 11.2 L
 - c. 6.8 L
 - d. 22.4 L
- _____ 12. What is the number of moles in 9.63 L of H_2S gas at STP?
- a. 0.104 mol
 - b. 0.430 mol
 - c. 3.54 mol
 - d. 14.7 mol
- _____ 13. What information is needed to calculate the percent composition of a compound?
- a. the weight of the sample and its density
 - b. the weight of the sample and its molar volume
 - c. the formula of the compound and the atomic mass of its elements
 - d. the formula of the compound and its density
- _____ 14. The lowest whole-number ratio of the elements in a compound is called the
- a. empirical formula
 - b. molecular formula

- c. binary formula
- d. representative formula

- _____ 15. Which of the following is an empirical formula?
a. $C_2N_2H_8$
b. C_3H_8O
c. $Be_2(Cr_2O_7)_2$
d. Sb_4S_6
- _____ 16. What is the empirical formula of a compound that is 40% sulfur and 60% oxygen by weight?
a. SO
b. SO_2
c. SO_3
d. S_6O_4
- _____ 17. The empirical formula of a compound is C_4H_6O . What is its molecular formula if its molar mass is 280 g?
a. C_4H_6O
b. $C_8H_{12}O_2$
c. $C_{12}H_{18}O_3$
d. $C_{16}H_{24}O_4$
- _____ 18. Which of the following sets of empirical formula, molar mass and molecular formula is correct?
a. CH , 78 g/mol, $C_{13}H_{13}$
b. CH_4N , 90 g/mol, $C_3H_{12}N_3$
c. CaO , 56 g/mol, Ca_2O_2
d. C_3H_8O , 120 g/mol, $C_3H_8O_2$

Problems

Solve each problem. Show your work.

19. Find the mass in grams of 3.10×10^{23} molecules of F_2 .

20. What is the percent composition of aspirin, $C_9H_8O_4$?

Short Answer

Answer the question in complete sentences.

21. Why does one mole of carbon have a smaller mass than one mole of sulfur?

APPENDIX C
ENGAGEMENT OBSERVATION TOOL

ENGAGEMENT OBSERVATION TOOL

Date: _____ Class Period: _____

Individual or Group task? Treatment or Non-treatment? # of students _____

Time Interval	# of Students on Task	Percentage on Task	Student 1	Student 2
5 min				
10 min				
15 min				
20 min				
25 min				
30 min				

Notes:

Source: Crofutt, J.R. (2014). *The Effect of Case-Based Learning in a High School Anatomy and Physiology Class on Student Motivation, Higher-Order Thinking Skills and College Readiness*. (Unpublished professional paper). Montana State University, Bozeman, Montana.

APPENDIX D

STOICHIOMETRY PRETEST AND POSTTEST

Stoichiometry Pretest**Multiple Choice**

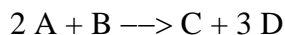
Identify the choice that best completes the statement or answers the question.

- _____ 1. If 1 egg and 1/3 cup of oil are needed for each bag of brownie mix, how many bags of brownie mix do you need if you want to use up all 3 eggs and 1 cup of oil?
- 1
 - 2
 - 3
 - 4
- _____ 2. Which of the following is true about the reaction shown below?
 $C_5H_{12}(l) + 8 O_2(g) \longrightarrow 5 CO_2(g) + 6 H_2O(g)$
- 9 moles of reactants chemically change into 11 moles of product.
 - 9 grams of reactants chemically change into 11 grams of product.
 - 9 liters of reactants chemically change into 11 liters of product.
 - 9 atoms of reactants chemically change into 11 atoms of product.
- _____ 3. How many moles of aluminum are needed to react completely with 1.2 mol of FeO?
 $2 Al(s) + 3 FeO(s) \longrightarrow 3 Fe(s) + Al_2O_3(s)$
- 1.2 mol
 - 0.8 mol
 - 1.6 mol
 - 2.4 mol
- _____ 4. Iron(III) oxide is formed when iron combines with oxygen in the air. How many grams of Fe₂O₃ are formed when 16.7 g of Fe reacts completely with oxygen?
 $4 Fe(s) + 3 O_2(g) \longrightarrow 2 Fe_2O_3(s)$
- 12.0 g
 - 23.9 g
 - 47.8 g
 - 95.6 g
- _____ 5. How many liters of hydrogen gas are needed to react with CS₂ to produce 2.50 L of CH₄ at STP?
 $4 H_2(g) + CS_2(g) \longrightarrow CH_4(g) + 2 H_2S(g)$
- 2.50 L
 - 5.00 L
 - 7.50 L
 - 10.0 L

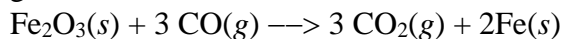
- _____ 6. Which of the following is true about limiting and excess reagents?
- The amount of product obtained is determined by the limiting reagent.
 - A balanced equation is not necessary to determine which reactant is the limiting reagent.
 - Both reagents are left over after the reaction is complete.
 - The reactant that has the smallest given mass is the limiting reagent.
- _____ 7. In a particular reaction between copper metal and silver nitrate, 12.7 g Cu produced 38.1 g Ag. What is the percent yield of silver in this reaction?
- $$\text{Cu} + 2 \text{AgNO}_3 \longrightarrow \text{Cu(NO}_3)_2 + 2 \text{Ag}$$
- 56.7%
 - 77.3%
 - 88.2%
 - 176%

Short Answer

8. What is the mole ratio of D to A in the generic chemical reaction?



9. How many grams of CO are needed to react with an excess of Fe_2O_3 to produce 209.7 g Fe?



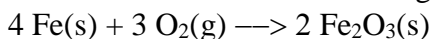
Stoichiometry Posttest**Multiple Choice**

Identify the choice that best completes the statement or answers the question.

- _____ 1. The calculation of quantities in chemical equations is called _____.
a. stoichiometry
b. dimensional analysis
c. percent composition
d. percent yield
- _____ 2. What is the first step in most stoichiometry problems?
a. add the coefficients of the reagents
b. convert given quantities to moles
c. convert given quantities to volume
d. convert given quantities to masses
- _____ 3. In the reaction $2 \text{CO}(g) + \text{O}_2(g) \rightarrow 2 \text{CO}_2(g)$, 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
- _____ 4. Which of the following is true about the reaction shown below?
 $\text{C}_5\text{H}_{12}(l) + 8 \text{O}_2(g) \rightarrow 5 \text{CO}_2(g) + 6 \text{H}_2\text{O}(g)$
a. 9 moles of reactants chemically change into 11 moles of products
b. 9 grams of reactants chemically change into 11 grams of products
c. 9 liters of reactants chemically change into 11 liters of products
d. 9 atoms of reactants chemically change into 11 atoms of products
- _____ 5. How many moles of aluminum are needed to react completely with 1.2 mol of FeO?
 $2 \text{Al}(s) + 3 \text{FeO}(s) \rightarrow 3 \text{Fe}(s) + \text{Al}_2\text{O}_3(s)$
a. 1.2 mol
b. 0.8 mol
c. 1.6 mol
d. 2.4 mol
- _____ 6. At STP, how many liters of oxygen are required to react completely with 3.6 liters of hydrogen to form water?
 $2 \text{H}_2(g) + \text{O}_2(g) \rightarrow 2 \text{H}_2\text{O}(g)$
a. 1.8 L
b. 3.6 L
c. 2.0 L

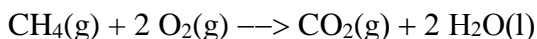
d. 2.4 L

_____ 7. Iron(III) oxide is formed when iron combines with oxygen in the air. How many grams of Fe_2O_3 are formed when 16.7 g of Fe reacts completely with oxygen?



- a. 12.0 g
- b. 23.9 g
- c. 47.8 g
- d. 95.6 g

_____ 8. Which conversion factor do you use first to calculate the number of grams of CO_2 produced by the reaction of 50.6 g of CH_4 with O_2 ? The equation for the complete combustion of methane is:



- a. 44.0 g CO_2 / 2 mol CO_2
- b. 2 mol O_2 / 1 mol CO_2
- c. 16.0 g CH_4 / 1 mol CO_2
- d. 1 mol CH_4 / 16.0 g CH_4

_____ 9. Which of the following is true about limiting and excess reagents?

- a. Both reagents are left over after the reaction is complete.
- b. A balanced equation is not necessary to determine which reagent is the limiting reagent.
- c. The amount of product obtained is determined by the limiting reagent.
- d. The reactant that has the smallest given mass is the limiting reagent.

_____ 10. Lead nitrate can be decomposed by heating. What is the percent yield of the decomposition reaction if 9.9 g $\text{Pb}(\text{NO}_3)_2$ are heated to give 5.5 g of PbO ?

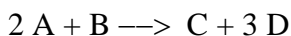


- a. 44%
- b. 56%
- c. 67%
- d. 82%

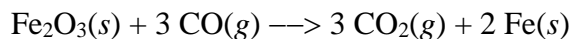
Problems

Solve the problems. Show your work.

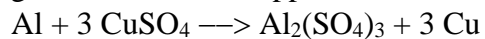
11. What is the mole ratio of D to A in the generic chemical reaction?



12. How many moles of CO are needed to react with an excess of Fe_2O_3 to produce 209.7 g Fe?



13. Metallic copper is formed when aluminum reacts with copper(II) sulfate. How many grams of metallic copper can be obtained when 54.0 g of Al react with 319 g of CuSO_4 ?



14. For the reaction $2 \text{Na}(s) + \text{Cl}_2(g) \longrightarrow 2 \text{NaCl}(s)$, how many grams of NaCl could be produced from 103.0 g of Na and 13.0 L of Cl_2 (at STP)?

15. Consider the following reaction: $2 \text{H}_2\text{S}(g) + 3 \text{O}_2(g) \longrightarrow 2 \text{SO}_2(g) + 2 \text{H}_2\text{O}(g)$

If O_2 was the excess reagent, 8.3 mol of H_2S were consumed, and 137.1 g of water were collected after the reaction has gone to completion, what is the percent yield of the reaction?

Essay

16. Describe an experience you've had making or building something where the amount of each ingredient or building block came in fixed ratios.

17. What is the importance of the coefficients in a balanced chemical reaction?

18. What is the general procedure for solving a stoichiometric problem?

APPENDIX E
MODELING RUBRIC

Rubric for Scientific Modeling

	Does Not Meet Expectations	Approaches Expectations	Meets Expectations	Advanced
<p>Explains Phenomena Does the model explain the phenomenon?</p>	Model does not explain the phenomenon.	Model includes some of the relevant parts needed to explain what caused the phenomenon. Model might include text and diagrams.	Model connects all relevant components and relationships needed to explain what caused the phenomenon. Model includes text and diagrams to describe model parts and processes.	Model includes the relevant parts needed to explain what caused the phenomenon as well as additional components and relationships that fit the scientific model.
<p>Fits with Evidence Does the model fit with the evidence collected?</p>	Evidence is not correctly related to the model.	Model correctly incorporates some of the evidence.	Model refers to a sufficient amount of relevant evidence to be compelling.	Model fits with all of the evidence and additional evidence that could be collected is described.
<p>Builds on Science Ideas Does the model incorporate established scientific ideas?</p>	Model does not include relevant scientific ideas.	Model includes some of the essential concepts, but not all that are needed	Model includes essential scientific concepts needed to explain the phenomenon.	Model includes essential scientific concepts and other relevant science ideas.
<p>Clarity of Communication Would someone else be able to understand the model?</p>	Model is not clearly described.	Model is somewhat clearly described.	Model is clearly explained in a way that allows others to understand how and why the phenomenon happens. Diagrams and text include consistent forms of representation.	Model is clearly described and additional communication or educational pieces are included for the audience.
<p>Generality Can the model be used to explain related phenomena?</p>	Model is not related to phenomena beyond that which was demonstrated.	Description of the model is applied to the demonstrated phenomenon and an attempt is made to another.	Model's explanation is applied to the demonstrated phenomenon and one other.	Model's explanation is applied to the demonstrated phenomenon and generalized to a broader natural system.

<p>Considers Alternate Models Does the model consider how others might explain the phenomenon?</p>	Model does not consider the ideas of others.	Models mentions how it is different from the ideas of others.	Model's explanation considers alternative explanations and clearly highlights why this model provides a better explanation.	Model considers alternative explanations, highlights why this model is better, and provides evidence for that.
<p>Revising the Model Was the model refined based on new evidence and developing understanding?</p>	Model was not revised OR it vaguely explains how it was changed, but the changes are not connected to evidence.	Model was changed to better explain the phenomenon, but only loosely connected to evidence.	Model was changed to better explain the phenomenon using substantial evidence.	Model was changed to better explain the phenomenon using substantial evidence and developing understanding of scientific ideas.
<p>Evaluating the Limitations of the Model Are the limitations of the model described?</p>	No limitations are described OR only cosmetic changes are suggested.	Some explanation of limitations. Little connection to the phenomenon the model represents.	Explanation of simplifications have been made in the model compared to the natural world.	Explanation of the limitations of the model and suggests improvements or addresses unanswered questions.

Adapted from Bell, P. and Peterman, T. learndbir.org/resources/Collaboratory-Draft-Modeling-Rubric-13Jan2016.doc

APPENDIX F
SCIENTIFIC MODELS SURVEY

SCIENTIFIC MODELS SURVEY

Mark your response to each of these statements. Be honest. Answering these questions is voluntary and participation or non-participation will not affect a student's grade or class standing in any way.

Statement	Strongly Agree	Agree	Disagree	Strongly Disagree
I am usually engaged in chemistry class.				
I find it easy to focus in class when the teacher is presenting a lecture.				
I find it easy to focus in class when we are doing modeling activities.				
When I see a diagram, it helps me understand the idea.				
Models help me learn chemistry.				
Lectures help me learn chemistry.				
Practice problems help me learn chemistry.				
I can apply what I am learning in chemistry to new situations.				
Using models increased my understanding of stoichiometry.				
Using models increased my ability to apply my knowledge of stoichiometry to new situations.				
Using models increased my ability to evaluate a scientific explanation and make it better.				
Seeing other people's models helped me refine my own model.				
I like using models in chemistry.				

Answer these questions.

What do you like about scientific modeling?

What don't you like about scientific modeling?

I learn chemistry best when ...

Is there anything else you would like me to know?

APPENDIX G

PRE-TREATMENT INTERVIEW QUESTIONS

PRE-TREATMENT INTERVIEW QUESTIONS

Answering these questions is voluntary and participation or non-participation will not affect a student's grade or class standing in any way.

1. Do you feel actively engaged in chemistry class? Why or why not?
2. Can you describe some problems you have when trying to learn chemistry?
3. What do you think of when I say "model?"
4. How can models help you understand chemistry?
5. Is there anything else you would like me to know?

APPENDIX H
POST-TREATMENT INTERVIEW QUESTIONS

POST-TREATMENT INTERVIEW QUESTIONS

Answering these questions is voluntary and participation or non-participation will not affect a student's grade or class standing in any way.

1. Can you describe what a scientific model is and provide an example?
2. Did the modeling activities help you understand the topic?
3. Did the modeling activities help you think more in-depth?
4. Describe how your thoughts about the topic changed as you went through the activities.
5. How does modeling affect your thinking about chemistry?
6. Do you feel actively engaged in chemistry class? Why or why not?
7. Is there anything else you would like me to know?