

TRACING MATTER AND ENERGY IN THE HIGH SCHOOL
CHEMISTRY CLASSROOM

by

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ABSTRACT

The purpose of my project was to improve students' understanding of matter at an atomic and molecular level and better address how energy flows during chemical changes. This action research project was administered to 3 honors chemistry classes consisting of 74 students. Within a chemical bonding unit, I incorporated an additional learning target on bonding energetics. In order to provide a more comprehensive, complete understanding of energy during chemical bonding, I studied the impact of additional energy instruction involving energy diagrams and energy conservation during different reaction types. Also incorporated were lab activities where students first model bond energy and then apply these concepts during a series of chemical reactions. In order to evaluate the effectiveness of this intervention, a pre- and post-unit assessment probed student understanding of carbon-transforming processes, a pre- and post-unit survey collected data on student attitudes, student interviews collected in-depth verbal feedback, and instructor field observations made qualitative observations throughout the unit. The results of this study show how students are clearly able to distinguish between matter and energy in explaining the effects of chemical reactions, explain how matter and energy are conserved, and explain the results of bonding energetics on the energy change that occurs within a chemical system.

INTRODUCTION AND BACKGROUND

Over the past eight years, I have had a position teaching a variety of science subjects for grades 9-12, including 9th grade physical science, 10th grade biology, 11th grade chemistry, and 12th grade physics. As a science department at DeForest Area High School, we have aligned our curriculum across these courses, considering the scope and sequence of content standards to construct a coherent, relevant curriculum as we work to adopt the Next Generation Science Standards (NGSS). I have had the unique opportunity to teach some of the same students in multiple courses, so I have been able to see their conceptual development in terms of understanding matter and energy. I have observed some persistent misconceptions and misunderstandings involving concepts of matter and energy; in addition, students demonstrate difficulty applying these concepts to new phenomena or across science subject areas. The focus of my action research included incorporating new tools and instructional methods that assist students in a deeper, more integrated comprehension of matter and energy.

DeForest Area High School, in DeForest, WI, is a public school consisting of 9th-12th grades located in a suburban community just outside of Madison, WI. According to the Wisconsin Department of Public Instruction, the student body is composed of 1,033 students containing the following ethnicities: White (83.5%), Hispanic (5.3%), Black or African American (4.3%), two or more Races (3.1%), and American Indian or Alaskan Native (.3%); in terms of student groups, 7.4% are students with disabilities, 16.7% are economically disadvantaged, and 1.1% have limited English proficiency (2017). My class schedule for 2017-2018 included 3 classes of Honors Chemistry and two classes of

Physics. I used my Honors Chemistry classes for my action research; this consisted of 74 students total.

The purpose of my action research was to improve students' understanding of matter at an atomic and molecular level, and I wanted to better address how energy flows during chemical changes. To accomplish these goals, I incorporated tools to help students trace matter and energy during a chemical reaction. I investigated the following focus question: What are the effects of tracing matter and energy on student understanding of chemistry? I also studied the following sub-questions: how does incorporating energy into a chemical bonding unit affect student understanding of energy in chemical reactions and how does the use of tools that allow students to trace matter and energy changes affect their understanding of the laws of conservation of matter and energy?

CONCEPTUAL FRAMEWORK

Current science curriculum, instructional practices, and assessments are largely being guided by the Next Generation Science Standards (NGSS). While not yet universally adopted, the NGSS (2013) were recently developed to closely follow *A Framework for K-12 Science Instruction*, which identifies core ideas within each science subject area as well as learning progressions at each “grade-band.” Chemistry, which falls under the discipline of physical science, incorporates core ideas including Matter and its Interactions and Energy. However, matter and energy are not only seen as Disciplinary Core Ideas (DCIs), but are also used as a Crosscutting Concept which broaches other disciplines, notably the life sciences. The Energy and Matter Crosscutting Concept requires that students understand the following: “changes of energy and matter in a

system can be described in terms of energy and matter flows into, out of, and within that system” and that “energy cannot be created or destroyed—it only moves between one place and another place, between objects and/or fields, or between systems” (NGSS Lead States, 2013).

While the NGSS are a relatively new addition to the United States academic standards, they represent the advancement of previous standards based on additional educational research as well as scientific progress. The background for the development of the NGSS has stemmed from the evolution of documents from both the National Resource Council, which created the *National Science Education Standards*, and the American Association for the Advancement of Science, which released the *Benchmarks for Science Literacy* and the *Atlas for Science Literacy* (NGSS Lead States, 2013).

A large body of research exists from the past couple of decades investigating student comprehension and learning progressions relating to matter and energy. Across a range of study methods, age groups, and all of the aforementioned science education standards, the research is unanimous on the difficulty students have applying the concepts of matter and energy to advanced situations. Most recently, the National Assessment of Educational Progress (NAEP) created a 2015 framework, modeled largely off of *The National Science Education Standards* and *Benchmark for Science Literacy*, to assess students across the nation on scientific literacy. In terms of assessing student learning progression, students at the 8th grade level are *Advanced* if they can “explain changes of state in terms of energy flow” and “trace matter and energy through living systems at multiple scales.” Students in 12th grade are *Basic* if they understand “transformations of

matter and energy in physical, Earth, and living systems,” *Proficient* if they understand “conservation laws” and “chemical mechanisms for metabolism, growth, and reproduction,” and *Advanced* if they can “explain differences among physical, chemical, and nuclear changes” and explain the “paths of specific elements through living systems” (U.S. Department of Education, 2015). These levels of comprehension are reasonable and based on research-based matter and energy learning progressions; however, recent NAEP results indicate that most students do not fully comprehend matter and energy based on their levels of achievement. According to the Nation’s Report Card, reporting NAEP Results, in 2015 2% of 8th grade students scored *Advanced*. For 12th graders, 38% scored *Basic*, 20% scored *Proficient*, and 2% scored *Advanced*. While assessing all aspects of science literacy, these results indicate that by 8th grade, students are unlikely to be able to trace matter and energy through physical and chemical changes, and by 12th grade a majority of students still may be unable to apply the conservation laws or trace matter and energy through more advanced processes (U.S. Department of Education, 2015).

While the NAEP results are generic to all science literacy skills, a body of current research compares learning progressions inherent in the academic standards to actual student achievement on matter and energy in order to determine if these progressions are accurate and appropriate for the age level. Liu’s (2006) findings, using the United States’ data from the Third International Mathematics and Science Study (TIMSS), “suggest that, while the National Science Education Standards are in general reasonable, the Benchmarks and Atlas for Science Literacy may have overestimated the abilities of

elementary, middle school, and high school students” (p. 15). Liu provides specific examples of these findings:

Our study found that 7th graders may understand physical properties and changes, they may not be able to understand chemical properties and changes; although 8th graders may understand chemical properties and changes, they may not be able to understand the particulate model of chemical change. For high school students, our study suggests that chemistry specialization students may be able to understand the kinetic and atomic models of chemical and physical changes; it remains doubtful whether or not they can understand theories about bonding. For nonchemistry specialization students, it may be unrealistic to expect them to understand the particulate theory of matter (p. 15).

Learning progressions research has additional input to offer on student comprehension. As it relates to carbon-transforming processes, including combustion, respiration, and photosynthesis, Parker (2014) found that generally only about 10% of American high school students can successfully account for the conservation of matter and energy in their explanations.

Recently, there is additional calling for improvement on these types of skills for our college students; the 2011 Vision and Change Report (American Association for the Advancement of Science), addressing core concepts that all undergraduate students should develop, included “Pathways and Transformations of Energy and Matter” (p. 31). The authors of this report describe this core concept as “principles of thermodynamics” which requires that all college students understand how “the laws of physics and chemistry” underlie biological processes. However, research shows that college undergraduate students demonstrate the same difficulties tracing matter and energy through chemical changes as 12th graders did. Based on surveys from first year college students enrolled in Chemistry, Nimmermark (2006) found the following:

Based on our findings we can assume that only about 20% of the first year students that university lecturers and instructors meet have a clear grasp of the concept of bond energetics. Most students confuse individual bond formation/breaking with exo- and endothermic processes, probably due to the use of examples such as the exothermic formation of solid sodium chloride from its elements as an example for teaching bond formation and breaking (p. 17).

Additionally, in studying students from undergraduate biology courses, Wilson (2006) found that students failed to account for the law of conservation of mass in explaining biological processes such as plant growth, claiming that “students are not approaching the question with a desire to explain the source of carbon, hydrogen, and oxygen molecules that make up the biomass of a plant” (p. 8). Arguing that the inability to trace matter and energy originates at a younger age, Wilson writes “findings at the K–12 level illustrate that students are rarely progressing to the undergraduate level with a set of sensemaking strategies that can be applied across a range of systems. Our results certainly confirm this to be the case” (p. 8).

The inability to trace matter and energy has been well documented by researchers, but there are strategies that have proven effective at improving these skills. Dauer (2014) claims that “the core of the problem is that students lack a systems view of the natural world that incorporates a model of matter and energy at the atomic–molecular scale” (p. 398). Based on research utilizing practices driven by the NGSS, Dauer’s group found success when students “were able to apply the rules of conservation of mass and atomic–molecular theory when investigations provided scaffolding that allowed them to trace matter more successfully” (p. 407); this scaffolding was based largely off of teacher instruction on “foundational understandings about matter and energy” (p. 407).

In the book *Teaching and Learning of Energy in K-12 Education*, Dauer's group (2014) offers specific challenges which must be overcome, based on learning progression research for successfully teaching about tracing matter and energy in "carbon-transforming processes:"

1. Understanding the purpose of the concept of energy
2. Identifying forms of energy in living systems
3. Tracing energy separately from matter (p. 50).

Due to its abstract and various nature, energy is difficult for students to comprehend. While Dauer's group recognizes that challenges exist in applying energy to situations involving biological systems, these challenges translate to non-living systems as well. Swackhamer (2005) makes the sentiment that energy "is now ubiquitous in school science curricula worldwide and regarded as of first importance universally by scientists and educators alike. Nonetheless, energy is not well understood by our students. Students graduating from secondary schools generally cannot use energy to describe or explain even basic, everyday phenomena" (p. 1). Swackhamer's input on understanding energy requires tracking energy within all types of systems based on the following guiding statements:

1. As an attribute, energy is viewed as a possession that can be "stored" or "contained" in a "container," namely, a physical system.
2. Energy can "flow" or be "transferred" from one container to another and so cause changes.
3. Energy maintains its identity after being transferred (p. 10).

Swackhamer advocates for developing "system schema" that students can then use to trace energy flows from one system to another. This method of modeling energy builds

on the necessity to conserve energy even while it is transferred between systems, and fits the instructional scaffolding recommended by Dauer--for energy foundations in this case.

Calling for a “systems view of the natural world that incorporates a model of matter and energy at the atomic–molecular scale” (Dauer, p. 398) is one method of improving student comprehension of matter and energy through instruction. Within educational research there is also a calling for more interdisciplinary and integrated approaches to teaching matter and energy. Stevens (2010) found that:

In order for students to develop conceptual understanding of complex ideas such as the model of atomic structure and how atoms and molecules interact, they must experience a curriculum that coherently supports their learning over several years ...Learning progressions (LPs) provide a promising means of organizing and aligning the science content, instruction and assessment strategies to provide students with the opportunity to develop deep and integrated understanding of a relatively small set of big ideas of science over an extended period of time (p. 2).

Written several years before its publication, this method of teaching matter and energy is now largely reflected in the NGSS crosscutting concepts mentioned earlier.

Studies have shown that comprehension of bond energetics is an especially troublesome concept; Cooper (2013) reflects that this difficulty is a result of the overall haphazard way that energy is taught in different disciplines, incoherently rather than as a unifying, crosscutting concept: “among different disciplines, the concept of energy is treated in ways that are quite discipline specific and often not obviously compatible” (p. 306). Cooper focuses on the difficult concepts of chemical energy and the energetics of breaking and forming chemical bonds. Misconceptions arise in biology due to the concept of chemical energy held within certain macromolecules: “because sugar is broken down during metabolism, and energy is released, it is a simple (and logical) step

to arrive at the incorrect conclusion that the energy resides within the bonds that are broken, rather than at the more abstract idea that the energy is released when more stable bonds are formed” (p. 308). Cooper contrasts this to physics curricula that generally only cover energy on the macroscopic scale; and then in chemistry it is taught at a macroscopic scale during the thermodynamics unit and then in an entirely different microscopic manner during the bonding unit. Cooper reflects that “it is important to note that the thermodynamic presentation of energy is discussed as thermal energy, heat, or enthalpy, while energy changes at the atomic level...are discussed in terms of potential energy and are often never explicitly reconciled” (p. 308). Cooper concludes that “what is clear from examining student responses is that the common traditional instruction sequence does not produce a coherent understanding of energy changes when chemical or physical changes occur” (p. 309). In a call for cross-curricular change, Cooper argues:

Simply put, we (biologists, physicists, and chemists) are not providing a coherent pathway for most students to develop a usable understanding of energy, particularly at the atomic–molecular level. We are failing our students by not making explicit connections among the way energy is treated in physics, chemistry, and biology. We cannot hope to make energy a cross-cutting idea or a unifying theme until substantive changes are made to all our curricula (p. 309).

In chemistry, part of this change requires teaching energy at the atomic-molecular scale in addition to the macroscopic scale, teaching energy in multiple contexts rather than in just an energy unit, and employing systems-based reasoning (Cooper, 2013). According to Cooper, a new approach to teaching bond energetics is that “our approach to bond energies and thermochemistry is to emphasize that energy is stored in a system of molecules (rather than in a particular molecule)” (p. 310-311); these ideas constitute the reform necessary for students to truly comprehend the interdisciplinary nature of energy

as a unifying concept as they attempt to “bridge the macroscopic–molecular gap that is so problematic” (p. 311). Figure 1 exemplifies how energy is stored within a system of molecules rather than within a particular molecule such as methane.

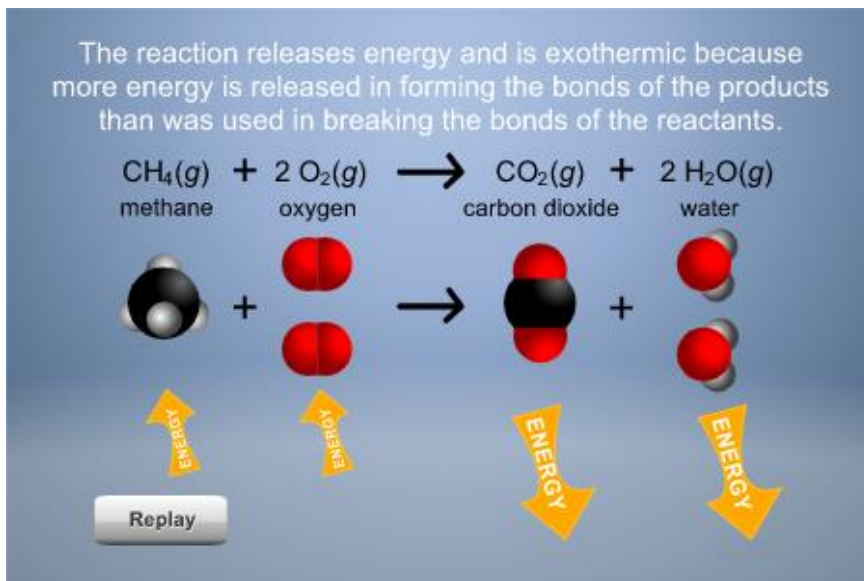


Figure 1. A System of Molecules Demonstrating an Exothermic Reaction (American Chemical Society, 2018).

In planning the scope and sequence of matter instruction across multiple disciplines, Liu’s (2006) findings can help guide curriculum development:

Our findings suggest that matter concept development is not a simple linear progression as suggested by the reform documents (AAAS, 1993, 2001; NRC, 1996). It requires the coordination among the four aspects of matter: composition and structure, conservation, chemical properties and change, and physical properties and change. Careful planning for the coordination of the scope and sequence of these matter concepts is critical to enable students to make connections among them and develop various models to represent, explain, and finally predict various changes involving matter (p. 448).

It is important to ensure that when planning curricula across the science disciplines, specific components of matter and energy instruction follow research-based, age-appropriate learning progressions. In a chemistry curriculum, Liu found that this means cycling between a macroscopic substance-based study of matter, the atomic scale,

and changes within chemical reactions. In addition, Liu's (2006) study "clearly demonstrates that for any given grade, we should always anticipate a large variation of competence in students on understanding matter. Therefore, differentiated curriculum and instruction is necessary for a given grade level" (p. 16).

In seeking additional strategies for enriching student comprehension of matter and energy in the digital age, Aydeniz (2012) recommends utilizing computer programs that "visualize the behavior of atoms and molecules related to the particulate nature of matter both at the macroscopic and microscopic levels" (p. 6). Aydeniz suggests that "science teachers may also benefit from assessment strategies such as the use of metaconceptual questions to identify and address students' misconceptions during instruction" (p. 6). In further reflection on assessment, Liu (2006) questions whether quantitative investigation of student matter comprehension may underestimate student comprehension and recommends more qualitative methods such as interviews to investigate student understandings and misunderstandings. Wilson (2006) advocates for qualitative application questioning strategies as well, toting them as:

...necessary tools in helping students progress from being memorizers of elaborate and detailed narrative accounts to being analyzers and pattern finders. We encourage other researchers and instructors to use simple questions such as ours to distinguish between students who are unaware of basic principles from those who are unable to apply them (p. 330).

In conclusion, the study of matter and energy is now seen within science curricula content standards as a cross-cutting concept that serves as a unifying theme throughout the scientific disciplines. Studies of student learning progressions of matter and energy show that these concepts are multi-faceted, follow a non-linear progression, and are

generally widely misunderstood or misapplied within the K-12 and college undergraduate levels. Curricular revisions are being called for and newly revised national education standards reflect these changes; this will mean school districts must revise their curricular scope and sequence across multiple levels and content disciplines. There are numerous instructional practices for matter and energy which show promise, including scaffolding of explicit matter and energy fundamentals, modeling matter and energy using a systems-based view on both microscopic and macroscopic scales, revisions to teaching chemical bond energetics, and overall using more integrated and interdisciplinary approaches to energy instruction.

METHODOLOGY

The purpose of my action research was to investigate the effects of intervention requiring students to trace matter and energy during chemical changes. Research was conducted at the beginning of second semester honors chemistry during our extensive unit on chemical bonding. Intervention for my classroom research project consisted of more extensive coverage of energy within this bonding unit. In the past, we have taught energy during our thermodynamics unit during first semester but done little else with it for the rest of the year.

The Methodology for this project has been approved by the MSU Institutional Review Board (Appendix A).

Participants

I utilized my intervention on 3 classes of honors chemistry students consisting of 74 students total. In terms of demographics, these classes were composed of 33 male

and 41 female students. While this is an elective course open to all students, the course recommendation is that students have received a B or better in the previous biology course; most students intend to pursue a college degree, many plan to pursue a degree in a science or medical field.

Intervention

I investigated the effects of intervention requiring students to account for matter and energy during chemical changes; this included additional energy instruction and resources within the context of chemical bonding. For data comparison purposes, I have data from the previous year, since I have given the Tracing Matter and Energy Assessment to past students. The previous year's results are used as the Comparison Group in order to determine the effectiveness of the intervention on the current year's Intervention Group.

Intervention for my action research consisted of adding the following learning target to our Bonding Unit: I am able to determine whether a reaction is endothermic or exothermic based on the bond energies of reactants and products (Appendix B). More explicit instruction on tracing matter and energy during a chemical change involved using energy diagrams and explanations for how the conservation laws apply during different reaction types. This instruction focused on energy involved in chemical bonding—this is a very difficult concept for students to grasp. In order to do this, I found a POGIL activity on bond energy which fit appropriately into this unit's curriculum. I also added to our chemical reaction types lab so that students reviewed and applied endothermic and exothermic reactions and bond energetics to a hands-on lab experience (Appendix C).

This additional lab experience allowed students to compare obvious endo- vs. exothermic reactions by mixing combinations of citric acid and sodium bicarbonate as well as calcium chloride and sodium bicarbonate. Students subsequently compared the reactions by tracking the temperature changes and observing how the reactions felt to the observer. Finally, additional material was added to the curriculum to connect the biological processes of photosynthesis and combustion to chemical reaction types and bond energy (Appendix D).

Data Collection

Table 1 summarizes the data collection matrix for this project. For my data pre- and post-assessment tool, I gave the Tracing Matter and Energy Assessment (Appendix E) which included both true and false questions on matter and energy conservation as well as open-ended assessment questions that gathered data on student understanding of matter and energy. These assessment questions related to combustion and to biological processes involving carbon-transformation. In order to determine the effectiveness of this intervention, comparison data was also used from honors chemistry students from the 2016-2017 school year, based on the Tracing Matter and Energy Assessment year-end results.

Table 1
Data Triangulation Matrix

Focus Questions	Data Source		
<i>Primary Question:</i> What are the effects of tracing matter and energy on student understanding of chemistry?	Pre- and Post-Unit Student Assessments	Pre and Post-Unit Student Interviews	Pre- and Post-Unit Student Surveys
<i>Sub-question 1:</i> How does incorporating energy into a chemical bonding unit affect student understanding of energy in chemical reactions?	Pre- and Post-Unit Student Assessments	Pre- and Post-Unit Student Interviews	Instructor Field Observations
<i>Sub-question 2:</i> How does the use of tools that allow students to trace matter and energy changes affect their understanding of the laws of conservation of matter and energy?	Pre- and Post-Unit Student Assessments	Pre- and Post-Unit Student Interviews	Instructor Field Observations

In addition to assessing student understanding, I developed a survey (Appendix F) consisting of Likert scale questions that assessed student attitudes on the chemical bonding unit. This survey consisted of a total of 35 questions designed to elicit student attitudes on a variety of chemistry skills as well as gauge students' personal interests and perceived relevance of chemistry content. These 35 questions were grouped into seven domains in order to better analyze the impact of the interventional unit on student attitudes. The seven domains are listed in Table 2.

Table 2
Chemistry Bonding Unit Survey

Domains	Description of Domain
Atoms and Bonding	Student understanding of atoms bonding to build molecules
Chemical Reaction Basics	Types of chemical reactions; understanding reactants and products in a chemical reaction
Energy of Chemical Reactions	Endothermic vs. exothermic reactions and bond energy
Real Life Relevance of Chemistry	Student perception on the importance of chemistry to everyday life
Personal Interest in Chemistry	Student affinity for learning chemistry
Problem Solving Abilities and Sense-Making	Self-perceptions on the ability to problem solve and correctly complete mathematical and chemistry based skills
Biology Connections	Student understanding of the chemical reactions for photosynthesis and cellular respiration

Following the bonding unit, a set of interview questions (Appendix G) was given to some students in order to gauge individual students' perspectives on the unit and the interventions that were applied. In selecting students for interview, I handpicked eight students total—with at least two students from the following academic grade bands (following the Unit 6 exam, prior to any test retakes): A, B/C, and D/F.

DATA ANALYSIS

This research project investigated the effects of tracing matter and energy on student understanding of chemistry, incorporating energy into a chemical bonding unit and using tools to account for matter and energy conservation. The initial Tracing Matter and Energy Pre-assessment was given at the beginning of second semester and the Unit 6 bonding unit. The Tracing Matter and Energy Post-Assessment was given following the Unit 6 instruction and prescribed interventions.

The results of the Tracing Matter and Energy Assessment are given in Figure 2, including pre- and post-unit assessment data as well as data from the previous year which is used for comparison purposes. When analyzing assessment data, I grouped the data into four categories for comparison based on the layout of the assessment: Conservation of Matter and Energy, Combustion, Photosynthesis, and Cellular Respiration. The comparison group data from the previous year was given during second semester of the 2016-2017 school year following the same bonding unit curriculum, but this group did not receive the intervention utilized in this action research project. In order to determine whether the previous year's students and my current students were comparable populations, a t-test was conducted using an identical stoichiometry exam that is unrelated to the interventional unit. The previous year's students had a mean score of 34.87 and the current students had a mean score of 36.48 out of 41 possible points. The p-value is .096629; the null hypothesis is accepted and the difference in scores is not significant on an unrelated exam based on the t-test.

The initial Tracing Matter and Energy Assessment scores for first semester were generally low (below 50% average) as most students are relatively unfamiliar with the concepts on the Tracing Matter and Energy Assessment at the beginning of the year. During our first semester chemistry curriculum, we covered introductory lessons on all four categories of the assessment: conservation of matter and energy, combustion, photosynthesis, and cellular respiration. However, these concepts were addressed more comprehensively once an introduction to bonding occurred in Unit 6 at the beginning of second semester. The results of the Pre-Assessment administered prior to Unit 6

instruction shows students had some comprehension (68%) on the Conservation of Matter and Energy; these questions were all True/False questions probing whether students can differentiate between the conservation of atoms and energy before and after chemical changes occur. Students showed diminishing understanding on the other categories of assessment, with 58% for combustion, 53% for photosynthesis, and 47% correct on the cellular respiration questions. All three of these categories required students to provide the balanced chemical equations for these processes—a skill that only some students could correctly complete at the beginning of Unit 6.

Based on the Post-Assessment data in Figure 2, students showed consistent gains on all four categories following the intervention, again with higher scores on Conservation of Matter and Energy and Combustion (78% and 77%, respectively) than on photosynthesis and cellular respiration (both with a 68% score). This is as expected, since we covered conservation of matter and energy and combustion extensively in our Unit 6 curriculum and interventions. While part of my intervention included material addressing photosynthesis and cellular respiration, we spent less time on this material; nevertheless, students still had positive gains on their post-assessment data. Another possible explanation for these lower scores is that the questions are relatively open-ended and in a different context than what students saw in class, so it's possible that some students were confused by the assessment questions.

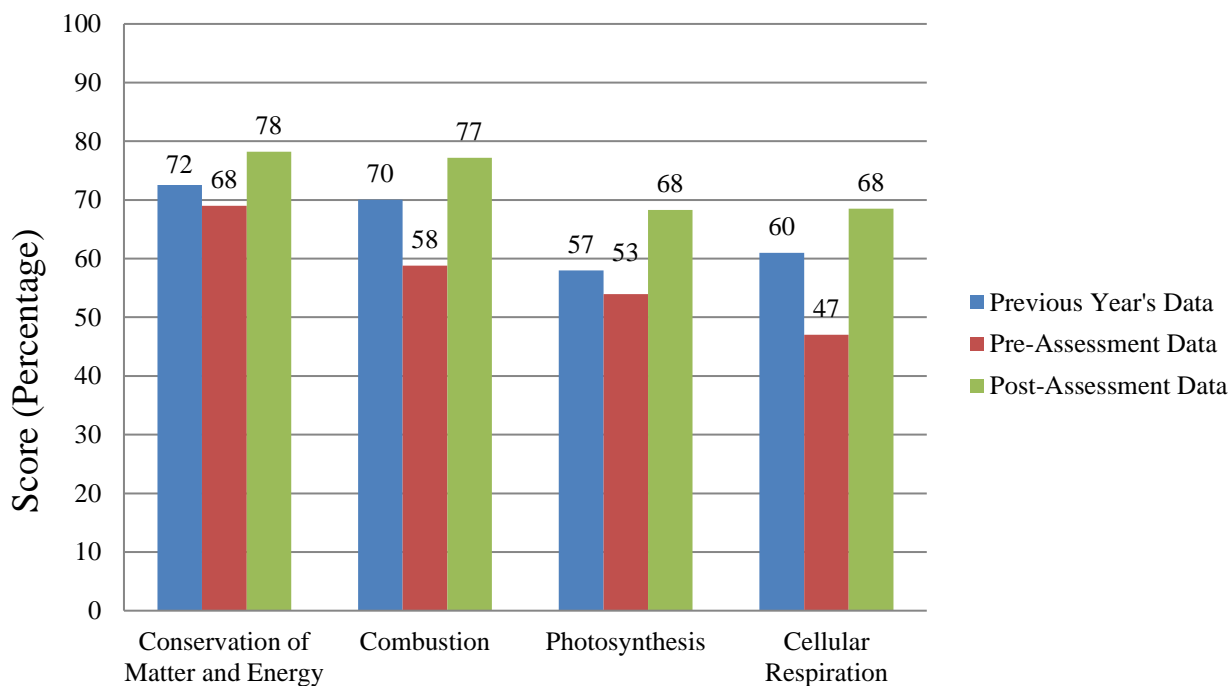


Figure 2. Average scores of comparison group ($N=47$), pre-Assessment ($N=73$) and post-assessment ($N=74$) groups on 4 categories of the tracing matter and energy assessment.

In terms of comparison, students that received the intervention, which are the current honors chemistry students, consistently performed better than the previous year's honors chemistry students which did not receive the intervention. Both groups received the same assessment; the previous year's students covered the same curriculum without the interventions added this year specifically addressing bond energy and the additional focus on the biological connections of photosynthesis and cellular respiration. The mean score for the non-intervention group was 16.33 and the mean score for the intervention group was 18.02 out of a possible 24 points. Despite these apparent gains, a t-test was conducted. The p-score was .067643; based on this score the null hypothesis is accepted, so the resulting gains for the interventional group are not statistically significant.

Students showed increasing comprehension on their short answer post-assessment responses compared to pre-assessment and comparison group data. For example, responses to how energy is produced when octane burns provide critical insight into student comprehension of bond energy as it relates to combustion reactions. One student explained that “energy is added to the system to break intramolecular bonds, then as new bonds form energy is released from the system and new substances are formed.” Another student wrote “when chemical bonds break and reform, especially in exothermic reactions such as combustion, they release energy and heat.” Most students could correctly equate the combustion reaction to an exothermic process, and students were able to correctly discuss the enthalpy change, with some students choosing to draw energy diagrams to support their answers. Even more promising, I began to see responses that I have not seen in the past which included discussion of chemical stability. One student responded: “the energy of C_8H_{12} stored in bonds is released when more stable compounds are formed”—it’s important to note that since technically the chemical system includes O_2 as well (this student did correctly write out the combustion reaction), this detail should also be included in this explanation. Another student explained “the intramolecular bonds are being broken and then reformed; the newly bonded substances are low energy stable states so energy is released.” While further elaboration would be helpful in some cases, it is clear that students are beginning to understand bond energy to a deeper degree than in the past due to the interventional focus on bond energy and energetic of the molecular system.

The Chemistry Bonding Unit Survey was administered concurrently with the Tracing Matter and Energy Assessment. Students eagerly provided feedback on this survey, and the outcome was more positive than what I had initially expected. Generally, the end of the bonding unit is a grueling time of year for students—it is a wintery February or early March in Wisconsin, all Wisconsin high school juniors are required to take the ACT which is draining on the students mentally, and spring break is usually several weeks away. At this point in the year, students generally lose their excitement for challenging chemistry concepts, and many start to grumble and complain. This year was no different; in fact, due to the interventions on bond energy, Unit 6 became even more challenging and slightly longer than before. For these reasons, I was very interested to see student responses to the survey in order to determine the impact of the bonding unit on student attitudes and morale.

As shown by the survey results in Figures 3 and 4, in all seven domains students become more positive on the Chemical Bonding Survey--agreeable responses on average followed the intervention. I had incorrectly anticipated that the student surveys would drop in agreeable responses, since it usually seems as though students are caught off-guard by the demands and challenges of second semester chemistry, starting with the bonding unit and continuing with the mole units and stoichiometry. The one domain from the survey that really stands out is Energy of Chemical Reactions. Students self-perceive that they have the greatest abilities in this category, with a surprising 62% average response of strongly agreeing to questions which included: “I can explain how energy is involved in the breaking and forming of bonds” (Figure 5), “I can identify the difference

between an endothermic and exothermic reaction based on bond energies” (Figure 6), and “in chemistry lab, I can easily identify an endothermic and exothermic reaction based on how it feels” (Figure 7).

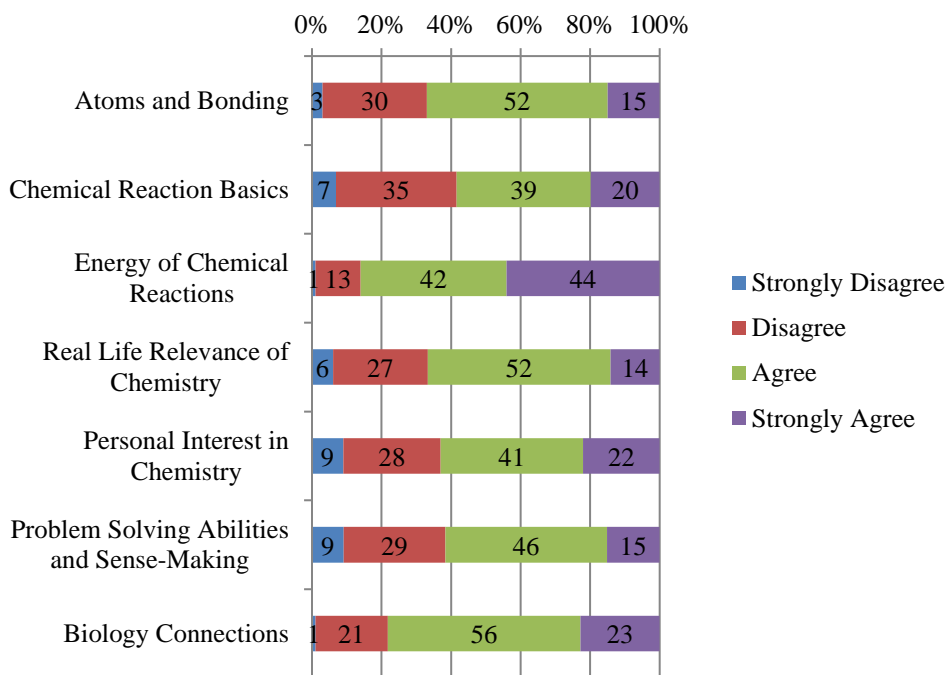


Figure 3. Chemical bonding pre-survey ($N=73$), student attitudes on seven domains.

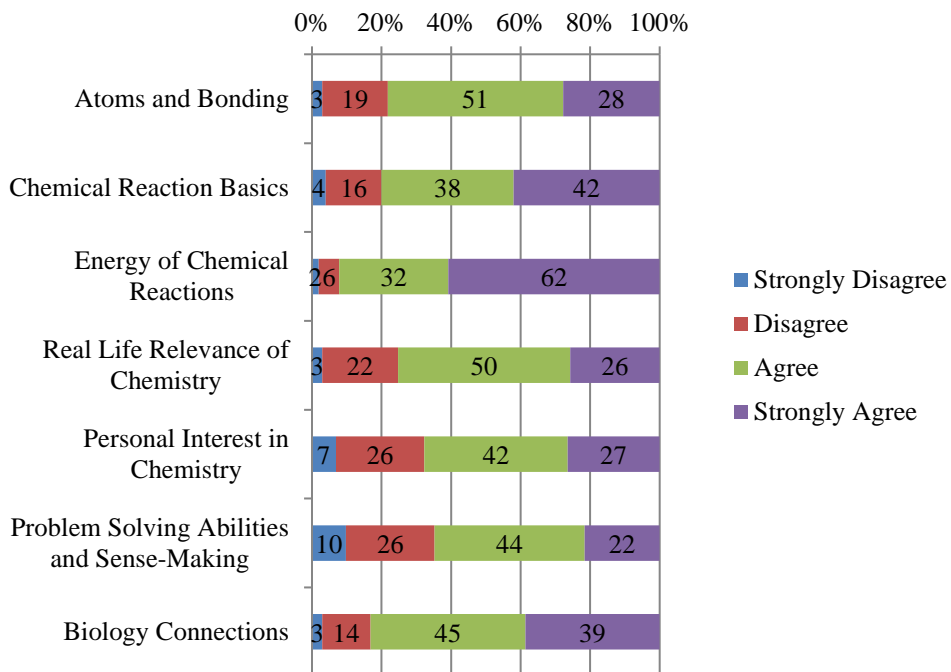


Figure 4. Chemical bonding post-survey ($N=73$), student attitudes on seven domains.

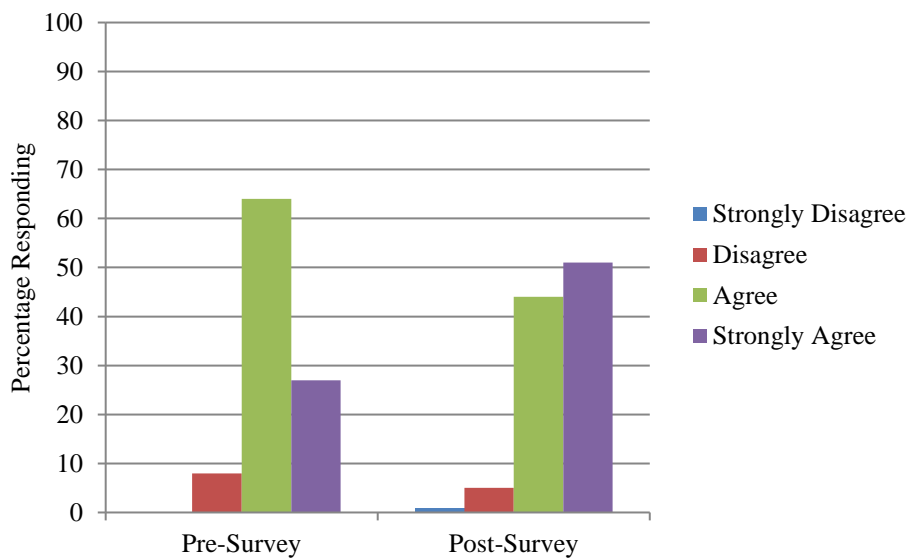


Figure 5. Chemical bonding pre-survey and post-survey ($N=73$), percentage of student responses to the question: “I can explain how energy is involved in the breaking and forming of bonds.”

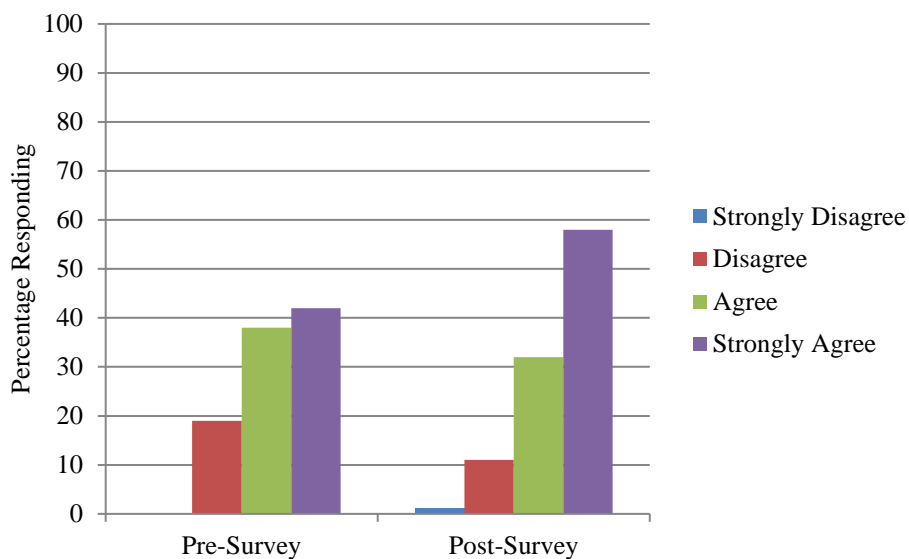


Figure 6. Chemical bonding pre-survey and post-survey ($N=73$), percentage of student responses to the question: “I can identify the difference between an endothermic and exothermic reaction based on bond energies.”

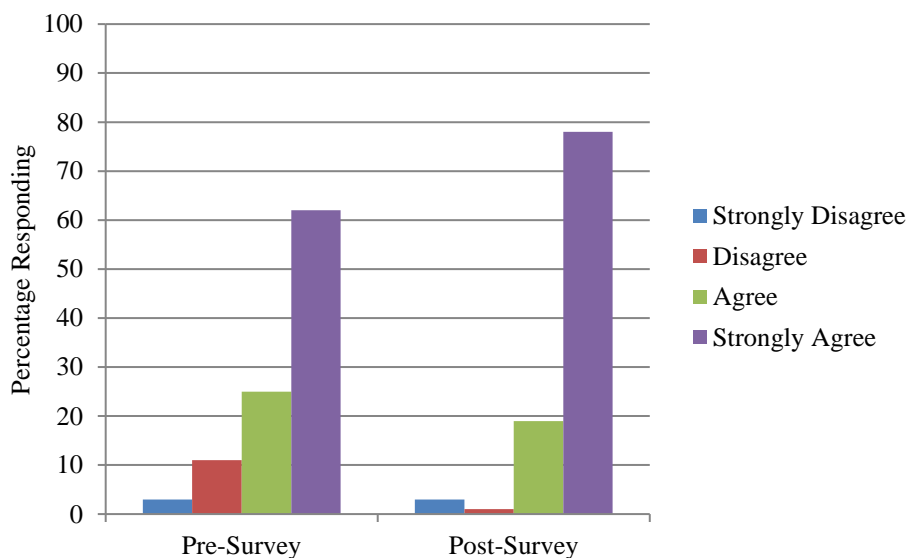


Figure 7. Chemical bonding pre-survey and post-survey ($N=73$), percentage of student responses to the question: “In chemistry lab, I can easily identify an endothermic and exothermic reaction based on how it feels.”

This is very promising that students feel such a large degree of confidence when it comes to the energy involved in chemical reactions, and to reinforce this data, their Tracing Matter and Energy Assessment results agree with the student attitudes on the

survey regarding chemical energy. However, as their chemistry teacher, I am cautious in consideration of these results--until all students completely comprehend enthalpy of chemical systems and the change in stability of the chemical substance before and after chemical change occurs, they may not truly understand bond energy at the deepest level. Nevertheless, for a high school level learning progression, these students seem to be confidently grasping the fundamental energy concepts covered in honors chemistry.

Throughout the bonding unit, a teacher journal provided further data collection and teacher reflection on student reaction to the intervention (teacher prompts for the journal are shown in Appendix H). Student responses were generally positive throughout the unit. At one point, groups were provided magnetic water molecule kits and instructed to explain where the intermolecular and intramolecular bonds would be represented by these models. I overheard one student comment “this is what makes chemistry fun.” These kits had to be removed from the students’ hands before proceeding with other instruction, as students will continue to fixate on these models. Another telling student comment was: “I thought that you overplayed how difficult this unit would be.” Some comments made over the course of the unit were not as positive. When one student was asked to predict the products of a chemical reaction for the first time, they stated: “I liked this unit until now” (I did observe that they were completing the task correctly). Another student griped that we should complete more labs—I will admit, we tend to spend a lot of time on modeling labs and paper-based activities; our current chemistry curriculum may benefit from more “wet” labs. There was also some grumbling when I introduced the POGIL activity that was used as part of the intervention, with one student shouting “I

hate POGILs” and there seemed to be some agreement among others at the lab table. This resistance to POGIL activities is new—I generally have my students complete only a few of these activities over the course of the year, so they aren’t familiar with them to the point that they would complain. However, from discussions with students, it seems that the previous biology class has started a heavy reliance on POGIL activities and some students have started to dislike them due to the repetition of using many guided inquiry activities.

Finally, eight interviews were given in-person for students to give individual verbal feedback on the interventions used in the bonding unit. In response to their feelings on the bonding unit, one student said “it was tricky, but with extra help I began to feel more comfortable,” others said it was “very complicated but interesting to learn about,” “fun, but a bit on the longer side,” and “super hard, confusing, and a lot to remember.” A couple of the interviewed students had a hard time explaining what tracing matter and energy meant specifically in terms of a chemical reaction. All of the students interviewed correctly associated exothermic reactions as feeling hot to an observer in the surroundings and endothermic feeling cold although some provided limited evidence during the interview in describing how energy is involved in a chemical reaction. When asked their feelings on taking chemistry courses in the future, one student less-than-enthusiastically responded that they have to take it. Most students were positive in their responses to further chemistry, including “I feel confident that I will do well in future chemistry courses” and several students excited to take more including a student that plans to major in chemistry. One student, interestingly, said that they were looking

forward to taking chemistry but they are concerned that their teacher in the future may not help them one-on-one like they need. Considering that chemistry honors is an elective course intended for advanced and college-bound students, it is not surprising that most students in the course are planning to take more chemistry at the college level.

In summary, based on results collected using the Tracing Matter and Energy Assessment, students improved on all 4 categories of the assessment following the intervention. Students that received the intervention, which are the current honors chemistry students, consistently performed better than the previous year's honors chemistry students which did not receive the intervention, but a t-test showed that the difference between the mean scores was not statistically significant. In terms of student attitudes towards the chemical bonding unit, responses become more positive on all seven domains of the Chemical Bonding Survey following the intervention. Students showed increasing self-confidence in using bond energetics in survey responses, and journaling and student interviews were generally optimistic towards learning chemistry and chemical energy.

INTERPRETATION AND CONCLUSION

The purpose of this research project was to improve students' understanding of matter at an atomic and molecular level and better address how energy flows during chemical changes. The intervention utilized tools to help students trace matter and energy during a chemical reaction within the chemical bonding unit. By clearly distinguishing that balancing chemical reactions addresses the need for conserving atoms of each element before and after a chemical change occurs while at the same time addressing how

energy is conserved through diagrams and explanation of bond energies, students can build a more coherent picture of the workings behind chemical change. Based on the results of the Tracing Matter and Energy Assessment, along with student confidence on the Chemistry Bonding Unit Survey and the evidence gained through interviewing and journaling student interactions, students have clearly advanced in their abilities to clearly explain and comprehend the difference between matter and energy.

This research project investigated how incorporating energy into a chemical bonding unit affects student understanding of energy in chemical reactions. With focused instruction on bond energy along with additional laboratory experiences where students investigate endothermic and exothermic reactions, students have shown growth on both the assessment and a positive attitude in being able to solve energy problems within chemistry. In fact, one of my principle concerns following this research is that students may be overly-confident in their understanding of chemistry. I think that students are appropriately confident in their ability to distinguish endothermic from exothermic based on lab evidence; my bigger concern is that students may need further instruction on the workings of bond energy in terms of the interaction between nuclei and electrons on bonding atoms with a focus on what leads to chemical stability. While this information was introduced as part of the intervention, these specific details may be more appropriate to address completely in either an Advanced Placement Chemistry or college chemistry course. Based on the new additions to the chemical bonding unit, I am confident that students have a solid foundation on the importance of energy in chemical bonding based on the results of this research project.

Finally, my research investigated the effect of the use of tools that allow students to trace matter and energy changes in terms of understanding the laws of conservation of matter and energy. From looking at the research literature, one of the concerns is that when students try to explain a process such as photosynthesis or cellular respiration, many fail to account for where the matter and energy are derived before and after the chemical change. Based on the results of my tracing matter and energy assessment, students could correctly answer a series of 9 true/false questions addressing the laws of conservation of matter and energy 78% of the time. Students could also correctly answer the questions on combustion 77% of the time. These results are promising, and when students incorrectly balanced the chemical equation for the combustion of octane, most had the correct chemical formulas in the reactants and products but missed balancing the chemical equation due to simple mathematical errors completed during mental computations.

A few students, when answering conservation of matter questions in a different context such as photosynthesis or cellular respiration, still failed to recognize that the atoms involved in the growth of plants or the human body's respiration must be accounted for. Atoms are physically coming and going into and out of the organism during these processes, and one can trace and explain their pathway. Fortunately, only a small number ($N=5$) students were still explaining that sunlight is being made into sugar to make the plant grow or that the human's fat atoms are being converted into energy. Following the intervention, it was much more common for students to mix up the

placement of the reactants and products on the correct side of the given chemical reaction, while still correctly accounting for the conservation of matter and energy.

As shown from the data collected through assessments, surveys, interviews, and journaling, the interventions applied during the bonding unit had a positive impact on student outcomes. However, my teacher journal throughout the interventional unit reflects on a few concerns which must be addressed. One of my primary concerns is that adding several lessons on bond energy required additional days within a unit which is already the longest of the year. Along with two ACT testing days, a snow day, and parent teacher conferences, this unit spanned nearly six weeks. In addition, there is a lot of material covered within one unit, much of it requiring memorization. Next year, I will likely break up this unit into two smaller units in order to alleviate the time and amount of material covered. In addition, I felt that without time constraints I could have done a better job in class discussion and reviewing the new material on bond energy. Students completed the bond energy POGIL and the lab with endothermic and exothermic reactions using an inquiry-based approach, but I generally like to use direct instruction and further class discussion as a follow-up—in some cases I ran out of time to do so due to our disrupted schedule. I would also have liked to review photosynthesis and combustion more completely. I added a simple worksheet that had students compare the enthalpy of these reactions but would have liked to address this through in-depth class discussion, as well. Next year, I intend to prioritize more time to review this new material on bond energy, photosynthesis, and cellular respiration prior to the exam.

VALUE

Promoting better student comprehension of chemistry fundamentals has been a goal of mine since I began teaching chemistry four years ago. I had previously taught physical science to freshmen, and after making the jump to teaching predominately juniors in a chemistry honors course, I was dismayed by how many students still did not understand the most fundamental chemistry concepts. Students did not seem to be making the connections that they needed to make between their previous biology course and the chemistry that I was trying to teach them. Near the end of my first year of teaching chemistry honors, I administered the Tracing Matter and Energy Assessment for the first time. Student performance was dismal, even after completing a year of chemistry honors curriculum. Initially, I was taken aback by this, and over the next several years I have been placing an increased focus on tracing matter and energy as well as building connections back to biology.

My goals for the past several years have been to help students see the connections between science fields and give context to some very important chemical reactions in our own lives, and also help students to comprehend how chemistry works rather than to memorize the “correct answers” for each exam. This has been a work in progress over the past three years, and I have made consistent adjustments to my curriculum. As shown by the results of my research project over the past year, progress has been made, but it seems that there are still some students that haven’t made all of the connections. There is room to improve—especially on the topics of cellular respiration and photosynthesis—crucial biological processes which some students still fail to comprehend fully despite learning

numerous times throughout their K-12 science education. During chemistry class, students sometimes groan when I mention biology concepts like photosynthesis and cellular respiration, as though they want to separate and compartmentalize the science content areas from each other. Nevertheless, in reflecting back on the progress that my students have made over the course of the past few years teaching chemistry, creating more connectivity between the sciences has been a rewarding and effective endeavor.

I have shared the results of my data collection and the curricular revisions with the other chemistry and biology teachers in my department, as I am helping to guide revisions across our department. The data shows that instruction on energy is difficult for students to grasp, and these are not concepts that should be covered in just one context or course. Additionally, I plan to present my findings to other science teachers at the 2019 Wisconsin Society of Science Teachers Conference in Madison, WI. Ultimately, I see students embracing the ideas presented in my interventional instruction as they seek a deeper understanding of the science content and the impact of science on their own lives and society as a whole. While I have developed some of these tools that allow students to trace matter and energy, many are adopted from other researchers in the educational field that are also working to promote richer, deeper understanding of the chemistry fundamentals. While many of the topics that we teach are abstract and complex, there are effective resources and pedagogy that help students to learn chemistry.

REFERENCES CITED

- American Association for the Advancement of Science (2011). *Vision and Change in Undergraduate Education: A Call to Action*, Washington, DC.
- American Chemical Society. (2018). Methane and Oxygen React. <http://www.middleschoolchemistry.com/multimedia/chapter6/lesson1>
- Aydeniz, M., & Kotowski, E. (2012). What Do Middle and High School Students Know About the Particulate Nature of Matter After Instruction? Implications for Practice. *School Science and Mathematics, 112*(2), 59-65.
- Carbon TIME: Transformations in Matter and Energy. <http://www.carbontime.bsccs.org/>
- Cooper, M., & Klymkowsky, M. (2013). The trouble with chemical energy: Why understanding bond energies requires an interdisciplinary systems approach. *CBE Life Sciences Education, 12*(2), 306-12.
- Dauer, J., Doherty, J., Freed, A., & Anderson, C. (2014). Connections between student explanations and arguments from evidence about plant growth. *CBE Life Sciences Education, 13*(3), 397-409.
- Dauer, J., Miller, H., Anderson, C. Conservation of Energy: An Analytical Tool for Student Accounts of Carbon-Transforming Processes. In *Teaching and Learning of Energy in K-12 Education*; Chen, R. F., Eisenkraft, A., Fortus, D., Krajcik, J., Neumann, K., Nordine, J. C., Scheff, A., Eds.; Springer: New York, 2014; pp 47-67.
- Liu, X., & Lesniak, K. (2006). Progression in children's understanding of the matter concept from elementary to high school. *Journal of Research in Science Teaching, 43*(3), 320-347.
- Neumann, K., Viering, T., Boone, W., & Fischer, H. (2013). Towards a learning progression of energy. *Journal of Research in Science Teaching, 50*(2), 162-188.
- NGSS Lead States. 2013. *Next Generation Science Standards: For States, By States*. Washington, DC: The National Academies Press.
- Nimmermark, A., Öhrström, L., Mårtensson, J., & Davidowitz, B. (2016). Teaching of chemical bonding: A study of Swedish and South African students' conceptions of bonding. *Chemistry Education Research and Practice, 17*(4), 985-1005.
- Parker, J., Santos, E., & Anderson, C. (2013). What learning progressions on carbon-transforming processes tell us about how students learn to use the laws of conservation of matter and energy. *Educación Química, 24*(4), 399-406.

Process Oriented Guided Inquiry Learning, Available at <http://www.pogil.org/>. Accessed November 2017.

Stevens, S., Delgado, C., & Krajcik, J. (2010). Developing a hypothetical multi-dimensional learning progression for the nature of matter. *Journal of Research in Science Teaching*, 47(6), 687-715.

Swackhamer, G. (2005). Cognitive resources for understanding energy. Retrieved February 14, 2017, from http://modeling.asu.edu/modeling/RESOURCES_10-03.pdf

U.S. Department of Education, Institute of Education Sciences, National Center for Education Statistics, National Assessment of Educational Progress (NAEP), 2015 Science Assessment.

Wilson, C., Anderson, C., Heidemann, M., Merrill, J., Merritt, B., Richmond, G., . . . Parker, J. (2006). Assessing students' ability to trace matter in dynamic systems in cell biology. *CBE Life Sciences Education*, 5(4), 323-31.

Wisconsin Department of Public Instruction, Office of Educational Accountability, School and District Report Cards, 2016-2017.

APPENDICES

APPENDIX A
INSTITUTIONAL REVIEW BOARD EXEMPTION



INSTITUTIONAL REVIEW BOARD
For the Protection of Human Subjects
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MEMORANDUM

TO: Daniel Curran and Eric Brunsell
FROM: Mark Quinn [Signature]
Chair, Institutional Review Board for the Protection of Human Subjects
DATE: November 16, 2017
RE: "Tracing Matter and Energy in the High School Chemistry Classroom" [DC111617-EX]

The above research, described in your submission of November 16, 2017, is exempt from the requirement of review by the Institutional Review Board in accordance with the Code of Federal regulations, Part 46, section 101. The specific paragraph which applies to your research is:

- X (b) (1) Research conducted in established or commonly accepted educational settings, involving normal educational practices such as (i) research on regular and special education instructional strategies, or (ii) research on the effectiveness of or the comparison among instructional techniques, curricula, or classroom management methods.
X (b) (2) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures or observation of public behavior, unless: (i) information obtained is recorded in such a manner that human subjects can be identified, directly or through identifiers linked to the subjects; and (ii) any disclosure of the human subjects' responses outside the research could reasonably place the subjects at risk of criminal or civil liability, or be damaging to the subjects' financial standing, employability, or reputation.
(b) (3) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures, or observation of public behavior that is not exempt under paragraph (b)(2) of this section, if: (i) the human subjects are elected or appointed public officials or candidates for public office; or (ii) federal statute(s) without exception that the confidentiality of the personally identifiable information will be maintained throughout the research and thereafter.
(b) (4) Research involving the collection or study of existing data, documents, records, pathological specimens, or diagnostic specimens, if these sources are publicly available, or if the information is recorded by the investigator in such a manner that the subjects cannot be identified, directly or through identifiers linked to the subjects.
(b) (5) Research and demonstration projects, which are conducted by or subject to the approval of department or agency heads, and which are designed to study, evaluate, or otherwise examine: (i) public benefit or service programs; (ii) procedures for obtaining benefits or services under those programs; (iii) possible changes in or alternatives to those programs or procedures; or (iv) possible changes in methods or levels of payment for benefits or services under those programs.
(b) (6) Taste and food quality evaluation and consumer acceptance studies, (i) if wholesome foods without additives are consumed, or (ii) if a food is consumed that contains a food ingredient at or below the level and for a use found to be safe, or agricultural chemical or environmental contaminant at or below the level found to be safe, by the FDA, or approved by the EPA, or the Food Safety and Inspection Service of the USDA.

Although review by the Institutional Review Board is not required for the above research, the Committee will be glad to review it. If you wish a review and committee approval, please submit 3 copies of the usual application form and it will be processed by expedited review.

APPENDIX B

BONDING UNIT LEARNING TARGETS

Honors Chemistry Unit 6–Bonding and Chemical Reactions

Goals	Notes
I am able to correctly draw Lewis Dot Structures for molecular compounds.	
I am able to correctly name the molecular shape of compounds based on their Lewis Dot Structures and determine if the molecule is polar.	
I am able to identify, name, and write the formulas for both ionic and molecular substances.	
I am able to write balanced chemical equations to represent the Law of Conservation of Mass during all types of Chemical Reactions.	
I am able to identify and predict the products of the following reactions: a. Synthesis/Combination b. Decomposition c. Combustion d. Single replacement e. Double replacement	
I am able to determine whether a reaction is endothermic or exothermic based on the bond energies of reactants and products.	

APPENDIX C
DESCRIBING CHEMICAL REACTIONS LAB

Unit 6: Describing Chemical Reactions Lab**Introduction and Purpose**

In this experiment you will observe examples of the five basic types of chemical reactions. You will also review energy changes during chemical reactions. You will learn to write balanced equations to effectively communicate the chemistry of the reactions.

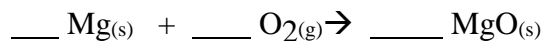
Procedure

Follow the individual procedures. Beneath each procedure you will balance the equation, write the word equation and record your observations.

A. Synthesis/Combination reactions:

1. Grasp a strip of magnesium ribbon in crucible tongs and ignite it in the burner flame. Hold it over a watch glass once it has ignited. **Do not look directly at the flame!** The ash should be disposed of in the garbage can.

Observations:



Write the equation in words:

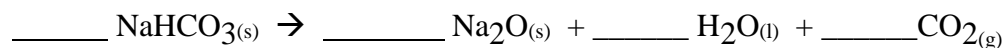
What did you observe that might lead you to conclude there is a difference in energy between the reactants (magnesium/oxygen) and the product (MgO) formed? Do the products have more or less energy than the reactants? Explain why.

Draw an energy diagram and label the axes in order to support your answer:

This reaction could be classified as (circle one) endothermic/exothermic.

B. Decomposition reactions:

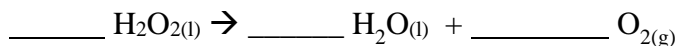
- Place about 1 scoopful of solid sodium hydrogen carbonate NaHCO_3 into a dry test tube. Heat the sodium hydrogen carbonate in the test tube strongly for 2 minutes (don't forget to point the test tube at the wall.) Observe any changes that occur during the heating. Toward the end of the heating, light a wood splint and insert the flaming splint into the mouth of the test tube. Note what happens to the splint. Once the tube has cooled, wash all contents down the sink with lots of water.
Observations:



Write the equation in words:

- Demo:** Your teacher is going to demonstrate the making of “elephant toothpaste.”

Observations:



Write the equation in words:

What did you observe that might lead you to conclude there is a difference in energy between the reactants and the product formed? Do the products have more or less energy than the reactants? Explain why.

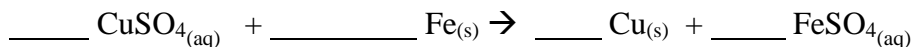
Draw an energy diagram and label the axes in order to support your answer:

This reaction could be classified as (circle one) endothermic/exothermic.

C. Single replacement reactions:

1. Place about 1 scoop of CuSO_4 in a 250 mL beaker add about 100 mL of water. Stir with a stirring rod to dissolve and make a CuSO_4 solution. Pull apart a small piece of steel wool (which is really pure iron) and place it in the beaker. Observe the reaction (this may take a few minutes – when both substances look different the reaction is over.) Use tongs to throw the steel wool away in the garbage can, the solution can be poured down the sink with lots of water.

Observations:

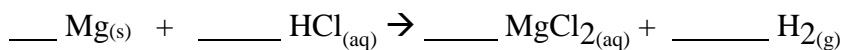


Write the equation in words:

2. Place about 10 mL of 6M HCl into a test tube. Place a piece of magnesium into the acid—keep the test tube in the test tube rack. Check to see if the temperature of the mixture has changed by feeling the outside of the test tube. While the reaction is occurring, collect the gases produced with a test tube and test with a flaming splint as in part B1.

Allow the reaction to take place until all magnesium has reacted (the production of bubbles will stop when the reaction is complete.) The remaining solution can go down the sink with lots of water.

Observations:

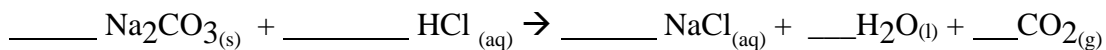


Write the equation in words:

D. Double replacement reactions:

- Place a scoopful of solid Na_2CO_3 in a test tube to a depth of about 1 cm. Add one dropper full of 3.0M HCl. Check to see if the temperature of the mixture has changed by feeling the outside of the test tube. The contents of the test tube can go down the sink with lots of water.

Observations:

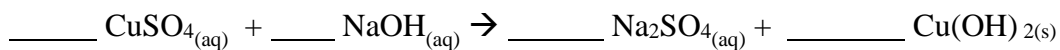


Write the equation in words:

This reaction could be classified as (circle one) endothermic/exothermic.

- Place 10 drops of .1 M CuSO_4 solution in a spot plate. Add 10 drops of .1 M NaOH into the same spot. Make observations of the reaction. The contents of the spot plate can go down the sink with lots of water.

Observations:

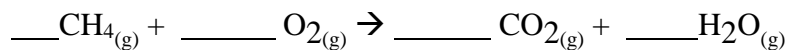


Write the equation in words:

E. Combustion reactions:

1. Think about the type of gas (methane) we use in the chemistry classroom. Light your Bunsen burner. Observe the flame.

Observations:



Write the equation in words:

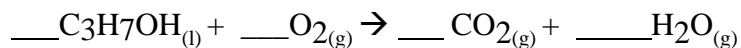
Why must you light a match in order to initiate this reaction? What purpose does the match's energy serve on a molecular level?

What evidence do you observe that indicates a change in energy of the system?

This reaction could be classified as (circle one) endothermic/exothermic.

2. Place about 10 drops of isopropyl alcohol, $\text{C}_3\text{H}_7\text{OH}$, on a watch glass with a pipet. Move the capped bottle of isopropyl alcohol away from all flames and make sure the lid is on tight. Ignite the alcohol from the top of the liquid with a wood splint. Make observations of what happens. (Be sure to look at the watch glass just outside of the flame.)

Observations:



Write the equation in words:

F. Lab Extension

Some reaction types do not neatly fit into the 5 reaction types that we have identified. For example, in solution citric acid and sodium bicarbonate (aka baking soda) react to form sodium citrate, water, and carbon dioxide.

Procedure:

1. Measure and add 11.5g of citric acid solution into a coffee cup. Add 30mL of distilled water to the cup, and stir into solution. Use a thermometer or other temperature probe to record the initial temperature.
2. Add 15g of sodium bicarbonate (baking soda) and stir. Track the change in temperature over time while stirring. Record the final temperature.
3. When you have completed your demonstration or experiment, wash the cup out in a sink.

Observations (Give temperature data):



Write the equation in words:

What evidence do you observe that indicates a change in energy of the system?

Draw an energy diagram and label the axes in order to support your answer:

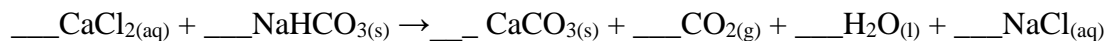
This reaction could be classified as (circle one) endothermic/exothermic.

Extension Continued:

Procedure #2:

1. Measure and pour 10mL of water into a coffee cup.
2. Add 7g of Sodium Bicarbonate
3. Use a thermometer or other temperature probe to record the initial temperature.
4. Add 11g of calcium chloride and stir. Track the change in temperature over time while stirring. Record the final temperature.
5. When you have completed your demonstration or experiment, wash the cup out in a sink.

Observations (Including temperature data):



Write the equation in words:

What evidence do you observe that indicates a change in energy of the system?

Draw an energy diagram and label the axes in order to support your answer:

This reaction could be classified as (circle one) endothermic/exothermic.

Analysis: Answer the following questions in complete sentences.

1. What are some of the observable changes that are evidence that a chemical reaction has taken place?
2. How did the flaming splint behave when it was inserted into the tube with CO_2 (g) in B1? In what way was this different from the reaction of the H_2 (g) to the flaming splint in C2?
3. Describe in general what you believe to be happening in each kind of reaction. (Hint: give a general description of the five types of chemical reactions.)
4. Explain how to determine, using experimental observations, whether a given reaction is endothermic or exothermic.

APPENDIX D

ENTHALPY OF PHOTOSYNTHESIS AND CELLULAR RESPIRATION

Worksheet on Enthalpy of Photosynthesis and Cellular Respiration

1. Write out the balanced chemical reaction for Photosynthesis:
2. The $\Delta H=4075.8$ kJ/mol to break the reactant molecule bonds during Photosynthesis.
The $\Delta H=-1274.5$ kJ/mol to form the product molecule bonds during Photosynthesis.
Draw an energy diagram for Photosynthesis and calculate the total ΔH for this reaction.
3. a. Is photosynthesis Endothermic or Exothermic? HDYK?

b. Where does the energy to drive this reaction originate?
4. Besides categorizing based on energy; what type of reaction would you consider photosynthesis? HDYK?
5. Write out the balanced chemical reaction for Cellular Respiration:
6. The $\Delta H=1274.5$ kJ/mol to break the reactant molecule bonds in Cellular Respiration.
The $\Delta H=-4075.8$ kJ/mol to form the product molecule bonds in Cellular Respiration.
Draw an energy diagram for Cellular Respiration and calculate the total ΔH for this reaction.
7. a. Is cellular respiration Endothermic or Exothermic? HDYK?

b. What is the energy produced by this reaction used for?
8. Besides categorizing based on energy; what type of reaction would you consider cellular respiration? HDYK?

APPENDIX E
TRACING MATTER AND ENERGY ASSESSMENT

Tracing Matter and Energy Pre and Post Assessment

Note: These questions are designed to learn more about how you as a chemistry student think about matter and energy.

1. **Burning gasoline.** Gasoline is mostly a mixture of molecules such as octane, chemical formula: C_8H_{18} . Choose whether each of the following statements about what happens to the atoms in a molecule of octane when it burns inside a car engine is true (T) or false (F).

T F Some of the atoms in the octane become part of carbon dioxide (CO_2) in the air.

T F Some of the atoms in the octane become part of air pollutants such as ozone (O_3) or nitric oxide (NO_2).

T F Some of the atoms in the octane are converted into energy that moves the car.

T F Some of the atoms in the octane are burned up and disappear completely.

T F Some of the atoms in the octane are converted into heat.

T F Some of the atoms in the octane become part of water vapor (H_2O) in the atmosphere.

2. **A. What happens to the atoms in the octane** when it burns inside a car? (hint: your explanation **should include a balanced chemical equation**)

B. What is the name given to this process?

3. **A.** As best you can, outline the **process by which energy is produced** when octane burns in the car's engine. (**hint:** you should discuss chemical bonds in your explanation)

B. Is this an endothermic, isothermic, or exothermic reaction? Explain how you know.

Growing and using corn. Here's a picture of a cornfield:



4. A. Each corn plant started out as a corn seed (or kernel) that weighed very little. At the end of its life, each plant weighed several pounds. How did it grow from a tiny seed to a big corn plant? Explain where the new mass came from (hint: your explanation should discuss atoms and should contain **a balanced chemical equation**).

B. What is the name for this process (you learned about this in biology class)?

5. a. Fat is mostly made of molecules such as stearic acid: $C_{18}H_{36}O_2$. Indicate whether each of the following statements is true or false about what happens to the atoms in a man's fat when he exercises and loses weight.



- T F Some of the atoms in the man's fat are incorporated into carbon dioxide (CO_2) in the air.
- T F Some of the atoms in the man's fat are converted into energy that he uses when he exercises.
- T F Some of the atoms in the man's fat are burned up and disappear completely.
- T F Some of the atoms in the man's fat are converted into heat.
- T F Some of the atoms in the man's fat are incorporated into water vapor (H_2O) in the atmosphere.

b. What happens to the atoms in the fat of a person who loses weight? (hint: your explanation should discuss atoms and should contain **a balanced chemical equation**)

c. What is the name for this process (you learned about this in biology class)?

Adapted from Carbon TIME: Transformations in Matter and Energy.

[http://www.carbontime.bsos.org/Interview Questions](http://www.carbontime.bsos.org/Interview%20Questions)

APPENDIX F

CHEMISTRY BONDING UNIT SURVEY

Chemistry Bonding Unit Survey

Participation in this survey is completely voluntary. You can choose to not answer any question that you do not want to answer, and you may stop at any time. Your participation or non-participation will not affect your grade or class standing in this course.

1. When I study a chemical reaction, I think about the interaction between atoms or molecules.
 - a. Strongly Disagree
 - b. Disagree
 - c. Agree
 - d. Strongly Agree
2. In terms of molecules, I can explain the difference between reactants and products in a chemical reaction.
 - a. Strongly Disagree
 - b. Disagree
 - c. Agree
 - d. Strongly Agree
3. In terms of reactant molecules and product molecules, I can identify and explain the type of chemical reaction.
 - a. Strongly Disagree
 - b. Disagree
 - c. Agree
 - d. Strongly Agree
4. I think about how atoms are connected into molecules when explaining a chemical reaction.
 - a. Strongly Disagree
 - b. Disagree
 - c. Agree
 - d. Strongly Agree
5. I can explain how bonds change before and after a chemical reaction occurs.
 - a. Strongly Disagree
 - b. Disagree
 - c. Agree
 - d. Strongly Agree
6. I can explain how energy is involved in the breaking and forming of bonds.
 - a. Strongly Disagree
 - b. Disagree
 - c. Agree
 - d. Strongly Agree

7. I can identify the difference between an endothermic and exothermic reaction based on bond energies.
- Strongly Disagree
 - Disagree
 - Agree
 - Strongly Agree
8. In chemistry lab, I can easily identify an endothermic and exothermic reaction based on how it feels.
- Strongly Disagree
 - Disagree
 - Agree
 - Strongly Agree
9. I can usually predict how two chemicals will react together.
- Strongly Disagree
 - Disagree
 - Agree
 - Strongly Agree
10. If given a chemical equation, I can explain what changes occurred.
- Strongly Disagree
 - Disagree
 - Agree
 - Strongly Agree
11. I understand how chemistry relates to my everyday life.
- Strongly Disagree
 - Disagree
 - Agree
 - Strongly Agree
12. I think that understanding atoms and molecules is important to my daily life.
- Strongly Disagree
 - Disagree
 - Agree
 - Strongly Agree
13. I think that understanding energy is important to my daily life.
- Strongly Disagree
 - Disagree
 - Agree
 - Strongly Agree

14. I can explain the types of energy around me, and I can explain energy changes that occur.

- a. Strongly Disagree
- b. Disagree
- c. Agree
- d. Strongly Agree

15. In my daily life, I can identify specific chemical reactions that occur around me.

- a. Strongly Disagree
- b. Disagree
- c. Agree
- d. Strongly Agree

16. I am excited about learning chemistry.

- a. Strongly Disagree
- b. Disagree
- c. Agree
- d. Strongly Agree

17. I intend to take more chemistry classes.

- a. Strongly Disagree
- b. Disagree
- c. Agree
- d. Strongly Agree

18. I think that it will be important to understand chemistry in my future career.

- a. Strongly Disagree
- b. Disagree
- c. Agree
- d. Strongly Agree

19. I confidently discuss chemistry subjects with my friends.

- a. Strongly Disagree
- b. Disagree
- c. Agree
- d. Strongly Agree

20. I find chemistry class to be challenging.

- a. Strongly Disagree
- b. Disagree
- c. Agree
- d. Strongly Agree

21. I like learning about abstract topics in science class, even if I can't see the topic myself.

- a. Strongly Disagree
- b. Disagree
- c. Agree
- d. Strongly Agree

22. I want to know more about challenging chemistry concepts.

- a. Strongly Disagree
- b. Disagree
- c. Agree
- d. Strongly Agree

23. I need to practice many chemistry problems before I understand the concept.

- a. Strongly Disagree
- b. Disagree
- c. Agree
- d. Strongly Agree

24. Chemistry makes sense to me.

- a. Strongly Disagree
- b. Disagree
- c. Agree
- d. Strongly Agree

25. I can explain how chemical reactions are important to living things and the study of Biology.

- a. Strongly Disagree
- b. Disagree
- c. Agree
- d. Strongly Agree

26. The chemical equations for Photosynthesis and Cellular Respiration make sense to me.

- a. Strongly Disagree
- b. Disagree
- c. Agree
- d. Strongly Agree

27. If I take a college Chemistry course, I know that I will do well.

- a. Strongly Disagree
- b. Disagree
- c. Agree
- d. Strongly Agree

28. I am confident explaining my understanding of a chemistry topic.
- Strongly Disagree
 - Disagree
 - Agree
 - Strongly Agree
29. I am confident using mathematics and calculations to answer a chemistry problem.
- Strongly Disagree
 - Disagree
 - Agree
 - Strongly Agree
30. Chemistry is intimidating to me.
- Strongly Disagree
 - Disagree
 - Agree
 - Strongly Agree
31. I do better in Chemistry than in my other courses.
- Strongly Disagree
 - Disagree
 - Agree
 - Strongly Agree
32. I feel like others around me understand Chemistry better than I do.
- Strongly Disagree
 - Disagree
 - Agree
 - Strongly Agree
33. I have a hard time understanding Chemistry problems unless my teacher explains it to me first.
- Strongly Disagree
 - Disagree
 - Agree
 - Strongly Agree
34. I feel very frustrated and inadequate when studying chemistry outside of class.
- Strongly Disagree
 - Disagree
 - Agree
 - Strongly Agree

35. I spend more time studying for Chemistry tests than other subjects.

a. Strongly Disagree

b. Disagree

c. Agree

d. Strongly Agree

APPENDIX G
INTERVIEW QUESTIONS

1. Do you like chemistry class?
2. What are your feelings on the Bonding Unit that we just covered?
3. Does discussing chemical reactions in terms of tracing matter and energy make sense to you?
4. Can you detail how energy is involved in a chemical reaction, discussing reactants and products?
5. Please describe how an exothermic reaction would feel compared to an endothermic reaction, assuming that you are in the surroundings.
6. How do you feel about taking more chemistry in the future?

APPENDIX H
PROMPTS FOR INSTRUCTOR FIELD OBSERVATIONS

Prompts for Daily Instructor Field Observation Journal

1. How did students respond to the day's intervention?
2. What did you feel went well in today's lesson?
3. What did you feel could be improved upon for the upcoming lessons?
4. How did you formatively assess student understanding during today's class?
5. How did students respond to formative assessment?
6. What type of questioning strategies did you employ during today's class?
7. What misconceptions or misunderstandings were visible in today's lesson?
8. What student comments or questions were relevant to the intervention?
9. How was student attitude or motivation visible during class today?