EFFECT OF THE 5E INSTRUCTIONAL MODEL ON STUDENT UNDERSTANDING AND ENGAGEMENT IN HIGH SCHOOL CHEMISTRY

by

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STATEMENT OF PERMISSION TO USE

DEDICATION

This is dedicated to my wonderful husband, Jim, and children Katie and Tyler. Without their unfailing love and support, I would not have been able to complete this.

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ABSTRACT

Twenty-nine students in two sections of high school chemistry were the focus of a study on the effect of the 5E instructional model on student understanding and long-term memory of chemistry concepts, and student and teacher attitude and engagement. In the 5E model, students cycle through Engage, Explore, Explain, Elaborate, and Evaluate phases of learning through the course of an entire curriculum unit. Each new phase builds upon and refers back to the previous phases. A nonintervention unit on chemical reactions was compared with two intervention units, stoichiometry and states of matter, which were taught according to the 5E model. While the data collected had mixed results as to the effect of the 5E model on student understanding of chemistry concepts, the data indicated that the 5E model may have a positive impact on student long-term memory of chemistry concepts. Students also became more engaged in the learning process during the intervention units, although they found the second intervention unit to be more challenging and frustrating. I was excited by the changes in my classroom, and frustrated when things did not go as planned. However, I look forward to trying to continue incorporating the 5E model into my teaching in the future.

INTRODUCTION AND BACKGROUND

In my chemistry classes at Saint Paul's School (SPS) in Concord, New Hampshire, I noticed that my students had difficulty applying concepts we studied earlier in the year to new concepts. When students were asked to predict the physical states of the reactants and products in a chemical reaction, they had forgotten that the magnitude of intermolecular forces impacts the state of a compound. Unfortunately, students had a much shallower understanding of the concepts we had studied. Students seemed to master the material in a given unit for a test, but then pushed it from their mind as we began a new topic or chapter. After reflecting on this, I decided to investigate whether taking a more long-range, student-centered approach that required students to take a more active role in their learning would deepen their understanding and improve their long-term memory of chemistry concepts.

Student-centered instruction (SCI, also called student-centered learning or learner-centered learning) is a general teaching methodology that involves a shift of some of the responsibility of learning from the teacher to the student (Felder, 2011; Felder & Brent, 1996; Wohlfarth et al., 2008). Active learning, where students engage in the learning process as opposed to passively receive information from the teacher, forms the basis of SCI. Cooperative or collaborative learning (which emphasize student interaction), as well as problem-based learning (where important principles are discovered in the context of solving a challenging problem), are also included in the broad range of approaches that comprise SCI (Prince, 2004).

While I have always incorporated SCI techniques to a certain extent in my classes, I realized that I tended to plan lessons as relatively isolated events. I needed to broaden my vision to encompass the goals and concepts for an entire unit if I wanted my students to also be able to form connections between different topics. I decided to design the intervention units for this project to follow the 5E instructional model developed by Biological Sciences Curriculum Study (BSCS). In this instructional approach, students cycle through Engage, Explore, Explain, Elaborate or Extend, and Evaluate phases of learning, each of which incorporates SCI techniques (Bybee et al., 2006). The cycle encompasses an entire curriculum unit, and each new phase builds upon and refers back to the previous phases.

Last year, the SPS faculty began a school-wide discussion about teaching methodologies. The school implemented a new class schedule this year, in which classes meet for two long (80 and 95-minute) and two short (45-minute) periods per week, as opposed to the 55-minute classes we traditionally taught. The longer class meetings require teachers to take a different approach than the traditional teacher-centered model. The new schedule provided an ideal opportunity for me to try using the 5E instructional model. The extended periods fit the 5E model well, as they allow ample time for students to work through the Explore and Explain phases.

SPS is a fully-residential boarding school for students in ninth through 12th grades. Approximately one-third of the student body identify as students of color, and one-fifth are international students. Students come from a range of economic backgrounds. All students attend four year colleges after graduation. This study focused on students in two sections of 10th grade chemistry.

My project focus question was: What are the effects of the 5E instructional model on student understanding of chemistry concepts? My project subquestions were: What are the effects of the 5E instructional model on student long-term memory of those concepts, what are the effects of the 5E instructional model on student attitude and engagement, and what are the effects of the 5E instructional model on my attitudes towards teaching?

Jewel Reuter, Ph.D. was my Capstone Advisor for this project. Terrill Paterson of the Intercollege Program in Science Education served as my Montana State University project reader. Lawrence Smith, Dean of Curriculum and Teacher Development at SPS, observed one class during each phase of the project to provide feedback on student and teacher attitude and engagement. My husband and mathematics teacher at SPS, Jim Watt, and my mother, Barbara Hirshfeld, provided support and feedback throughout the project.

CONCEPTUAL FRAMEWORK

According to constructivist theory, knowledge is created by assimilating new information into existing constructs. New constructs must be generated when new information doesn't fit existing models (Bodner, 1986). If an attempt is made to connect new concepts to existing knowledge, then meaningful learning can occur. When no such attempt is made, rote learning occurs, and new knowledge can't be transferred or applied to other situations (Novak, 2002). Transferring notes from teacher to student does not build knowledge. It is simply stenography (Felder & Brent, 1996). Therefore, student-centered approaches, including active learning, cooperative learning, and problem-based learning, can allow students to more effectively construct knowledge.

Students bring existing knowledge (preconceptions) to each new situation. If this existing knowledge does not accurately explain new concepts, it can be described as a misconception. Because knowledge must be constructed by the student, simply telling a student their misconception is wrong has very little impact on changing their understanding. Instead, students must be actively engaged in developing a new view of the concept (Bodner, 1986).

In the 5E model, an entire curriculum unit includes five phases: Engage, Explore, Explain, Elaborate, and Evaluate. In the Engage phase, student interest and curiosity is sparked, often through a demonstration or discrepant event (Bybee et al., 2006). This phase is also designed to activate preconceptions and misconceptions. Students then explore and attempt to explain the concepts illustrated in the Engage phase, prior to any direct explanation from the teacher. Only after students have explained the concepts in their own words, does the teacher clarify the explanation, adding specific scientific vocabulary. In the Elaborate phase, the concepts are extended to new applications. Both the Explore and Elaborate phases can include collaborative and problem-based learning, key principles of SCI. Finally, student understanding is assessed in the Evaluate phase through a traditional or performance assessment. One hallmark of the 5E model is flexibility. There does not have to be a linear progression through the five phases. Formative assessments are often used to get feedback on student understanding during every phase.

Throughout the 5E process, students are active participants in their learning. Many studies have shown improvement in student understanding of science concepts as a result of actively engaging students in the learning process. Balcit, Cakiroglu, and Tekkaya (2006) compared the effectiveness of three teaching approaches (traditional, 5E, and the use of conceptual change texts which are designed to confront common misconceptions) on eighth grade students' understanding of photosynthesis and cellular respiration. Students who experienced the 5E model had the greatest pretest to posttest increase in score, although the average increases for the 5E model and the conceptual change text approach were not significantly different. Results from both experimental groups were statistically better than those of the group that had traditional instruction. Sadi and Cakiroglu (2010) compared four classes of 11^{th} grade biology students who were taught the human circulatory system in different styles. Two classes were taught in a traditional manner, which focused on teacher directed note-taking, while two classes were taught with the 5E model. Students in the 5E classes had a mean increase of 9.13 points from pretest to posttest, while the mean score increase of students in the traditional classes was only 2.31 points.

Teacher-centered instruction tends to result in students memorizing a set of disconnected facts for a test, while the construction of scientific knowledge and an appreciation for the scientific process is more likely to result from student-centered instruction (Taraban, Box, Myers, Pollard, & Bowen, 2007). In a study of 288 high school chemistry students at two schools in California, Roehrig and Garrow (2007) found that students taught in a more inquiry-based style performed better not only on algorithmic questions, but also on more complex questions. Francis, Adams, and Noonan (1998) redesigned their college introductory physics class in a manner similar to the 5E model. Students explored and explained concepts through inquiry-based tutorials prior to any direct instruction from the teacher. Lecture classes following the tutorials were designed to elaborate upon and extend the tutorial experience. To assess a change in understanding, students took the Force Concept Inventory (FCI) before and after the course. Three groups of students also took the FCI up to three years postinstruction to assess long-term retention of the physics concepts. The researchers suggested that if students relied on rote memorization to succeed on the postinstruction test, they would forget the correct answers over time, and delayed test scores would be greatly reduced. If, however, the instruction led to conceptual change, then higher scores would persist over time. The group that was brought back one year postinstruction had a 47% average increase from pretest to posttest, and only an 8% decrease on the delayed assessment. The group brought back two years postinstruction had a 35% average increase from pretest to posttest score, and only dropped 12% on the delayed assessment. The students brought back three years postinstruction improved by 33% from pretest to posttest, and scored only 2% lower on the FCI three years later. Much of the conceptual understanding stayed with them for several years postinstruction.

Studies have shown that SCI has positive effects on student attitude and engagement. Based on student survey data, Anjur (2011) found that high school physiology students who designed their own labs rather than completing only cookbook style labs decreased their study time, while their academic performance improved not only in the physiology course, but in other academic subjects as well. Students presumably learned how to study through SCI, and that skill transferred to other academic experiences. Students more frequently turned in optional ungraded assignments in the experimental group, which indicated a higher level of engagement in the course. Wohlfarth et al. (2008) found that psychology graduate students responded positively to the trust between student and teacher that naturally develops in an SCI setting. They worked harder and more effectively for the rewards of the SCI environment, than because of the fear of a large assessment.

While students may want to learn in SCI environments, some studies note initial student resistance to the implementation of SCI. (Felder & Brent, 1996; Wohlfarth et al., 2008). Evans (2004) redesigned a high school chemistry unit on gas laws according to the 5E model. Most of her students enjoyed the unit and wanted her to teach more units in a similar manner. However, some students wanted to be taught the material, rather than what they perceived as having to teach themselves. In a study of eighth grade Earth science students, Chang (2006) determined student learning style preferences using the Constructivist Learning Environment Survey. This study found that students had the most positive attitudes when the instruction style matched their preferred learning style. Therefore, the interaction of the student with the learning environment should not be ignored.

Implementing an SCI approach, such as the 5E model, can initially be a challenging experience for a teacher. The benefits may not be immediate as the learning curve for both teachers and students can be steep (Felder & Brent, 1996). Teachers who had favorable ratings by students using teacher-centered instruction methods may initially experience a drop in student ratings with the implementation of SCI. Therefore, some teachers revert to more traditional methods rather than working through the learning curve of adjusting to a new approach (Felder, 2011). Evans (2004) found that implementing the 5E model was a lot of work, but characterized it as “rewarding” due to the positive effects on student attitude and engagement. Bullard and Felder (2007) also noted the large advance planning time, but on a positive note found that once activities were carefully designed, little preparation for class was required. Due to the preparation time, and the fact that not all subjects lend themselves equally well to SCI, Bullard and Felder suggested that a teacher begin the transition to SCI gradually.

Developing an effective 5E lesson requires bringing together many elements. To promote conceptual change, misconceptions need to be directly addressed. When designing a 5E lesson, the Engage phase should bring misconceptions and other prior knowledge to light (Balcit et al., 2006). The key to the 5E model is the placement of the Explore phase before the Explain phase (Bybee et al., 2006). The first part of the explanation should be led by students. Students should find patterns, answer questions, and propose relationships to explain the findings of the exploration phase. Only then does the teacher expand upon the student explanation with appropriate terms and vocabulary (Balcit et al., 2006). According to constructivist theory, understanding is developed slowly through repeated similar experiences. Giving students the opportunity to apply newly developed knowledge to new situations in the Elaborate phase is essential for building knowledge (Schlenker, Blanke, & Mecca, 2007).

By actively engaging students in the learning process through SCI techniques such as the 5E model, studies have shown an increase in student understanding of science concepts, and a decrease in the persistence of misconceptions. Students also learn how to study more effectively, and therefore, the benefits may extend beyond an individual classroom. However, making the transition to SCI, while desirable to both teachers and students, can be difficult. Wohlfarth et al. (2008) suggest that a balance between SCI and traditional methods of teaching may be the best approach. Despite the initial challenges to both teachers and students, the benefits of SCI outweigh the negatives in the long run (Felder & Brent, 1996). The failure of an SCI approach, such as 5E, is not typically due to the educational method, but to the implementation of it (Felder, 2011).

METHODOLOGY

Project Intervention

The purpose of this project was to investigate how the 5E instructional model would impact my students' understanding of chemistry concepts. This project consisted of three consecutive, approximately two-week, curriculum units. A nonintervention unit on chemical reactions, taught through traditional methods, was followed by two intervention units: stoichiometry and states of matter with gas laws. Both intervention units were taught according to the 5E model. The research methodology for this project received an exemption by Montana State University's Institutional Review Board, and compliance for working with human subjects was maintained.

The nonintervention unit focused on writing and balancing chemical equations. I taught this unit in a traditional way, including direct instruction followed by student practice of the new concepts. I walked students through examples of different types of chemical reactions on the board: single replacement, double replacement, decomposition, combination, and combustion reactions. I performed demonstrations of each type of chemical reaction, explaining how to write a balanced chemical equation to describe each one. Students then worked in pairs or larger groups to write and balance additional equations. Students conducted two cookbook- style labs that required them to write and balance many chemical reactions. One of the labs, in which students performed a series of double replacement reactions in spot plates, and identified precipitates that formed, is included in Appendix A.

Instead of planning each individual class as an isolated event, as I had typically done, I broadened my course planning to include the entire two-week intervention unit. With the major concepts of the unit in mind, I developed a plan based on the different stages of the 5E model. The structure of the 5E model has inherent flexibility, and several cycles of phases often occur within a single unit. Each intervention unit in this project included two Explore, Explain, Elaborate cycles in order to introduce several sets of concepts.

The first intervention unit focused on stoichiometry. To engage students I began the first class with a stoichiometry “balloon race.” Varying amounts of baking soda (ranging from 1 gram to 9 grams) were placed in five balloons attached to the mouths of Erlenmeyer flasks, each containing 100 milliliters of vinegar. Students were asked to write the balanced chemical equation for the reaction that would occur when the baking soda was tipped into the vinegar, and to predict what would happen to the five balloons. The handout for this activity is included in Appendix B.

Students explored the concept of stoichiometry through two class activities. First, working in small groups, students wrote a chemical reaction representing the construction of a S'more from graham crackers, marshmallows, and chocolate, and calculated how much of each ingredient would be required to make one S'more for each member of the class. Each group then explained to the class how they completed the calculations. Students then conducted the Michigan Stoichiometry Lab. In this lab, 0.50 grams of three different salts react with hydrochloric acid. Students were challenged to predict which reaction would produce the greatest mass of solid product, and to provide an explanation for their prediction.

Based on the general student discussion of the S'mores activity and the Michigan Stoichiometry Lab, I then introduced the concept of mole ratios, and explained the basic process for performing stoichiometric calculations, linking my explanation to those proposed by students during the Explore phase. In the Elaborate phase, students worked in pairs to complete the lab calculations from the Michigan Stoichiometry Lab, and also worked through additional stoichiometry practice problems.

Students returned to the S'mores example in a second Explore phase. This time, students calculated the maximum number of S'mores that could be made from a given amount of ingredients, and how much of each ingredient, if any, would be left over. I circulated among the groups to ensure that students were on the right track, asking questions to redirect and clarify their explanations. Following student explanation of their calculations, I introduced the concepts of limiting and excess reactants, and provided some strategies for how to approach this type of problem, again linking my explanation to their proposals. The balloon race demonstration was revisited, and students were challenged to determine which reactant was limiting in each case. Additional limiting and excess reactant problems were completed by students in small groups.

To evaluate student understanding, two performance assessments were completed. In the Decomposition of Baking Soda Lab (Appendix C), students identified the appropriate chemical reaction for this decomposition based on stoichiometry calculations. In the Air Bag Simulation (Appendix D), students calculated how much vinegar and baking soda they should combine to completely fill a Ziploc bag.

The second intervention unit focused on states of matter and gas laws. To access prior knowledge and activate misconceptions, students were asked if it was possible to boil water at 50 degrees Celsius. Student interest was then sparked with two discrepant event demonstrations. An Erlenmeyer flask containing very hot water was corked, inverted, and cooled with ice until the water began to boil again. The water continued to boil until it had cooled to approximately 60 degrees Celsius. For the second demonstration, the conditions necessary to achieve the triple point of water were created using a bell jar and vacuum pump.

In the Explore phase, students worked through a series of questions about the phase diagram of water designed to highlight the relationships between temperature, pressure and the state of matter. The class was then divided into four groups. Each group researched a different set of vocabulary words relating to states of matter, and explained them to the class. The first group researched characteristics of solids, liquids, and gases. The second group focused on different types of phase changes. The third group defined volume, temperature, and pressure measurements in several different units, and the fourth group explained the more general concepts of dynamic equilibrium, kinetic theory, kinetic energy, and vapor pressure.

Groups were then reassigned such that each group had a representative from each of the original four vocabulary groups. Each group wrote the vocabulary terms on separate sticky notes. Initially, I challenged each group to create a large concept map including all of the vocabulary terms, hoping that with an “expert” from each original vocabulary group, the new teams would be able to work out how the different sets of vocabulary terms related. This proved to be too challenging of a task, and resulted in only a few students really engaging in the discussion.

To break the material down into smaller chunks, I prepared a series of demonstrations of increasing complexity, and asked each group to write a sentence to explain the demonstration that accurately used as many of the vocabulary terms as possible. For the first demonstration, an Erlenmeyer flask containing a small amount of water was sealed with a pressure sensor, and the pressure was observed to increase as the water was heated. A more challenging demonstration to explain was when a small amount of water was placed in an empty soda can and brought to a boil. Once the water in the can had been boiling for about a minute, the can was inverted into a tub of ice water, and collapsed instantly. After each demonstration, students shared their explanations, and I either reinforced or elaborated upon their explanation, successively pulling in more vocabulary terms. For the final demonstration, I repeated the demonstration used in the Engage phase where an inverted flask containing very hot water began to boil once an icepack was placed on top.

Students then explored the relationships between volume, pressure, and temperature through the gas law investigation, which is included in Appendix E. Following the investigation, students presented their findings to the class, and the mathematical equations for Boyle's Law, Charles Law, Gay-Lussac's Law and the ideal gas law were developed. In the Elaborate phase, students applied the gas laws to conceptual and mathematical practice problems based on real world situations. For the Evaluate phase, students determined the molar mass of magnesium through a performance assessment lab. The lab handout is included in Appendix F.

Data Collection Instruments

SPS is located in Concord, New Hampshire, a city of approximately 40,000 people which is the state capital. The fully-residential campus is situated on 2000 acres, including several ponds and forested areas, and is located several miles from the city center. Students enrolled at SPS come from a wide range of geographic, racial, and economic backgrounds. Of the population of 536 students, 39% identify as students of color, including 16% international students who come from 23 different countries. Domestic students represent 34 of the 50 states. While the cost of tuition, room and board approaches $50,000 per year, 35% of students receive financial aid. The average need-based award is approximately $44,000 per year.

This study focused on 29 students in two sections of 10th grade chemistry at SPS. Approximately 40% of the 10th grade students at SPS take a fast-paced, accelerated chemistry course based on the recommendation of their previous science teacher. However, since SPS has a highly selective admission process, in which only 18 percent of applicants are accepted, the students are generally quite academically motivated. Average math, verbal, and writing SAT scores for the SPS class of 2012 were approximately 670. Classes at SPS are capped at 16 students, and the overall student to faculty ratio is five to one. All students and faculty reside on campus and, therefore, strong relationships develop between faculty and students. Some students routinely meet with their teacher for additional instruction outside of class hours.

In this study, Section A included six girls and 10 boys, while Section B included six girls and seven boys. Two of the boys in Section A are in ninth grade, having placed out of the physics class typically taken by freshmen at SPS. One student in each section qualifies for 50% extended time on assessments. Nine students in the two sections identify as students of color or international students. Five of the students performed very poorly in class for the first month of the school year, but began to show significant improvement in October and November. One boy joined Section B in December after dropping down from accelerated chemistry.

Each week the two sections of chemistry met for 45 minutes on Monday and Tuesday, and two longer periods (80 minutes and 95 minutes) in the second half of the week. Section A met Monday, Tuesday, Thursday, and Saturday each week. Section B met Monday, Tuesday, Wednesday, and Friday. I have taught this course for five years, and am very familiar with the content of the course. Therefore, I felt it was an appropriate course in which to try new teaching strategies.

To investigate the project questions related to the 5E model, a variety of data collection instruments, both qualitative and quantitative, were used. Table 1 is a triangulation matrix of the data collection instruments, showing what types of data were used to assess each project question.

Table 1
Triangulation Matrix

Focus Questions	Data Source 1	Data Source 2	Data Source 3
Primary Question 1. What are the effects of the 5E model on student understanding of chemistry concepts?	Pre and postunit assessments	Pre and postintervention student surveys	Pre and postunit student interviews with concept maps
Subquestions			
2. What are the effects of the 5E model on student long-term memory of these concepts?	Postunit and delayed unit assessments	Pre and postintervention student surveys	Postunit and delayed unit student interviews with concept maps
3. What are the effects of the 5E model on student attitude and engagement?	Teacher weekly reflection journaling	Nonintervention and intervention observer field notes with prompts	Pre and postintervention student surveys
4. What are the effects of the 5E model on my attitudes towards teaching?	Teacher weekly reflection journaling	Nonintervention and intervention observer field notes with prompts	Pre and postintervention teacher surveys

The primary project question and the first subquestion focused on student understanding of chemistry concepts. A short assessment with questions of varying difficulty was developed to assess student understanding. The assessment questions are included in Appendix G. This assessment was given to all students in the study before and after each unit to assess the change in understanding of chemistry concepts during the unit. In order to compare results from different units, the percent change from preunit to postunit assessment score was calculated according to the following formula:

$$\text{Percent Change} = \frac{\text{postunit score - preunit score}}{\text{preunit score}}$$

Due to varying preunit scores, a normalized gain was also calculated to compare the change in understanding between units. The normalized gain was calculated as follows:

$$\text{Normalized Gain} = \frac{\text{postunit \% - preunit \%}}{\text{100 - preunit \%}}$$

A similar assessment was given approximately 14 days after the postunit assessment of each unit in order to assess long-term memory of those concepts. For the second intervention unit, the delayed assessment was given 25 days after the postunit assessment due to a three-week school vacation. The percent change from postunit to delayed unit assessment score was calculated to compare the results between units. A student survey, included in Appendix H, was also conducted to assess student perceptions of their understanding before and after the intervention.

Student understanding was also assessed through student interviews. Students in the study were divided into three groups (high, middle, and low-achieving students) based on their fall term final grades. One male and one female student from each group were selected to participate in structured concept interviews before, after, and two weeks following each unit. During the interviews, students created concept maps of keywords from the unit in order to assess student understanding, long-term memory, and ability to explain connections between concepts. The concept maps were scored using a rubric that focused on the links between concepts. The terms included in the concept maps are in Appendix I.

To assess the effects of the 5E model on student and teacher attitude and motivation, I completed a weekly journal reflection about student attitude and engagement, and my own feelings about the lessons. The journal prompts are included in Appendix J. Once during each unit, Lawrence Smith, the SPS Dean of Curriculum and Teacher Development, observed section A. He completed a feedback form, which is included in Appendix K. The previously mentioned student survey (Appendix H) also gathered information about student attitude and engagement in chemistry near the end of the nonintervention unit, and again near the end of the second intervention unit. I completed a similar pre and postintervention survey, in which I ranked and explained aspects of student and teacher attitude and engagement. This survey is included in Appendix L.

The effect of using the 5E model on student understanding of chemistry concepts was analyzed by comparing pre and postunit assessments and student interviews, and pre and postintervention surveys. The effect on student long-term memory was analyzed by comparing the results of postunit and delayed unit assessments, student interviews, and student surveys. Changes in student attitude and engagement as a result of the 5E model were assessed by comparing pre and postintervention surveys, teacher journal entries, and observer ratings. Changes in teacher attitude were also assessed through those tools.

This study was implemented primarily during January and February 2013. The delayed assessment for the second intervention unit was given 25 days after the postunit assessment, on the first day of class following SPS spring vacation. Delayed concept interviews for the second intervention unit were conducted between 26 and 30 days after the postunit interviews. Each of the three units lasted approximately two and a half weeks. A complete timeline of the project is included in Appendix M.

DATA AND ANALYSIS

The primary focus of this project was to assess the effect of the 5E model on student understanding in my chemistry classes. The change in student understanding was evaluated through percent change between pre and postunit assessment scores. These values are included in Table 2. There was a much higher percent change in student understanding in the first intervention unit compared to the other two units. Low-achieving students had higher average percent change in both intervention units compared with the nonintervention unit.

The most ideal situation for comparison of knowledge is to have equal value preassessment scores. To account for higher preunit scores in the nonintervention unit and second intervention unit, the normalized gain of the average postunit scores were calculated, and are also included in Table 2. The average normalized gain of the nonintervention unit assessment was slightly higher than the first intervention unit assessment, and higher than the second intervention unit gain. The high-achieving students had larger normalized gains in the intervention units compared to the nonintervention unit, while middle and low-achieving students had the highest normalized gain in the nonintervention unit. Although low-achieving students had a larger percent change in the second intervention unit, the normalized gain was the least.

Table 2
Average Pre and Postunit Assessment Scores with Percent Change, and Normalized Gain

Nonintervention Unit				
Assessment Scores	Student Achievement Level			
	All (*N*=25)	High (*n*=10)	Middle (*n*=7)	Low (*n*=8)
Pre	2.4	2.6	2.1	2.3
Post	9.2	9.3	9.4	8.8
% Change	280	260	350	280
Normalized Gain	0.90	0.91	0.92	0.84
Intervention Unit 1				
Assessment Scores	Student Achievement Level			
	All (*N*=27)	High (*n*=10)	Middle (*n*=9)	Low (*n*=8)
Pre	0.9	1.1	1.1	0
Post	8.9	9.8	8.8	7.8
% Change	890	790	700	780*
Normalized Gain	0.88	0.98	0.87	0.78*
* calculated with the assumption that the preassessment score was 0.01				
Intervention Unit 2				
Assessment Scores	Student Achievement Level			
	All (*N*=27)	High (*n*=10)	Middle (*n*=9)	Low (*n*=8)
Pre	2.8	3.8	2.7	1.6
Post	8.6	9.6	8.6	7.2
% Change	210	150	220	350
Normalized Gain	0.81	0.94	0.81	0.67

Note. Maximum raw score is 10.

Student understanding was also assessed through concept interviews with a small group of students before and after each unit. Two students from each achievement group met with me to develop a concept map of the key terms of each unit. The concept maps were scored using a rubric that gave points for propositions (correctly formed links between two concepts), organization of the map into levels, and cross-links, which connect several propositions. There was no maximum score for the concept maps. A higher score indicates a greater level of detail and linkage in the map. Pre and postunit concept map scores and percent change in score are summarized in Table 3.

Table 3
Average Pre and Postunit Concept Map Scores and Percent Change

Student Achievement Level	Nonintervention Unit Concept Map Score			Intervention Unit 1 Concept Map Score			Intervention Unit 2 Concept Map Score		
	Pre	Post	%Change	Pre	Post	%Change	Pre	Post	%Change
High Female	74	62	-16	43	75	74	53	74	40
High Male	61	66	8	37	67	81	58	61	5
Average High	68	64	-4	40	71	78	56	68	23
Middle Female	57	60	5	35	37	6	35	65	86
Middle Male	61	61	0	46	58	26	NA	NA	NA
Average Middle	59	61	3	41	48	16	35	65	86
Low Female	32	49	53	26	31	19	31	57	84
Low Male	61	61	0	46	48	4	32	32	0
Average Low	47	55	27	36	40	12	32	45	42
Average	58	60	8	39	53	35	42	58	43

Note. NA = student was not interviewed.

All students interviewed generally showed larger percent change in concept map scores in the intervention units compared to the nonintervention unit. It should be noted that the nonintervention unit interviews were conducted after one period of instruction during which most of the concepts were briefly explained. This would explain higher preunit concept map scores, and a lower percent change in score. High-achieving students had larger gains in the first intervention unit than the second, while middle and low-achieving students tended to have higher gains in the second intervention unit.

The large gains by the high-achieving students in the first intervention unit were due to additional cross-linking of concepts, such as connecting the concept of limiting reactant to several other terms. The large gains by the middle and low-achieving students in the second intervention unit were for additional valid propositions based on definitions of concepts, connecting concepts in a more linear fashion. The increase in knowledge of the two high-achieving students during in the first intervention unit represented a much more interconnected understanding of stoichiometry compared to the more vocabulary driven understanding of the middle and low-achieving students in the second intervention unit. Although the average percent change for the low-achieving students is lower than that of the middle-achieving students, the low-achieving male student was interviewed a few class periods after the start of both intervention units. This may explain his low percent change values for both intervention units. Excluding his results, low and middle-achieving students had similar changes in understanding.

Student perception of their understanding was assessed through a survey given towards the end of the nonintervention unit and again towards the end of the second intervention unit. Students were asked to use a five-point Likert scale to respond to the statement, “I am confident in my understanding of the material we studied this unit.” As shown on Figure 1, the distribution of student responses was very similar on the two surveys. The median response in both cases was “Agree.” Overall, there was little difference between the data for nonintervention and the intervention units, indicating no significant change in student confidence in their understanding.

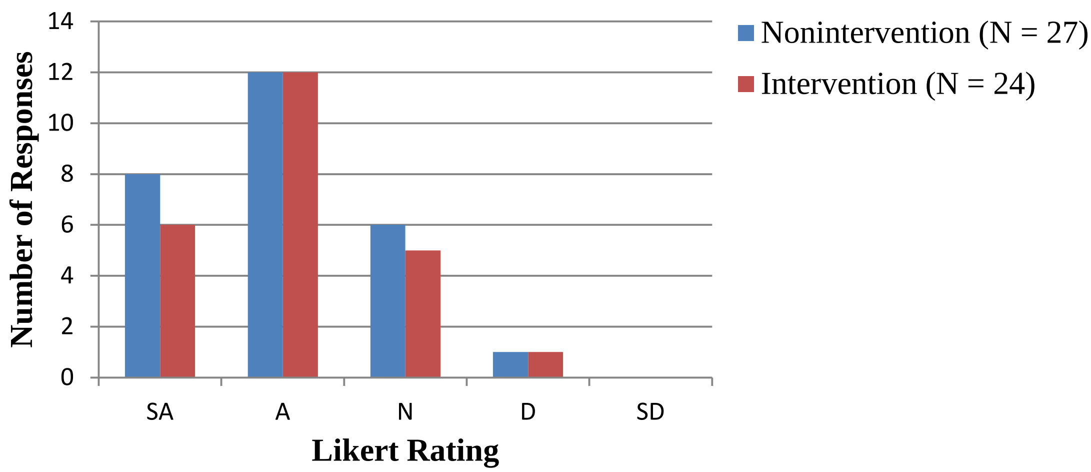

Figure 1. Distribution of student rating of confidence in understanding as measured according to surveys.
Note. SA = Strongly Agree, A = Agree, N = Neutral, D = Disagree, SD = Strongly Disagree.

The distribution of student Likert responses to the statement, “The teaching style is effective in helping me learn,” is shown on Figure 2. The median response was “Agree” for each survey. The distribution of student responses was similar, with the intervention responses shifting slightly lower. The drop in “Strongly Agree” ratings in the intervention unit represents two fewer high-achieving students and two fewer middle-achieving students compared to the nonintervention unit. (It should be noted that three middle-achieving students did not take the intervention survey, and this could contribute to the decrease in “Strongly Agree” responses.) The one student who selected “Disagree” on the intervention survey noted, “I like learning on my own, but then when I see a problem written in a way different than my own, I panic and second guess myself, causing me to do everything wrong.” Overall, there were similar ratings for the effectiveness of the teaching style in the nonintervention and intervention units. Most students "agreed" or "strongly agreed" that the teaching style was effective each time.

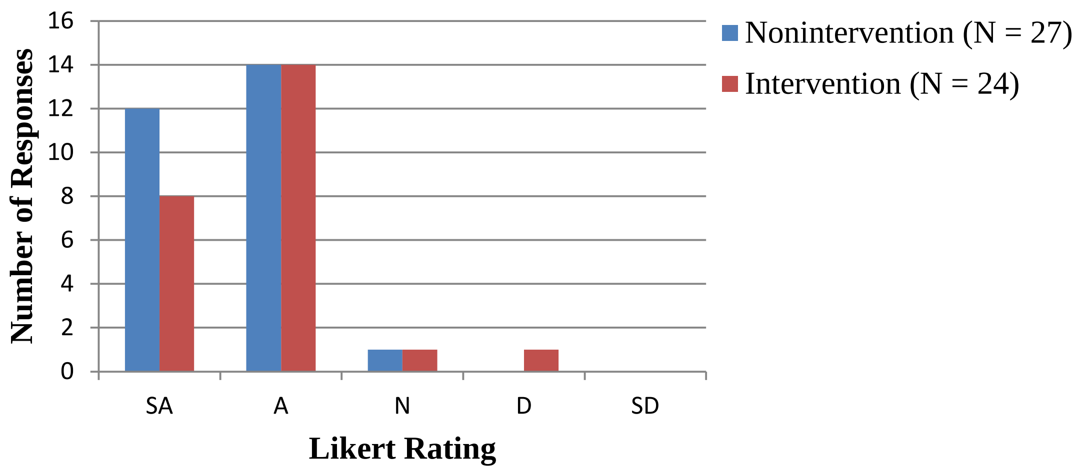

Figure 2. Distribution of student rating of effectiveness of teaching style as measured according to surveys.
Note. SA = Strongly Agree, A = Agree, N = Neutral, D = Disagree, SD = Strongly Disagree.

Triangulation of the data show mixed results for the effect of the 5E model on student understanding of chemistry concepts. Students were equally confident in their understanding during the nonintervention and second intervention unit, and median Likert ratings for the effectiveness of the teaching style were the same for both units. The average normalized gains on postunit assessments were similar for the nonintervention unit and first intervention unit, and lower for the second intervention unit. One complicating factor is that the complexity of the material included in this study increased from the nonintervention unit to the second intervention unit. Even so, high-achieving students had higher normalized gains in both intervention units compared to the nonintervention unit, suggesting that perhaps the 5E model pushed high-achieving students to a higher level of understanding.

The two high-achieving students who were interviewed also had the greatest increase in connected knowledge during the first intervention unit as shown by percent change in concept map scores. Although the average percent change in concept map scores was higher for both intervention units than for the nonintervention unit, it is difficult to compare scores because the preunit interviews for the nonintervention unit were conducted after one day of instruction.

A secondary focus of this project was to assess the effect of the 5E model on student long-term memory of chemistry concepts. Students were given an assessment similar to the postunit assessment approximately two weeks later. The delayed assessment for the second intervention unit was given more than three weeks later due to the school's spring vacation. Table 4 summarizes the average post and delayed unit assessment scores, percent change, and normalized gain.

The second intervention unit had the largest drop in delayed unit assessment scores. Not only was the delayed assessment for this unit given nearly 10 days later than in the previous two units, but students were also on vacation during this period as opposed to studying chemistry. Both factors could potentially lead to a decrease in delayed unit assessment scores.

The decrease in scores was similar for the nonintervention and first intervention units, with slightly larger drops on average for the first intervention unit. The first intervention unit focused on stoichiometry, which relies heavily on chemical reactions, the subject of the nonintervention unit. Therefore, students were continually exposed to the nonintervention unit material during the first intervention unit. In fact, the

Table 4

Average Postunit and Delayed Unit Assessment Scores, Percent Change and Normalized Gain

Nonintervention Unit	Assessment Scores				
	Post*	Delay*	% Change	Normalized Gain Post	Normalized Gain Delay
All (*N*=25)	9.2	8.9	-3.3	0.90	0.86
High (*n*=10)	9.3	9.5	2.2	0.91	0.93
Middle (*n*=7)	9.4	8.8	-6.4	0.92	0.85
Low (*n*=8)	8.8	8.2	-6.8	0.84	0.77
Intervention Unit 1	Assessment Scores				
	Post*	Delay*	% Change	Normalized Gain Post	Normalized Gain Delay
All (*N*=27)	8.9	8.5	-4.5	0.88	0.84
High (*n*=10)	9.8	9.3	-5.1	0.98	0.92
Middle (*n*=9)	8.8	8.2	-6.8	0.87	0.80
Low (*n*=8)	7.8	7.8	0.0	0.78	0.78
Intervention Unit 2	Assessment Scores				
	Post*	Delay*	% Change	Normalized Gain Post	Normalized Gain Delay
All (*N*=27)	8.6	6.8	-21	0.81	0.56
High (*n*=10)	9.6	7.7	-20	0.94	0.63
Middle (*n*=9)	8.6	7.2	-16	0.81	0.62
Low (*n*=8)	7.2	6.1	-15	0.67	0.54

Note. *Postunit and delayed unit assessment scores, maximum raw score is 10.

high-achieving group scored better on average on the delayed nonintervention unit assessment than on the postunit assessment. However, the states of matter concepts in the second intervention unit did not overlap very much with stoichiometry, and therefore that material was not reinforced before the delayed unit assessment. Therefore, the similar drops in delayed unit assessments with and without reinforcement of the material may imply that students achieved a better long-term memory of stoichiometry through the 5E model. Additionally, the average score of the low-achieving group was the same on the post and delayed unit assessments for that unit.

Conceptual long-term understanding was also assessed by comparing postunit and delayed unit concept maps prepared by students during individual interviews. The average post and delayed unit concept map scores and percent change are summarized in Table 5. On average, and for nearly all of the students interviewed, delayed concept map scores were higher than postunit concept map scores, implying that students improved their conceptual understanding of the material with distance and time for reflection. While middle and low-achieving students tended to have larger positive gains, high-achieving students had the highest delayed concept map scores.

Table 5
Average Postunit and Delayed Unit Concept Map Scores and Percent Change

	Nonintervention Unit			Intervention Unit 1			Intervention Unit 2		
	Post*	Delay*	% Change	Post*	Delay*	% Change	Post*	Delay*	% Change
High Female	62	66	6	75	69	-8	74	NA	NA
High Male	66	73	11	67	67	0	61	61	0
Average High	64	70	9	71	68	-4	61	61	0
Middle Female	60	59	-2	37	59	59	65	50	-23
Middle Male	61	62	2	58	NA	NA	NA	NA	NA
Average Middle	61	61	0	37	59	59	65	50	-23
Low Female	49	50	2	31	46	48	57	71	25
Low Male	61	72	18	48	53	10	32	NA	NA
Average Low	55	61	10	40	50	29	57	71	25
Average	60	64	6	52	59	22	54	61	1

Note. *Postunit and delayed unit assessment scores, NA = student was not interviewed.

The largest positive change was in the first intervention unit. As noted previously, concepts in the nonintervention unit were reinforced in the first intervention unit, potentially increasing nonintervention delayed unit scores, while this was not the case for the first intervention unit. The students with the largest gains in the first intervention unit concept maps were able to create more cross-links in the delayed unit maps than they had in the postunit map. Thus, the greater increase in delayed unit scores without content reinforcement implies that the 5E model generated a more lasting understanding of concepts.

The delayed interviews for the second intervention unit were conducted approximately four weeks postunit, as opposed to two weeks for the nonintervention and first intervention units, due to a three-week spring break. Of the three students who were able to complete the delayed interview, the high-achieving student drew essentially the same map he had postunit, the middle-achieving student had the same overall structure to her map, but included fewer details, and the low-achieving student was able to include more propositions and cross-links in her final map. In all three units, the students interviewed maintained the same general understanding of the concepts, and in most cases were able to connect them more extensively in the delayed unit interviews.

In the survey given at the end of the nonintervention and second intervention units, students were asked to rate their confidence in their understanding of the previous unit using the previously described Likert Scale. The distribution of responses to the statement, “If I were given a quiz on the previous unit today, I would be able to earn a good grade,” is summarized in Figure 3. The median response to this statement shifted from “Agree” during the nonintervention unit to “Strongly Agree” during the intervention unit. The median response also became more positive in the intervention unit for all achievement groups. It should be noted that the previous unit for the nonintervention unit survey was before a three-week winter vacation, while the stoichiometry unit referred to in the intervention survey was completed only two weeks prior to the survey.

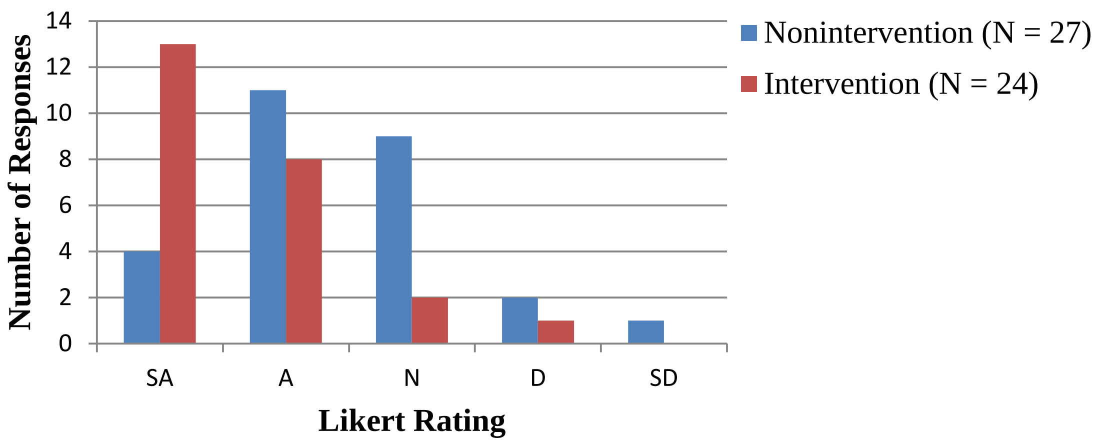

Figure 3. Distribution of student rating of confidence in long-term memory as measured according to surveys.
Note. SA = Strongly Agree, A = Agree, N = Neutral, D = Disagree, SD = Strongly Disagree.

All three data sources indicated that the 5E model may have a positive impact on student long-term memory of chemistry concepts. Students felt more confident in their long-term memory of concepts taught using the 5E model than in concepts taught in a traditional style. Delayed concept interviews showed that students maintained or even improved their conceptual understanding of the material in all three units, with the most improvement in the first intervention unit. Retention of more specific details decreased, as shown by similar drops in delayed unit assessment scores in the first two units and a larger drop for the second intervention unit. However, the first intervention unit relied on and reinforced material in the nonintervention unit, possibly boosting the delayed nonintervention unit score. In contrast, the second intervention unit was unrelated to the first intervention unit. Interestingly, the delayed unit assessment score of the low-achieving group did not change from the postunit score for intervention unit 1. Results for long-term memory of the second intervention unit were lower, but this assessment was further delayed than the previous two units, and came after a long vacation.

I also investigated the effects of the 5E model on student attitude and engagement. Four questions on the student survey asked for Likert ratings about student interest and engagement in chemistry class. The distribution of student responses to the statement, "I enjoy going to chemistry class," was similar for both surveys, and is shown on Figure 4. The median response for all achievement groups was the same for the nonintervention and intervention surveys. The median response for middle and low-achieving groups as well as the entire student sample was "Agree," while the median response for high-achieving students was "Strongly Agree."

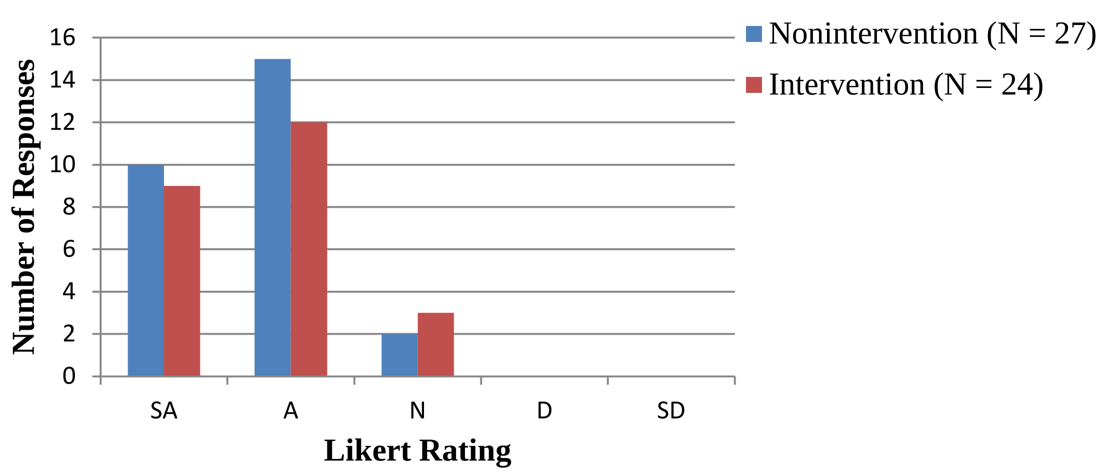

Figure 4. Distribution of student rating of enjoyment as measured according to surveys. *Note.* SA = Strongly Agree, A = Agree, N = Neutral, D = Disagree, SD = Strongly Disagree.

The median response to the statement, "This class keeps me engaged and interested," was "Agree" for the entire student sample and for middle and low-achieving students on both surveys. The median response for high-achieving students dropped from "Strongly Agree" to "Agree" on the intervention survey. The distribution of student responses about engagement is shown on Figure 5.

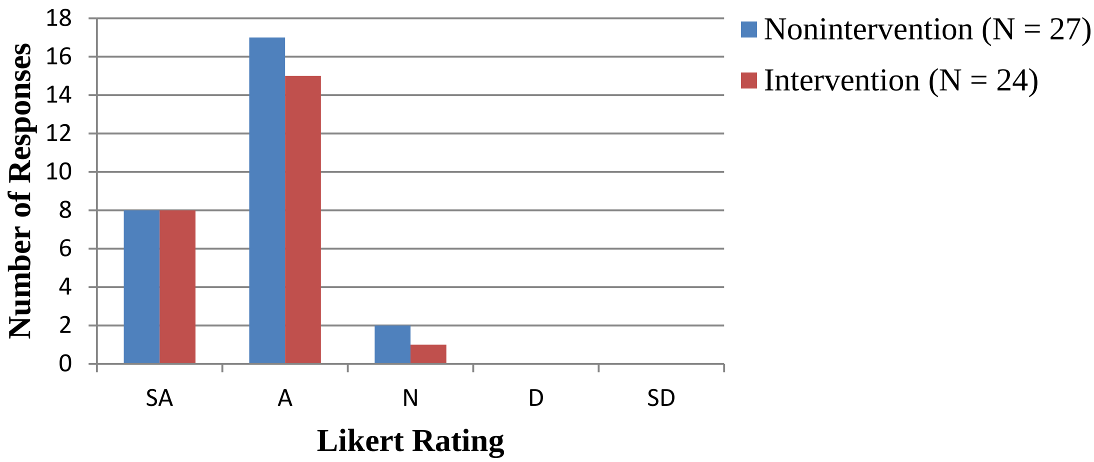

Figure 5. Distribution of student rating of engagement as measured according to surveys. *Note.* SA = Strongly Agree, A = Agree, N = Neutral, D = Disagree, SD = Strongly Disagree.

Some students seemed to be less curious about the concepts studied in the second intervention unit compared to the nonintervention unit, as shown by the distribution of responses to the statement, "I am curious about the concepts we are studying," which is shown on Figure 6. The median response for the entire student sample (Agree), high-achieving students (Strongly Agree), and middle-achieving students (Agree) was the same for both surveys. The median response for low-achieving students dropped slightly from between "Agree" and "Neutral" to "Neutral." However, there is a broader distribution of responses to the intervention survey compared to the nonintervention survey. The students who selected "Neutral" or "Disagree" on the intervention survey did not include any written comments to explain their response.

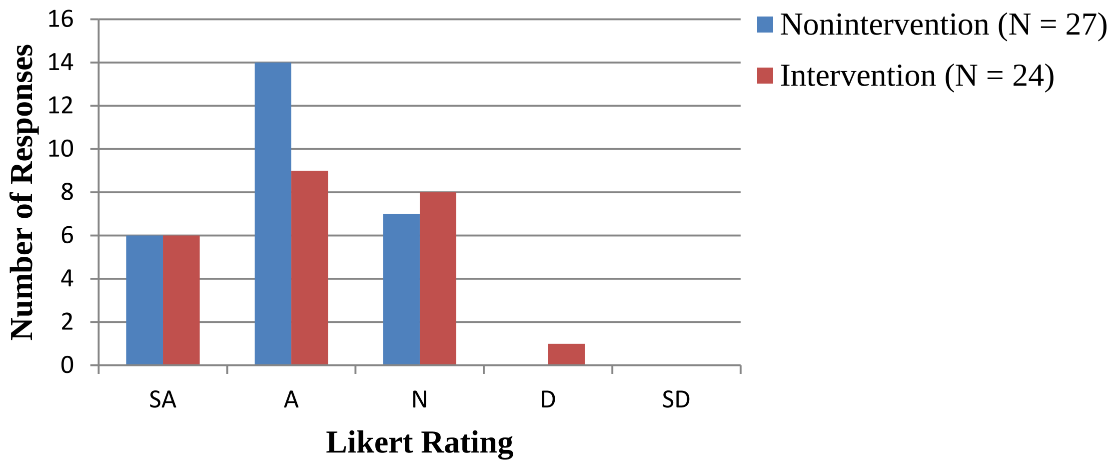

Figure 6. Distribution of student rating of curiosity about chemistry as measured according to surveys.
Note. SA = Strongly Agree, A = Agree, N = Neutral, D = Disagree, SD = Strongly Disagree.

The distribution of responses to the statement, “The teaching style keeps me interested in chemistry,” is shown on Figure 7. Although there seemed to be less curiosity about the topics discussed in the second intervention unit, students did not attribute that

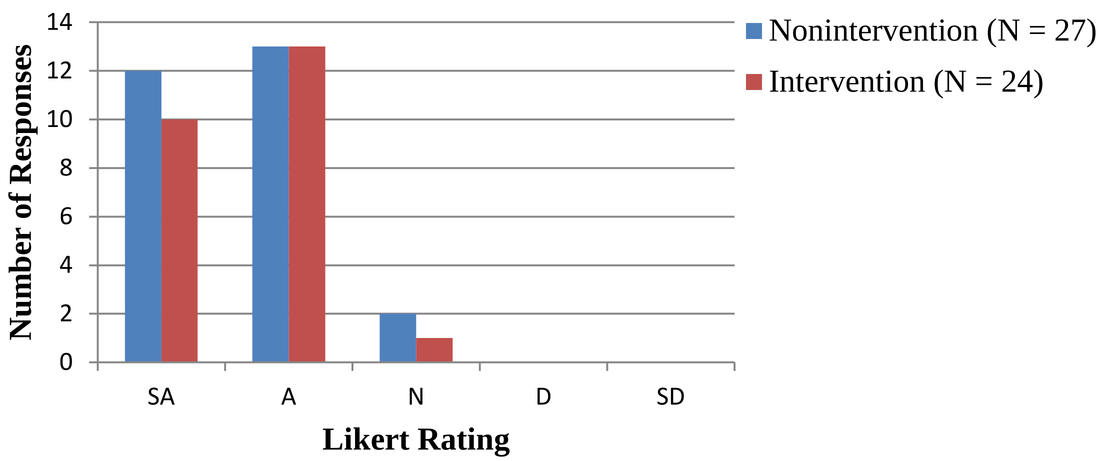

Figure 7. Distribution of student rating of interest in chemistry based on the teaching style as measured according to surveys.
Note. SA = Strongly Agree, A = Agree, N = Neutral, D = Disagree, SD = Strongly Disagree.

to the intervention teaching style. There was no change in the median response for the entire student sample or each achievement group between surveys. The distribution of the responses to the two surveys is also very similar. High-achieving students had a higher median response (Strongly Agree) than other achievement groups (Agree).

Lawrence Smith observed one class period of Section A during each of the three units. He focused his observations on one student from each of the three achievement groups, and also rated the entire class on several statements relating to attitude and engagement. His ratings are displayed on Figure 8.

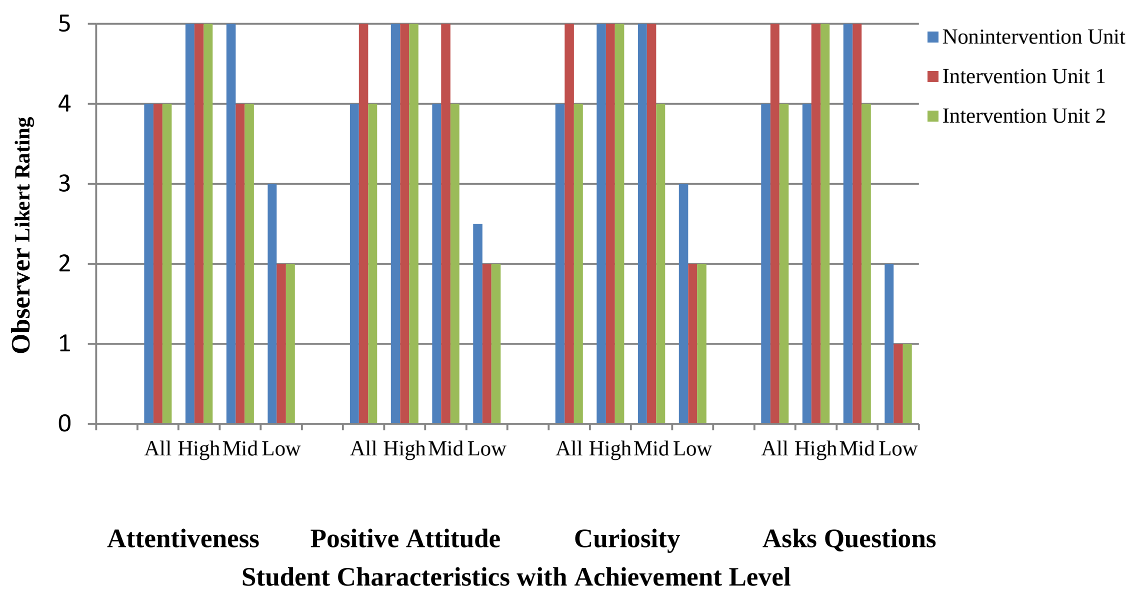

Figure 8. Observer rating of student attitude and engagement during class visits. *Note.* Strongly Agree = 5, Agree = 4, Neutral = 3, Disagree = 2, Strongly Disagree = 1. All (*N*=16), High (*n*=1), Middle (*n*=1), Low (*n*=1).

Overall, his ratings were most positive for the first intervention unit compared to the other two units. Most of the class period he observed during the first intervention unit was devoted to a problem-solving competition between groups of students. Each time, though, he noted the class was quite engaged and “plugged-in.” He felt that the two intervention unit classes could not be improved, while he thought that students could explore the concepts more on their own in the nonintervention unit. For several statements he noted a stark contrast between the level of engagement of the low-achieving student he observed and the majority of the class, which is evident in his Likert ratings. When describing student attentiveness during the second intervention unit he noted, “The weak student who I am watching is almost aggressively distracted – he has no commitment to the class or material … Everyone else is on task and engaged.”

For the final two statements, although his ratings showed a drop from “Strongly Agree” to “Agree” for the class as a whole between the intervention units, Lawrence’s comments noted a different trend in the three classes he observed. In the nonintervention unit, he observed that questions were mainly clarifying and focused on getting the correct answer. In the intervention units, he noticed student questions became deeper and more inquisitive, and students were not afraid to take some risks in the second intervention unit. The weakest student he observed did not ask any questions in the three class periods, and only spoke when directly called upon.

Throughout the project I completed a weekly journal entry, rating statements about student attitude and engagement using the same Likert scale. Figure 9 shows my weekly responses to the statement, “Students were excited about class this week,” and Figure 10 shows my weekly responses to the statement, “Students were enthusiastic participants in class this week.” Similar to Lawrence, I felt the students were most excited and engaged during the first intervention unit.

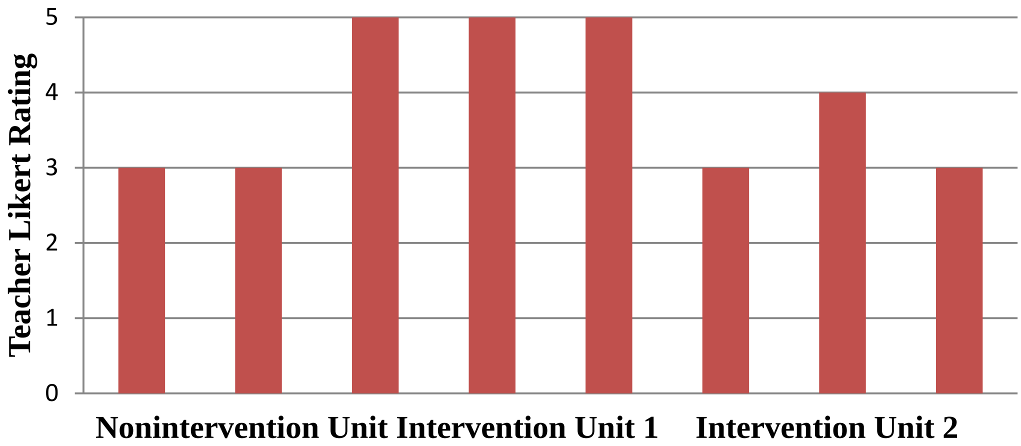

Figure 9. Weekly teacher rating of student excitement for class.
Note. Strongly Agree = 5, Agree = 4, Neutral = 3, Disagree = 2, Strongly Disagree = 1.

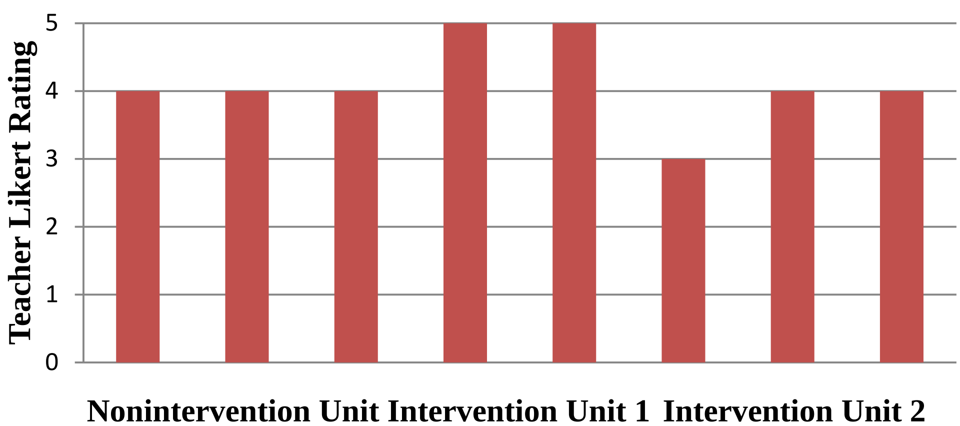

Figure 10. Weekly teacher rating of student enthusiasm for class.
Note. Strongly Agree = 5, Agree = 4, Neutral = 3, Disagree = 2, Strongly Disagree = 1.

In the nonintervention unit, students became excited about demonstrations and labs, but otherwise were pretty unemotional. They worked hard and were attentive, but with no real joy in learning. There seemed to be the right amount of practice in class for students to master writing and balancing chemical equations and net ionic equations. Students were very nervous about the preunit assessment, and frustrated that they didn't understand the questions.

Students had much enthusiasm throughout the first intervention unit for competitive and hands-on activities. In the Explore portion of the unit, students were asked to make predictions about how much product would be generated from a series of chemical reactions during the Michigan Stoichiometry Lab. They were nervous and resistant to this process, and wanted to know instantly if they were correct. They were hesitant to be wrong, and gave a brief answer instead of an extensive explanation. As the unit progressed, students seemed to become less resistant to coming up with explanations themselves. They seemed to gain confidence in talking to each other and working through problems. I was impressed that they were able to figure out limiting and excess reactant problems on their own by relying on the previously used S'mores analogy. Some of the weakest students in section A were the most engaged they had been all year. During performance assessments, students were still nervous and wanted to know if their calculations were correct.

The second intervention unit on states of matter and gas laws is always a difficult unit for me to teach. In contrast to the previous three chapters, the scope of the material is much broader and more conceptual. The demonstrations used during the Engage phase of the 5E model were great, with lots of surprised enthusiasm about water boiling at a low temperature. Some student comments included, "It's magic!" and, "That's sick!" However, my class concept mapping activity for the Explain phase was not successful, and I quickly had to develop a new plan. Students were disengaged as there was not enough work to keep everyone occupied. It also required much higher level thinking than solving stoichiometry problems, and it was difficult to get students to buy into this at the end of a long winter term. As I shifted gears to having students explain specific demonstrations using the concepts, students became more engaged. In contrast to the first intervention unit, there was not as much resistance to having to explain things. I was also impressed with how students were able to work together to solve gas law problems at the end of the unit without my first walking them through several examples.

Both my reflections and ratings from my observer indicated that students had the most positive attitude during the first intervention unit. Although student ratings didn't show a change in attitude between nonintervention and intervention, and even indicated a decrease in curiosity about the concepts studied during the second intervention unit, both Lawrence and I noted growing curiosity, engagement in the learning process, and confidence in taking risks as the intervention units progressed.

Finally, I looked at the effects of the 5E model on my own attitude towards teaching. Lawrence "strongly agreed" that I was enthusiastic about the class each time he observed. In the nonintervention class he noted, "Her good, positive and supportive energy made for an excited and enthusiastic class." Following the class during the first intervention unit he noted, "She is enthusiastic about the subject matter as well as with the students." During intervention unit 2 he wrote, "Mary Ann's enthusiasm and energy make this a lively and creative classroom."

I reflected on the teaching process in a weekly journal entry and a survey that I completed at the end of the nonintervention and second intervention units. My sentiments in these two reflection media were similar. Table 6 is a summary of the Likert survey responses. The nonintervention unit was easy for me to teach as I had taught this unit in a

Table 6
Likert Responses to Teacher Survey

	Nonintervention Unit	Intervention Unit
I look forward to planning class in this style.	A	SA
I look forward to going to class.	A	A
I am excited about the learning that is occurring in my classroom.	A	A

Note. Strongly Agree=SA, Agree=A, Neutral=N, Disagree=D, Strongly Disagree=SD.

similar fashion for the past several years. Although the planning for the intervention units took more time, I liked looking at the unit as a whole, and thinking about how I could circle back to concepts we had already discussed. Beginning the Engage phase with a demonstration that I could refer back to in order to reinforce concepts was very effective. The stoichiometry unit worked really well, but the states of matter and gas laws unit was much more complex and difficult, and I need to continue to refine that unit. Despite the difficulty of the second intervention unit, I was excited to see my students drawing better connections between concepts through the 5E model than I recall from previous years.

During the intervention units, I used PowerPoint slides to pose questions for the students to work on in groups. On successive slides I included answers that students could look at after they solved the problem. Although it took work to prepare, the class time was relaxing for me as I could concentrate on the students, not on what I was writing on the board. I also liked giving the students a model to review afterwards.

According to my journal entries, prior to this project, I felt that students worked hard in my class, but didn't always have a lot of spirit or enthusiasm. I was excited to see that students were much more engaged in the learning process during the intervention units, rather than just repeating what I showed them. It was satisfying to see them ask each other better questions, gain confidence as the units progressed, and work more independently by the end of the second intervention unit.

To my outside observer, my attitude towards teaching did not change between the nonintervention and intervention units. Based on my own reflection, however, I gained enthusiasm for teaching as I watched my students become more active learners during the intervention units. Despite the challenges and frustrations of the second intervention unit, I could see the potential for success of the 5E model in this unit.

INTERPRETATION AND CONCLUSION

Based on the data collected during this project, the 5E model seemed to have mixed effects on student understanding of chemistry concepts. On assessments, high-achieving students consistently had slightly higher gains in the intervention units, while the middle and low-achieving students showed slightly lower gains in the first intervention unit, and the least improvement in the second intervention unit. In my classes, the 5E model seemed to have the most positive impact on high-achieving students. Students were equally confident in their understanding during the nonintervention and second intervention units, and did not note much difference in the effectiveness of the teaching style of the two units.

The 5E model had a positive effect on student long-term memory of chemistry concepts. Students had similar decreases in delayed assessment scores in the first intervention unit as in the nonintervention unit, without the benefit of reinforcement of the material. Delayed unit concept map scores were also highest for the first intervention unit, and, according to the survey results, students were more confident in their long-term memory of concepts taught using the 5E model. The results were least positive for the second intervention unit, possibly due to the complexity of the material or the extra time before delayed assessment.

Based on my own and my observer's feedback, students were most engaged and had the most positive attitude in class during the first intervention unit. According to my observations, the challenging breadth of material in the second intervention unit combined with its timing at the end of a long winter term, made student attitudes seemingly slightly worse during the second intervention unit. Except for a slight decrease in curiosity about the topics studied during the second intervention unit compared to those studied in the nonintervention unit, the student survey responses did not support this decline in attitude. However, my students seemed to grow as learners when exposed to the 5E model, and their increased independence, curiosity, and willingness to take risks in their learning was observed by both me and Lawrence. According to my journal entries, I was excited by this growth in my students, and while teaching in a new style is challenging, I could see the benefits of adapting curriculum units to the 5E model.

During this project, I was interested to see the negative student reaction to the preunit assessments. Students were anxious about not knowing the answers, and seemed defeated when they finished the short assessment. However, beyond using the scores for data analysis purposes, the preassessments were also valuable tools for eliciting preconceptions and misconceptions about the chemistry concepts we were about to study, and priming students for future learning. Going forward, I hope to acclimate my students to preassessments early in the year in order to reduce anxiety and take full advantage of the benefits.

One challenge inherent in the assessment of this project was the variation among the three units in the study. The nonintervention unit was the most limited in scope, and was reinforced during the first intervention unit. The conceptual and broad nature of the second intervention unit made it the most challenging to teach. The delayed assessment of this unit also occurred much later relative to the first two units, following a three-week school vacation. Most data collected in this study had the least positive results for the second intervention unit. With three such varied units, it is difficult to compare assessment results at face value.

The concept map interviews were the most difficult data source to analyze in this project. Although I used a defined rubric to assess the concept maps, it was challenging to compare scores due to the great variability among student maps. The changes in hierarchy, complexity, and cross-links of concepts was worth many points and this caused me some concern since I was a novice at scoring maps. I think it would have been more comfortable for me to assess and compare student understanding if I had asked specific concept questions with a limit of 100 points instead. However, doing this project has made me see the value of concept mapping as a way to visualize the change in student knowledge without a limit to the highest score and as a learning tool. Several of the students I interviewed commented on how creating the concept map helped improve their understanding of the topic. Therefore, I hope to incorporate concept mapping into my curriculum for the entire class on a more frequent basis.

VALUE

Through this study I observed positive impacts of the 5E model on student understanding, long-term memory, attitude, and engagement in class. As I saw during the six weeks of the intervention phase, my students gained confidence and independence in their learning, representing a shift towards an improvement in critical thinking skills. By having students explore concepts independently and explain their findings more regularly from the start of the year, I hope that my future students will be more willing to take risks in their learning and to discuss thoughts with their peers. It will be exciting to see what my students can accomplish with this sort of approach.

An additional positive outcome of this project was that three of the students I interviewed, including both low-achieving students and the male middle-achieving student, had large improvement in their overall performance in my class during the winter term compared to the fall term. Both low-achieving students noted that it was very helpful for them to be able to talk about the concepts with me as they created the concept maps. The visual nature of the concept map, as well as the physical manipulation of the concepts on a large board targets different learning styles than simple problem solving. The improved performance of these three students supports the value of concept mapping in solidifying understanding of subject matter, as well as the positive impact of one-on-one interactions with students. Whenever possible, I hope to continue to incorporate these elements in my teaching.

I enjoyed the holistic approach to teaching according to the 5E model, and was excited to see my students gain enthusiasm and independence in the classroom. While the second intervention unit did not go as well as I had hoped, teaching in a new style is always challenging. Some subject areas and units of study may lend themselves better to the 5E model than others, and it may take several attempts to refine the approach for a given unit. Regardless, it seems starting a unit with an engaging demonstration or discrepant event that I can cycle back to periodically during the unit was very effective.

Next year I am excited to have the opportunity to coteach one of my chemistry classes with a teaching intern. As I discuss full-year and daily course planning with this new teacher, it will provide a perfect opportunity for me to think critically about how I teach each curriculum unit, and identify areas in which I can incorporate concept mapping and the 5E model. One challenge in analyzing the data from this project was the variability of the content studied in the nonintervention and intervention units. By teaching the nonintervention unit in the 5E style next year, I could compare the assessment results for the two different years, but I will need to keep in mind the variation in the students participating.

This project has also shown me the value of stepping back and planning how I teach with a larger view in mind. Finding the extra time to think about how to teach something as opposed to just what to do during a given class period is challenging at times but critical. Teaching colleagues are a wonderful resource and support system for finding new ways to approach yearly curriculum topics. I hope to share the results of my research with the other chemistry teachers at my school. For the past several years, we have not been very deliberate or consistent about sharing teaching ideas. Because I am somewhat more reserved and have less teaching experience than my colleagues, I have been somewhat hesitant to begin these critical conversations. However, I hope that sharing the results of this project with my colleagues will serve as a starting point to renew those conversations, and therefore improve all of our teaching.

Just as the preunit assessments and the intervention units pushed my students out of their comfort zones and encouraged them to take risks, this project pushed me to be more communicative with my students about their learning, and to open myself to honest feedback from my students. As I interviewed individual students, or discussed this project informally with my students, we had great conversations about learning. Ultimately, education is about the collaboration of students and teachers in the learning process. Feedback between students and teachers about the learning process is just as important as understanding the chemistry concepts. This communication helps to better fit the teaching and learning. It also helps the students to become more metacognitive and to take more ownership of their learning. Going forward, I hope to continue to increase this level of communication with my students, both informally and formally. Whether I develop new curriculum units according to the 5E model, or explore other techniques, I will strive to develop a partnership in learning with my students.

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APPENDICES

APPENDIX A

NONINTERVENTION PRECIPITATION LAB

Precipitation Lab

Prelab: List the products that would form when each pair of compounds reacts. Then using the solubility rules and tables, identify if either product would form a precipitate. ***Circle the products that you expect will form precipitates.***

Set 1

	$MgCl_2$	Na_2SO_4	NaOH	$BaCl_2$	$MgSO_4$
KCl					
$MgCl_2$	X				
Na_2SO_4	X	X			
NaOH	X	X	X		
$BaCl_2$	X	X	X	X	

Set 2

	$Mg(NO_3)_2$	Na_2CrO_4	$Al_2(SO_4)_3$	K_2CrO_4	$AgNO_3$
$BaCl_2$					
$Mg(NO_3)_2$	X				
Na_2CrO_4	X	X			
$Al_2(SO_4)_3$	X	X	X		
K_2CrO_4	X	X	X	X	

For each set of aqueous ionic compounds that form a precipitate when mixed write

1) The complete balanced equation. (include states of each species)
2) The complete ionic equation. (include states of each species)
3) The net ionic equation. (include states of each species)
4) Your observations of the result of the reaction.

This lab was developed from Addison-Wesley's *Chemistry Laboratory Manual*, copyright 1987.

APPENDIX B

ENGAGE INTERVENTION UNIT 1

BALLOON RACE

Balloon Race

Five balloons containing 1, 3, 5, 7, and 9 grams of baking soda ($NaHCO_3$) are attached to the mouths of Erlenmeyer flasks, each containing 100 milliliters of vinegar ($HC_2H_3O_2$).

Write the balanced chemical equation for the reaction that will take place when the baking soda is tipped into the vinegar.

What do you think will happen to the balloons? Explain your prediction.

This activity was developed from Guenther (2007).

APPENDIX C

EVALUATE INTERVENTION UNIT 1

DECOMPOSITION OF BAKING SODA

Decomposition of Baking Soda

In the Decomposition of Baking Soda performance assessment, students decompose a small sample of baking soda by heating it in a crucible. Based on measurements of mass of the sample in the crucible before and after heating, they complete stoichiometric calculations and choose the reaction that represents the thermal decomposition of baking soda.

Possible reactions for the thermal decomposition of baking soda:

A. Sodium bicarbonate decomposes into sodium hydroxide and carbon dioxide

B. Sodium bicarbonate decomposes into sodium oxide, carbon dioxide, and water

C. Sodium bicarbonate decomposes into sodium carbonate, carbon dioxide and water

This lab was developed based on Figueira (1988) and McCamish (1987).

APPENDIX D

EVALUATE INTERVENTION UNIT 1

SIMULATED AIR BAG CONSTRUCTION

Lab Problem: Simulated Airbag Construction

In the Simulated Airbag Construction performance assessment, students simulate the construction of an automobile airbag using a Ziploc bag, baking soda and vinegar. Using stoichiometry, students determine the quantities of baking soda and vinegar required to exactly fill the sealed Ziploc bag with carbon dioxide gas. Students are assessed based on the quality and accuracy of their calculations, as well as how fully the bag inflates.

This lab was developed by SPS chemistry teacher, Ellen Bryan.

APPENDIX E

EXPLORE INTERVENTION UNIT 2

INVESTIGATION OF BEHAVIOR OF GASES

Investigation of Behavior of Gasses

Investigations conducted with Vernier LabPro, Gas Pressure Sensor, Temperature Probe, and LoggerPro software.

Pressure and Volume

What is the independent variable?

What is constant in the experiment?

What is the dependent variable?

Describe the shape of your graph of pressure vs. volume.

Based on the graph, what is the relationship between pressure and the volume of a set amount of gas?

Write an equation to express the mathematical relationship between pressure and volume.

If you halve the volume, what will happen to the pressure of the gas?

If you triple the volume, what will happen to the pressure of the gas?

Pressure and Temperature

What is the independent variable?

What is constant in the experiment?

What is the dependent variable?

Describe the shape of your graph of pressure vs. temperature (in Kelvin).

Based on the graph, what is the relationship between pressure and the temperature of a set amount of gas?

Write an equation to express the mathematical relationship between pressure and temperature.

If you halve the Kelvin temperature, what will happen to the pressure of the gas?

If you triple the Kelvin temperature, what will happen to the pressure of the gas?

At what Kelvin temperature will the gas exert no pressure on walls of the flask?

Volume and Temperature

Watch the following YouTube video (MIT Physics Demo – Balloons in Liquid Nitrogen) and then answer the following questions.

http://www.youtube.com/watch?v=ZvrJgGhnmJo

What is the independent variable?

What is constant in the experiment?

What is the dependent variable?

What happens to the volume of the balloon when the temperature increases?

What happens to the volume of the balloon when the temperature decreases?

Based on your observations of the balloon in various conditions, what is the relationship between volume and temperature of a set amount of gas?

Write an equation to express the mathematical relationship between volume and temperature.

APPENDIX F

EVALUATE INTERVENTION UNIT 2

DETERMINATION OF THE MOLAR MASS OF MAGNESIUM

Determination of the Molar Mass of Magnesium

In this performance assessment, students react a known quantity of magnesium ribbon with hydrochloric acid in a gas collection tube. The volume of hydrogen gas generated by the single replacement reaction is measured, as well as the temperature and pressure in the room, and the difference in pressure between the room and the gas collection tube. Through a series of stoichiometry and gas law calculations, students determine an experimental value for the molar mass of magnesium and compare their value to the accepted value. They explain experimental sources of error that cause the calculated value of the molar mass of magnesium to deviate from the accepted value.

This lab was developed based on Flinn Scientific, Inc. (2003).

APPENDIX G

STUDENT ASSESSMENTS

Group: ________

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

Nonintervention Unit (chemical reactions)

1) Identify the reactants and products in the following chemical equation:
   $Mg + O_2 \rightarrow MgO$
2) Balance the following chemical equation: $KClO_3 \rightarrow KCl + O_2$
3) Identify the type of reaction: $CH_4 + O_2 \rightarrow CO_2 + H_2O$
4) Complete and balance the following chemical equation: $Mg + HBr \rightarrow$
5) Complete and balance the following chemical equation, and identify the states of all substances: $Ca(NO_3)_2 + K_2CO_3 \rightarrow$

Intervention Unit 1 (stoichiometry)

Given the following chemical reaction $2\ H_2 + O_2 \rightarrow 2\ H_2O$

1) What is a mole ratio in a chemical equation?
2) Define the term limiting reactant.
3) How many moles of water would be produced when 3.0 moles of oxygen were burned in excess hydrogen? Show your work to explain your answer.
4) How much oxygen would you need to completely burn 2.0 grams of hydrogen? Show your work to explain your answer.
5) If 4.0 moles of H_2 were burned in 3.0 moles of O_2, how many grams of H_2O would be produced? Show your work to explain your answer.

Intervention Unit 2 (states of matter and gas laws)

1) Describe what happens to a substance as it changes from a liquid to a gas?
2) Could you get water to boil at 50 degrees Celsius? Explain.
3) What causes gas pressure?
4) If you squeeze a sample of gas into a smaller volume, while maintaining a constant temperature, what happens to the pressure the gas exerts? Explain.
5) If you put a balloon in your car on a hot summer day, what might happen to it? Explain.

APPENDIX H

STUDENT SURVEY

Group _____

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

For each of the following statements, please select the best response, and explain your choice. (SD = Strongly Disagree, D = Disagree, N = Neither Agree nor Disagree, A = Agree, SA = Strongly Agree)

1) I enjoy going to chemistry class.

SD D N A SA

Explain

2) This class keeps me engaged and interested.

SD D N A SA

Explain

3) I am curious about the concepts we are studying.

SD D N A SA

Explain

4) I am confident in my understanding of the material we studied in this unit.

SD D N A SA

Explain

5) If I were given a quiz on the previous unit today, I would be able to earn a good grade.

SD D N A SA

Explain

6) The teaching style (5E method for intervention units) keeps me interested in chemistry.

SD D N A SA

Explain

7) The teaching style (5E method for intervention units) is effective in helping me learn.

SD D N A SA

Explain

8) What class activities help you learn the most? Explain.

9) What class activities keep your interest the most? Explain.

10) What did you enjoy most about this unit? Explain.

11) What did you find most frustrating about this unit? Explain.

12) Is there anything else you would like to tell me about the work you did in class during this unit?

APPENDIX I

STUDENT CONCEPT INTERVIEWS

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

Please think out loud as you create a concept map using the following terms. You can add additional terms and give examples as you see fit. The linking phrases that you use between each of the terms is also important to making the map

Nonintervention Unit (chemical reactions)

Balanced chemical equation, reactant, product, coefficient, moles, Law of Conservation of Mass, combination reaction, decomposition reaction, single replacement reaction, double replacement reaction, combustion reaction

Intervention Unit 1 (stoichiometry)

Mole ratio, balanced chemical equation, limiting reactant, excess reactant, product, theoretical yield, experimental yield.

Intervention Unit 2 (states of matter and gas laws)

Solid, liquid, gas, vapor pressure, pressure, temperature, volume, phase change, kinetic energy, evaporation

APPENDIX J

WEEKLY TEACHER JOURNAL PROMPTS

1) Students were excited about class this week. Explain.

SD	D	N	A	SA

Explain

2) Students were enthusiastic participants in class this week. Explain.

SD	D	N	A	SA

Explain

3) What did students complain about this week? Explain
4) What positive comments did students make this week? Explain
5) What was the most satisfying aspect of class this week? Explain
6) What was the most frustrating aspect of class this week? Explain
7) How did students react to the teaching style (traditional or 5E method) this week? Explain

APPENDIX K

OBSERVER FEEDBACK FORM

Date: ____________ Time: ____________ Observer:__________________

Please describe the flow of class activities

Beginning	Middle	End

For each of the following, please select the best response for the class as a whole, and for a specific high, middle, and low achieving student. (SD = Strongly Disagree, D = Disagree, N = Neither Agree nor Disagree, A = Agree, SA = Strongly Agree) Explain your responses.

1) Students were attentive and on task for the majority of the class.

Class	SD	D	N	A	SA
High	SD	D	N	A	SA
Middle	SD	D	N	A	SA
Low	SD	D	N	A	SA

Explain

2) Students had a positive attitude in class.

Class	SD	D	N	A	SA
High	SD	D	N	A	SA
Middle	SD	D	N	A	SA
Low	SD	D	N	A	SA

Explain

3) Students were curious about the class topic.

Class	SD	D	N	A	SA
High	SD	D	N	A	SA
Middle	SD	D	N	A	SA

Low	SD	D	N	A	SA

Explain

4) Students asked questions that applied to the class topic.

Class	SD	D	N	A	SA
High	SD	D	N	A	SA
Middle	SD	D	N	A	SA
Low	SD	D	N	A	SA

Explain

5) The teacher seemed enthusiastic about the class.

	SD	D	N	A	SA

Explain

What was the best part of the class? Explain.

What could be improved about this class? Explain.

APPENDIX L

TEACHER SURVEY

1) Students were attentive and on task.

SD D N A SA

Explain

2) Students had a positive attitude in class.

SD D N A SA

Explain

3) Students were curious about the class topic.

SD D N A SA

Explain

4) Students asked questions that applied to the class topic.

SD D N A SA

Explain

5) I look forward to planning class in this style (traditional or 5E method).

SD D N A SA

Explain

6) I look forward to going to class.

SD D N A SA

Explain

7) I am excited about the learning that is occurring in my classroom.

SD D N A SA

Explain

APPENDIX M

PROJECT TIMELINE

Dates	Class Plan	Data Collection Instruments
Nonintervention Unit: Chemical Reactions		
Fri January 4 Sat January 5	Practice balancing chemical equations and identifying types of chemical reactions	Nonintervention preunit assessment and student concept interviews
Mon January 7	Predicting products of single and double replacement reactions; demonstrations of reactions	Nonintervention colleague observation
Tues January 8	Predicting products of combination and decomposition reactions; demonstrations of reactions	
Wed January 9 Thurs January 10	Recycling of Copper Lab	
Fri January 11 Sat January 12	Finish Recycling of Copper Lab	Teacher journaling with prompts
Mon January 14	Worksheet predicting products of chemical reactions and identifying type or reaction	
Tues January 15	Writing net ionic equations for double replacement reactions	
Wed January 16 Thurs January 17	Precipitation Lab	Nonintervention student and teacher survey
Fri January 18 Sat January 19	Write equations for precipitation lab	Teacher journaling with prompts Student concept interviews (postunit nonintervention and preintervention 1)
Intervention Unit 1: Stoichiometry		
Tues January 22	*Engage:* stoichiometry balloon race	Preintervention 1 assessment
Wed January 23 Thurs January 24	Chapter 11 Test	Postunit questions included in assessment
Fri January 25 (No Saturday)	*Explore:* Michigan Stoichiometry Lab	Teacher journaling with prompts
Mon January 28	*Explore:* S'mores problem *Explain:* student explanation, then direct teaching of mole ratios and solving stoichiometry problems	Intervention 1 colleague observation

Tues January 29	*Elaborate:* Michigan Stoichiometry Lab calculations and additional practice problems	
Wed January 30 Thurs January 31	*Explore:* S'mores problem *Explain:* student explanation, then direct teaching of limiting and excess reactant problems.	
Fri February 1 (B)	*Evaluate:* Decomposition of baking soda performance assessment	Teacher journaling with prompts
Tues February 5	*Elaborate:* Calculations of limiting and excess reactants in the balloon race demonstration and additional practice problems	Delayed nonintervention assessment
Wed February 6 (B)	*Evaluate:* Air Bag Lab performance assessment	
Thu February 7 (A)	*Evaluate:* Decomposition of baking soda performance assessment	
Fri February 8 (B)		Teacher journaling with prompts Student concept interviews (delayed nonintervention, postintervention 1, preintervention 2)
Sat February 9 (A)	*Evaluate:* Air Bag Lab performance assessment	Student concept interviews (delayed nonintervention, postintervention 1, preintervention 2)
Mon February 11	Chapter 12 Test	Postintervention 1 questions included in assessment
Intervention Unit 2: States of Matter and Gas Laws		
Tues February 12	*Engage:* Boiling at room temperature and triple point of water demonstrations	Preintervention 2 assessment
Wed February 13 Thurs February 14	*Explore:* freezing and melting of water lab; phase diagram of H_2O with questions	
Fri February 15 Sat February 16	*Explore:* vocabulary definitions	
Tues February 19	*Explain and Elaborate:* states of matter demonstrations	Intervention 2 colleague observation
Wed February 20	*Explore:* gas law investigation	

Thurs February 21		
Fri February 22 Sat February 23	*Explain:* students present findings of gas law investigation; direct instruction of gas law equations	Teacher journaling with prompts Intervention student and teacher surveys
Mon February 25	*Elaborate:* practice problems with gas laws	Delayed intervention 1 assessment
Tues February 26 Wed February 27	*Evaluate:* Molar Mass of Magnesium performance assessment	Student concept interviews (delayed intervention 1, postunit intervention 2)
Thurs February 28 Friday March 1	Chapters 13 and 14 Test	Postunit questions included in assessment Teacher journaling with prompts
SPS vacation March 2 to March 25		
Monday March 25		Delayed intervention 2 assessment and student survey Begin delayed intervention 2 student concept interviews