

STUDENT MISCONCEPTIONS – IDENTIFYING AND REFORMULATING
WHAT THEY BRING TO THE CHEMISTRY TABLE

by

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ABSTRACT

The primary goal of this project was to investigate methods of identifying student misconceptions as they related to the particulate nature of matter, and then to determine what types of treatments might be effective toward helping students redefine their concepts. Misconceptions were identified through the Particulate Nature of Matter Assessment, as well as through knowledge probes and the Conceptual Change Model. The primary methods of treatment included laboratory activities, model building and animations. Post-assessments and interviews revealed an improvement in the understanding of molecular size and conductivity of solutions at a conceptual level, while student understanding of phase changes did not improve as much. Interviews and small group discussion proved to be surprisingly useful and hold promise for future lesson planning.

INTRODUCTION AND BACKGROUND

Project Background

Teaching Experience and Classroom Environment

Question: What will happen to the mass of iron nails if left out in a moist environment over several weeks' time?

This question is extracted from a knowledge probe, "The Rusty Nails," from Keeley, Eberle, & Farrin (2005). My experiences using this probe, and others like it were quite intriguing and provided me with some insight as to what knowledge my students were bringing to the "chemistry table." I started to fully comprehend the reality when assigned to administer several formative assessments and discovered that despite my best efforts, my students could identify the reaction for the oxidation of iron written in formulas as a synthesis or addition reaction; but when confronted with a written scenario, a large portion of the students identified that same situation as a decomposition reaction. The responses I received from my students led me to the inclination that many of the students had some poorly defined conceptual frameworks. This might have come as less of a surprise to someone teaching in a low performing school; but I teach in an academically recognized district in Texas, in a fairly high performing suburban high school with a student population of approximately 2800 students where the demographic make-up includes: White: 66.1%, Hispanic: 24.8%, African American: 6.4%, Asian: 2.3%, and Native American: 0.3%, with 21.6% of the student population qualifying as Low Income. My teaching schedule includes one section of AP Chemistry and four sections of PreAP Chemistry I. PreAP Chemistry is essentially an honors level class; and in an honors level

class often the difference is not the topic, but the depth to which the students are held responsible for learning. Thus, one of my goals as a teacher is to help my students do more than just describe or restate a specific scientific principle; I want them to be able to use a specific scientific principle in their explanation of other scientific phenomena.

Focus Question

In order to use scientific principles in their explanations, my students will require a sound conceptual framework which leads me to the primary question in my research: How can I identify some of the major misconceptions related to the particulate nature of matter that might act as barriers or detractors from learning in a first-year, high school chemistry class; and what can I do to facilitate students in a reconstruction of their understanding to a lasting, scientifically accepted conceptualization? Additionally, I want to find some methods for diagnosing misconceptions and some treatments that would help students reconstruct their conceptualizations. Lastly, I want to effectively assess whether the remediation of misconceptions was successfully retained and how my experience in this project would affect my approach to teaching conceptually based material in the future.

Support Structure

As with any project, having a team you can count on for support is paramount. For this particular project I selected four people who have helped me before, and who I trust to give me honest feedback in the area(s) that I ask them to help and a back-up person in case of emergencies or in case I feel the need for another perspective. Dr. Alton

Royer, Assistant Principal for Instruction at Katy High School, was our department evaluator when we started Professional Learning Communities a few years ago, and he was very supportive of our team as we ventured into the sometimes treacherous waters of a new system. I have found him to be encouraging, helpful, honest and reasonable. Also, since he has earned a higher degree, he understands the demands, frustrations, and rewards of the process. Mrs. Jane Gray is a retired Physical Science Teacher, who although is retired from teaching on a 7:10 – 3:10 daily basis, has not retired from teaching altogether. She and I worked together at Katy High School for 17 years, have a very good working relationship, respect each other both personally and professionally, and still present workshops together at conferences. Jane is extremely supportive and because she is retired, I can get her opinion in the evenings or on weekends when some of my other colleagues are not available. Ms. Carol Srack is an AP English Teacher and Department Chair and even though we teach totally different subjects, we respect each other's talents. I trust her implicitly to give me feedback on parallel structure, grammar and the dreaded comma. She also will be honest in telling me if she can understand what I'm trying to say, from a layman's perspective. Mrs. Carol Rogers teaches AP Biology, and I can honestly say that her strength and role on my team will be for emotional support. She is the cheerleader of our department, and if one of the other team members has a personal or family matter arise I would not hesitate to ask her to step into their place.

Because each person on my team has different strengths and different roles, my plan involved seeking their advice on an individual basis, and to solicit their advice in a

manner which least intrudes on their schedules and available time, scheduling a full team meeting when necessary.

CONCEPTUAL FRAMEWORK

Ideas and Instruction

In looking for some theoretical basis for my work, my goal was to locate literature that delved into the areas of student ideas and concepts, science instruction (preferably chemistry), and instruments for data collection. One such piece of literature was an article that focused specifically on misconceptions and how they affect chemistry instruction. Dorothy Gabel (1989) describes the three main ways that people learn or acquire their conceptual ideas about science; “They acquire them from nature, from language, and from instruction” (p.727). When she says “from nature” she is referring to life experience, like touching objects or observing objects and constructing a naïve concept based on that, whereas “from language” becomes a little more challenging. Science books and adults, through idiomatic speech, will sometimes use language that when used in a different context, has different meaning. When students learn terms outside of the context, they may form an alternative explanatory structure in their brain, which leads them to have a concept or visual image that pertains to the wrong context and interferes with their ability to understand the correct explanation. Lastly, “from instruction” refers to what the students learn as a part of their formal education in lectures and laboratory settings. If instruction is limited to only one or two contexts, that may not be enough to

overcome any preconceived notions and the student will retain the earlier conceptual framework. Alternatively, a concept might be introduced either before the student is intellectually mature enough to understand the idea behind it (kinetic theory) or the explanation may be simply at a level that is too high for understanding (particulate nature of phase changes vs. chemical changes) (Gabel, 1989). The students have formed foundational concepts through life experience by the time they reach high school so in this case my focus would be on identifying what those foundational concepts are and then trying to address them through age appropriate language, instruction and activities designed to help them rework that conceptual structure.

Keeley, Eberle, and Tugel (2007) provide additional insight for my study, beyond the original impetus of “The Rusty Nails”, in a second volume of formative assessments. The knowledge probe “What’s in the Bubbles?” (p.65) encouraged me to rethink what my students know about phase changes at the molecular level. In the introduction of the book, there are several suggestions as to how teachers might incorporate the assessment probes into their repertoire. These include using the probes “to engage students in investigating new ideas and phenomena, elicit students’ ideas, help them be more aware of their thinking and construct new ideas through discourse with their peers” (p.7). Recommendations also included the use of the probes not just on an individual student basis, but as a group or class discussion prompt or as a student-teacher interview topic for more in-depth assessment or, as illustrated in the “Floating Logs” vignette (pp.13-15), probes can be use to stimulate student-centered inquiry labs.

As I was narrowing my focus toward finding articles related to student ideas and teaching techniques, one that provided potential for a lab experience investigated the

effectiveness of using a “four-step constructivist teaching method” (Calik, 2008). He was focusing on the understanding of the process of boiling and its relation to vapor pressure and external pressure. The four steps involved determining any prior knowledge or ideas students held about boiling; a guided lab phase in which students manipulated and made observations about the behaviors of several liquid samples in sealed syringes and then discussed a series of questions within their groups; a phase which required students to defend their group results and make connections between the lab results and their existing knowledge; and finally a phase where the students are asked to apply their knowledge to an unfamiliar situation. Most students showed an improvement in understanding and the change appeared to be somewhat permanent because the test given later to assess retention was not statistically different from the post-test that was given fairly quickly after the intervention; thus providing evidence that a student’s conceptual framework about a specific topic can be restructured and improved over a fairly short period of time, which makes it feasible for a one semester research study. I have done portions of the lab activity that was described with some of my classes in the past, but I really liked the added solutions and discussion factor. The focus of this article intertwines nicely with the earlier reviewed article that referred to the idea that “from nature, from language, and from instruction” (Gabel, 1989, p.727) is where we develop our conceptual framework.

In addition to Gabel (1989) and Calik (2008), Joseph Stepan (1994) suggests using the Conceptual Change Model, or CCM. The Conceptual Change Model incorporates six phases into lessons that provide students with opportunities to examine and refine (or redefine) their personal conceptual framework. The model consists of six specific stages requiring that:

- “Students *become aware* of their own preconceptions about a concept by thinking about it and making predictions (committing to an outcome) before any activity begins.
- Students *expose their beliefs* by sharing them, initially in small groups and then with the entire class.
- Students *confront their beliefs* by testing and discussing them in small groups.
- Students work toward *resolving conflicts* (if any) between their ideas (based on the revealed preconceptions and class discussion) and their observations, thereby *accommodating the new concept*.
- Students *extend the concept* by trying to make connections between the concept learned in the classroom and other situations, including their daily lives.
- Students are encouraged to *go beyond*, pursuing additional questions and problems of their choice related to the concept” (p.7).

Stepans provides several activities related to the physical sciences, a category into which chemistry falls, that are ready made for teachers. Through these activities students have the opportunity to experience situations that are not necessarily intuitive or are outside their personal experience and develop or refine their concepts to incorporate the new situation. One interesting activity is “ACTIVITY I: How Much Matter?” (pp.24-25); which has students looking at the space occupied by matter. The part of the activity that I

found interesting was that it was a two-part activity with the first part only going through the first three stages and the second part covering all six pages. The idea that one activity can be set up as a “precursor” to the second was appealing to me because I like to link activities together and sometimes students have so little knowledge about a subject that they might need some initial experience before they can be comfortable committing to an outcome.

Ideas and Data Acquisition

Reworking the conceptual structure will, of necessity, require me to first determine what the students’ current conceptual framework is; so now I turn to literature that provides some insight into options for data collection. One article actually provided two areas of usefulness; intervention, by way of animations and data collection through an instrument called the Particulate Nature of Matter Assessment (Yeziarski & Birk, 2006) or ParNoMA. Students were administered the ParNoMA as a pre-test and a selected sample of students were also interviewed about their responses with the authors looking for “data to help us explain quantitative findings from the pre-test and post-test” (p.955). The interventions were short, sound-free animations that the students viewed in class and then participated in subsequent questions and discussion. The teachers “acted solely as mediators calling on students who volunteered to respond” (Yeziarski & Birk, 2006, p.956). A separate text box provided the questions that were asked during the treatment. One goal of the study was to determine if the animation treatment had any gender effect, and the discussion of results and corresponding tables indicated that the treatment groups outgained the control group and that the females in the treatment group

- average gain 4.54 - had larger overall gains than their corresponding male counterparts - average gain 3.33 (Yeziarski & Birk, 2006, p.957) . The significant gains by the treatment group indicate to me that animations are definitely something to consider as a potential part of an overall treatment plan. The ParNoMA instrument (2006) itself started as a way to “evaluate students’ misconceptions (1) including the following topics. Size of particles, Weight of particles, Phases and phase change, Composition of particles and Energy of particles” (p.1). Misconceptions that have been studied and published provide the question items and the distracters are from a previous study by one of the authors, Yeziarski. To test the instrument the authors administered it to college students, believing that “college students would score the highest and likely reveal a ceiling effect if one was inherent in the test” (p. 2) and finding there was no ceiling effect. The ParNoMA, as it stands now, contains 20 questions of a conceptual nature including both diagrams at the particulate level and questions related to a scenario where the students are asked to predict a relative value or choose the best explanation for an occurrence.

Along the same vein as the ParNoMA was an article that described the development of “the Chemical Concepts Inventory (CCI), a multiple-choice inventory that can sample the extent of alternate conceptions” (Mulford & Robinson, 2002, p.739). In addition to describing the development of the CCI, the remainder of the article focused on the results of the inventory before and after students experienced a first-year college chemistry course. What they found was that students, even at the college level, bring several misconceptions with them and that “a traditional chemistry course results in only modest improvements” (Mulford & Robinson, 2002, p.742). Detractors from the study suggested that the illustrative nature of many of the choices in the CCI were not

understood by the students, but through the interview process Mulford & Robinson were able to determine that the students were interpreting the representations in the illustrations correctly. Additionally, data is provided that indicates that inventory results were statistically significant. Interestingly, many younger faculty members and graduate students were less surprised by the results of the inventory than their older colleagues. The authors suggest that as we get older, we perhaps work through our misconceptions as we observe, reflect on and have to explain them to others, and that we may forget our previously held views as we reconstruct our new framework. Having accessed the actual Chemical Concept Inventory (2001) I found that many of the concepts tested are, in fact, related to my specific area of interest; namely, the particulate nature of matter in phase changes. Because of the statistical significance of the CCI I feel as though I could use several of the items from the CCI for triangulation purposes, in conjunction with the ParNoMA and interview data.

Just identifying misconceptions will provide me only with that information – what the misconceptions are. One study looked at the “content and the organization of the students’ ideas” (Nakhleh & Saglam., 2005, p.582) at both the macroscopic and microscopic level. The information was gathered through an interview process, which was recorded both with written notes and audiotape, and the results were then coded into several sub-categories related to the macroscopic or microscopic nature of the student responses. Descriptions of these subcategories, as well as the results of student responses were both organized into tables for ease of perusal. Additionally the authors presented graphical comparisons of the frequency of macroscopic vs. microscopic responses throughout their discussion of the student explanations and a copy of the actual interview

questions in the appendix. The collected data provided several pieces of information regarding how students learn about matter, but the one that is most important for my research focus would be the fact that the interview process provided “data on the structure and quality (organization, coherence, and explanatory scope) of middle school students’ ideas about the nature of matter” (Nakhleh & Saglam 2005, p.607) . This leads me to believe that the interview process will have to be an integral part of my study as a diagnostic tool and post-treatment assessment tool as I look for retention of the restructured framework of the students’ concepts. Thus, the literature provides me with several methods for determining what students think through probes and conceptual assessments; and how I might affect their ideas, specifically through language and instruction opportunities designed to help them experience the concepts, confront their own ideas, and reflect on their new conceptual framework.

METHODOLOGY

All of my students participated in the treatment related classroom activities, as they were a part of our normal school day; and because we work in teams focusing on a set curriculum all students needed to have the same learning opportunities. A total of 53 students spread out over four class periods returned the required Informed Consent paperwork, and were therefore included in data collection, although periodic absences affected participation during individual portions of the project and therefore the N= fluctuated. In addition to being approved by the Katy Independent School District Executive Committee on External Research, 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. Because I was looking for information about which strategies might be effective in helping students rebuild their conceptual frameworks, there were several types of assessments and treatments built into my research plan.

Table 1 summarizes the treatment and data collection schedule for the first set of treatments.

Table 1
Schedule of Treatment Set 1 and Data Collection

Activity	Purpose	Unit of Study	Date Range
ParNoMA	Pre-Assessment	Heat problems	09/07 – 09/10/10
Lab – Reactions of Metals	Treatment #1	Periodic Trends	12/13 – 12/18/10
Reaction Demonstrations	Treatment #2	Reactions	01/05 – 01/21/11
Electrolysis Demonstration	Treatment #3	Reactions	01/14 – 01/21/11
Lab – Generation of Gases	Treatment #4	Reactions and Gases	01/24 – 02/11/11
Lab Experience Survey	Data Collection	KMT and Gases	02/14 – 02/17/11

The first facet of my research question focused on identification of the misconceptions, so before any treatments could take place I needed to administer a pre-assessment; in this case the instrument was called the Particulate Nature of Matter Assessment (Yeziarski, 2006) or ParNoMA (Appendix A). Following the initial pre-assessment phase, and seeing the need for students to know how to test for hydrogen and oxygen gases, I had the students participate in a series of labs and demonstrations related to the formation of gases and definitive tests for those gases. Specifically, at the end of

first semester when studying our unit on periodic trends, the students did a lab comparing the reactivity of calcium metal and magnesium metal with water (Appendix B). The calcium metal, being more reactive, produced hydrogen gas as a by-product. The students tested the hydrogen with a burning splint, resulting in the classic “pop.” At the start of the second semester we were studying types of chemical reactions and for two of the types I chose demonstrations that produced hydrogen (single replacement between Mg and HCl) and then oxygen (MnO₂ catalyzed decomposition of H₂O₂) respectively. In each case, the students were allowed to observe the container in which the reaction was happening, feel for any temperature changes and see the bubbles of gas being produced. When sufficient gas had been produced (about 30 sec – 1 min for H₂ and 1-2 min for the oxygen) the gas was tested. The hydrogen, tested with the burning splint, produced the characteristic “pop” and the oxygen caused the glowing splint to relight, showing evidence that it supported combustion. I also set up a Hoffman apparatus so the students could observe the electrolysis of water. This was more of an anticipatory event at this point as the students would go on to perform electrolysis on their own later in the semester. At the end of the unit related to reactions and stoichiometry, I had the students do a lab entitled “The Microscale Generation of Hydrogen and Oxygen and Their Stoichiometric Ratio” (Appendix C). In this lab the students generated hydrogen gas in a syringe and oxygen gas in a separate syringe. They then attached a small hose to the syringes and blew bubbles in soap solution; first with hydrogen, then with hydrogen and a small amount of air, and lastly mixed the gases into one syringe with a 2:1 ratio of hydrogen to oxygen and blew bubbles with that mixture. In each case the bubbles were touched with a burning splint and the explosion observed. The next day, as follow up to the lab, we had a

class discussion about the explosions and reinforced the 2:1 ratio of $\text{H}_2:\text{O}_2$ as being the ideal amount. The lab activities were related to the properties of gases, the make-up of water and molecular size. We also noted that the hydrogen and oxygen did not react in the syringe, but required the spark to get them started. At this point, I administered a survey (Appendix D) to assess how students felt about lab activities and demonstrations they had done and seen, and to what degree the labs and demonstrations helped them to learn.

As I shifted to the second round of treatments the focus was more on the molecule of water and its interactions and size. During our unit on Lewis structures and intermolecular forces the students participated in one demonstration, two animations, one knowledge probe and two hands-on activities related to the area of interest, namely matter at the particulate level. The demonstration was related to attractive forces between molecules of water and rubbing alcohol, where students had a drop of each substance placed on the back of their hand and were encouraged to make and share observations, first alone, then with a partner, and finally with the class. Most of the students determined that the forces holding the water together were stronger than those holding the alcohol together. The animations were showing the displacement of electrons during bonding to create non-polar and polar bonds. They were then asked to apply that information as a part of a lab exercise in building models of molecules and assessing their polarity. Water would continue to be our primary focus from that activity as the students then participated in a knowledge probe called “What’s Going on During Freezing?” (Appendix E). Finding that a majority of the students believed that water molecules actually changed size when they froze, we then did a guided lab activity with Water Kits,

from 3-D Molecular Designs™. The students were allowed to “play” with the model pieces in the cup for a time and then were asked to Think-Pair-Share some observations about the molecules and their behavior. After the class established which color represented which type of atom and agreeing on ends of repulsive and attractive qualities, I then guided them through the process of building an ice crystal and then trying to fit the crystal back into the cup; the purpose being to see that the arrangement of the molecules, and not their size, was the cause of expansion. The following day I interviewed nine students, who were selected randomly (one 11th grader and eight 10th graders), about the activity with the ice building. The interview questions are found in Appendix F. The interviewees were selected by first taking all students with a signed consent form and then based on grade distribution, a random stratified sampling of students were selected from each category: three from the high achieving, four from medium achieving, and three from lower achieving. One of the lower achieving students did not attend her interview. Though this and subsequent interviews by themselves are intended as a data collection tool, because some of the interview questions will require them to explain their thinking, the interview process may help some students to clarify the concepts in their own schema; thus serving the dual purposes of data collection and treatment. Table 2 summarizes the flow of treatments and data collection for the second and third phases of the project.

Table 2
Schedule for Treatment Set 2 and Data Collection

Activity	Purpose	Unit of Study	Date Range
Demonstration of forces and animations of polarity	Treatment #5	Lewis structures	02/28 – 03/04/11
Knowledge Probe – What’s Going on During Freezing?	Data collection & Preparation for Treatment #6	Lewis Structures	02/28 – 03/07/11
Lab – Building Ice	Treatment #6	Lewis Structures	03/07 – 03/09/11
Student Interviews	Data Collection	Lewis Structures	03/09 – 03/11/11
CCM Lab – Mixture	Treatment #7	Solutions	03/21 – 03/24/11
Animations on Dissolving	Treatment #8	Solutions	03/22 – 03/25/11
Student Interviews	Data Collections	Solutions	03/22 – 03/25/11
CCM Lab – Boiling	Treatment #9	Solutions	03/25 – 04/01/11
Lab – Inquiry on Gas Composition	Treatment #10	Solutions	03/31 – 04/04/11
Student Interviews	Data Collection	Solutions	04/01 – 04/05/11
ParNoMA	Post-Assessment	Acids and Bases	04/05 - 04/07/11
ParNoMA and CCI	Retention Assessment	Acids and Bases	04/13 - 04/18/11

As shown above, the last phase of the treatments occurred after spring break and fell into the topic of solutions. Focusing on the size of the molecule as being something important, but not changing during physical processes, the students were asked to do a lab activity (Appendix G) modeled after the aforementioned “ACTIVITY I: How Much Matter?” (Stepans, 1994, pp.24-25). There were two primary changes to this activity: one, the order was switched so that the solids-in-water were tested before the alcohol-in-water; and two, when the students performed the alcohol-in-water activity they were given a model kit to use for accommodating of concept, extending the concept and going

beyond. As the students worked, I went from group to group asking questions about their thinking and having them clarify answers that were not complete or were too vague. Following the activity the nine students from the earlier interview were interviewed again, about this activity (Appendix H). The next day, as a part of our class notes the students were given the opportunity to view 2 animations on dissolving solids and electrolytes vs. non-electrolytes. These animations served as an extension of the dissolving activity and as a precursor to the final lab treatment which was the electrolysis of water. The electrolysis of water lab was done as a refresher on reactions (specifically decomposition) and a reinforcement of what electrolytes are and why they can be useful. Each group attempted to perform the electrolysis with distilled water first and then with the addition of sodium sulfate; they tested the gases that were generated to verify their composition. Again the selected group of students was interviewed on the process (Appendix I).

As I mentioned earlier, the Particulate Nature of Matter Assessment, or ParNoMA (Yeziarski, 2006), is an assessment tool that I felt would help me with the first part of my main research question, and first and third sub-questions: identifying some of the misconceptions students bring with them to a first-year high school chemistry class and determining retention of learning. A significant portion of the questions in this instrument is related to matter's phases and phase changes at a particulate level (see Appendix A). Having been used in the pre-assessment phase of the project, the ParNoMA was also administered at the end of treatment to assess retention. Additionally, selected questions (topic specific) from the Chemical Concepts Inventory (2001) (Appendix J) were also administered for triangulation purposes. I chose to include the Chemical Concepts

Inventory questions along with the ParNoMA not only for triangulation purposes but also because both instruments, having been previously tested and reviewed, provided me with a degree of validity and reliability that was difficult to achieve with a self-generated assessment. All administrations of the ParNoMA and the Chemical Concepts Inventory were done using the CPS™ modules. In addition to addressing the first part of my main research question and two sub-questions with the ParNoMA, interviews with students were paramount in data collection related to the second portion of my primary question along with the second and fourth sub-questions, looking for ways to facilitate students' reconstruction of their concepts and assessing my potential use of inquiry.

Finally, at several junctures throughout and after the treatment processes, I wrote reflections in a journal. This writing provided me an opportunity me to reflect on how I felt the process was going and where I felt I was having successes and difficulties. In addition, I'll was able to incorporate any observations of students that I'd made. The reflections, along with the previously mentioned data sources provided me with a range of data that I was able to triangulate in order to address my primary question and sub-questions for my project (Table 3).

Table 3
Triangulation Matrix

Focus Questions	Data Source 1	Data Source 2	Data Source 3
<i>Primary question:</i>			
How can I identify misconceptions related to the particulate nature of matter; and then facilitate students in a reconstruction of their understanding to a lasting, scientifically accepted conceptualization	Pre-test with ParNoMA	Knowledge probes	CCM activities
<i>Secondary questions:</i>			
What are some methods I can use to diagnose misconceptions?	ParNoMa	Knowledge probes	CCM activities and teacher journaling
What are some treatments I can provide to help students to reconstruct their conceptualizations?	Lab Activities	Models and Animations	CCM activities with discussion and teacher journaling
How can I effectively assess whether the remediation of the misconceptions has been successfully retained?	Post-treatment student interviews	Lab experience survey and teacher journaling	Post-test with ParNoMA and CCI
How will this experience change my approach to using different teaching techniques when teaching conceptually based material in chemistry?	Post-treatment student interviews	Teacher journaling	Student lab reports

DATA AND ANALYSIS

Data collection and analysis was mostly relegated to the second semester because of the required sequence of our curriculum, but I started in the first semester with a very

important pre-assessment of student ideas and concepts using the ParNoMA. There are twenty questions in the instrument and I started by analyzing the overall results for each class separately and then combined all the data for a broader view of the results. Table 4 shows the overall scores for each class for all twenty questions:

Table 4
Overall ParNoMA Results – Pre-Assessment, (N=39)

Class Period	4 th Period GT and PreAP	4 th Period no GT	5 th Period	6 th Period	Combined classes	Combined classes no GT
Average Score	63%	56%	57%	58%	60%	57%
Median Score	60%	50%	55%	58%	58%	55%
Mode Score	45%	45%	50%	65%	50%	50%
Standard Deviation	0.17	0.14	0.08	0.13	0.14	0.12
Range of High and Low Scores	45	40	25	45	55	45

You may have noticed this data is representative of $N=39$ as opposed to the $N=52$ that was previously mentioned. The reason for this is a technological failure with the CPS™ units in my first period class that caused some of the student responses to not be recorded. As a result, I chose not to include the pre-assessment data for the first period class. However, they were included in treatments, interviews, post-assessment and retention data collection. On the ParNoMA pre-assessment the students averaged knowing a little more than half of the material, which was higher than I expected. In my fourth period class 40% of my students scored 70% or better. This class does have a

PreAP/GT designation and contains a cluster of eight students that are classified as Gifted and Talented, so I was interested in how that may have affected the class score. However, two of the students with GT designation scored fairly low (45% and 50%), and one student without the GT designation scored fairly high (85) but his grades are very inconsistent due to lack of work completion. Table 4 shows a fairly small difference in the combined class values and only seven percentage points on the 4th period/4th period no GT comparison. At this point early point in the project the differences did not seem significant, but I will revisit them later in the analysis process.

My focus at this point, was the group of questions that appeared to indicate potential misconceptions. Through my work with disaggregating state testing data for the students in my school, I have found that attractive, incorrect answers will result in a fairly high percentage of choices, where guessing generally results in a more evenly dispersed percentage of choice by the students. For example if, on question 1 the distribution was 0% A 40% B 50% C and 10% D, with choice C being correct, there is a good chance that the students might have a misconception from prior learning that causes them to favor choice B. On the other hand, if the distribution was 24% A 19% B 30% C and 27% D, it would be more likely that the students were simply guessing. The design of the ParNoMA is such that it asks the students questions about the same topic in different ways, allowing the assessor to look for consistency in the student beliefs and understanding. In this pre-assessment between 10 – 12 questions in each class stood out as being of concern to me as being potential misconceptions. Using the distribution of answer choices as my indicator, what I found in my analysis was that potential misconceptions existed in two major areas: molecular size and physical vs. chemical

changes in water at the molecular level. In relation to molecular size, there were five questions: numbers three, six, thirteen, fourteen and nineteen. Figure 1 shows a compilation of the data from questions 3, 6, 14, and 19.

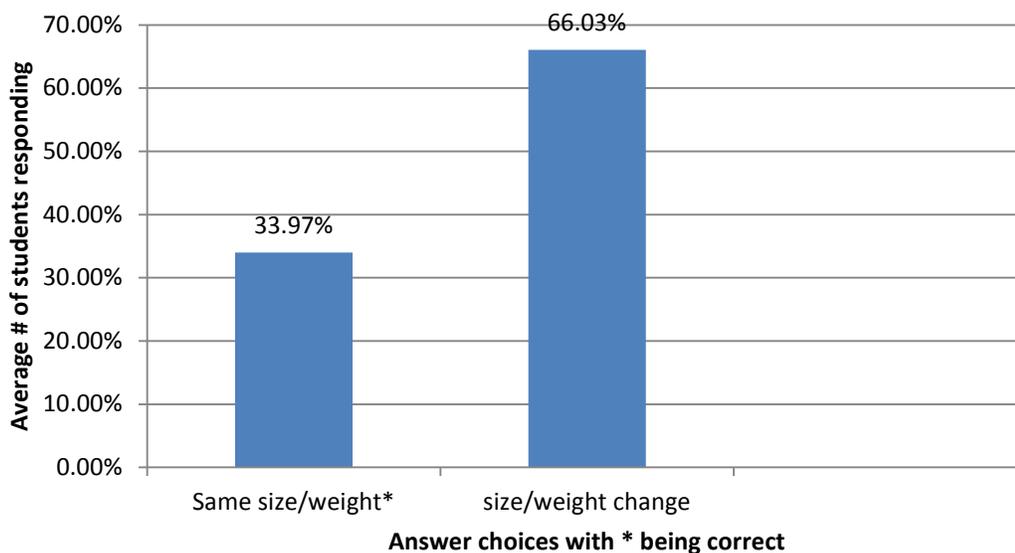


Figure 1. Student Beliefs about Molecular Size as Related to Phase/Temperature Change, (N=39)

Question 3 asked “Which of the following processes will make water molecules larger?” with the choices of: Freezing, Melting, Evaporation, Condensation, and None of the above, respectively. There were two clusters of answers at Freezing and None of the above (Appendix K, Figure K1). On question 14, much the same thing happened; the question asked, “Which of the following processes will make molecules smaller?” with the choices and responses being the same as in question 3. In the 4th and 6th period classes, you can see an example of guessing evidenced by the wide distribution of choices (Appendix K, Figure K2). Overall, only 23.1% of the students correctly answered both questions 3 and 14 correctly, while only two students chose Evaporation for both

questions. This indicated to me that many of the students felt that phase change and molecular size were related in some way, but they weren't sure how.

Still looking at questions related to molecular size questions 6 and 19 looked at size vs. weight as compared to the phase of water. Question 6 posed, "A water molecule in the gas phase is _____ a water molecule in the solid phase." While Question 19 posed, "A water molecule in the liquid phase is _____ at water molecule in the solid phase." In each case the answer choices were Smaller than, Lighter than, Heavier than, Larger than, and The same weight as, with "The same weight as" being correct. Here, as with questions 3 and 14, there were clusters of answers where significant numbers of students chose something other than the correct answer. In this particular case (Appendix F, Figures F3-F4), the distinct misconception is not quite as obvious, but clearly many of the students seem to believe that molecules change size and/or weight when they undergo a phase change. Question 13 was the last of the questions related at all to molecular size, providing the students with an opportunity to complete the statement, "When water molecules in the gas phase are heated, the molecules themselves ____." The available choices were, in order: Expand, Move faster, Become less massive, Change to a liquid, Release air, with Move faster being correct.

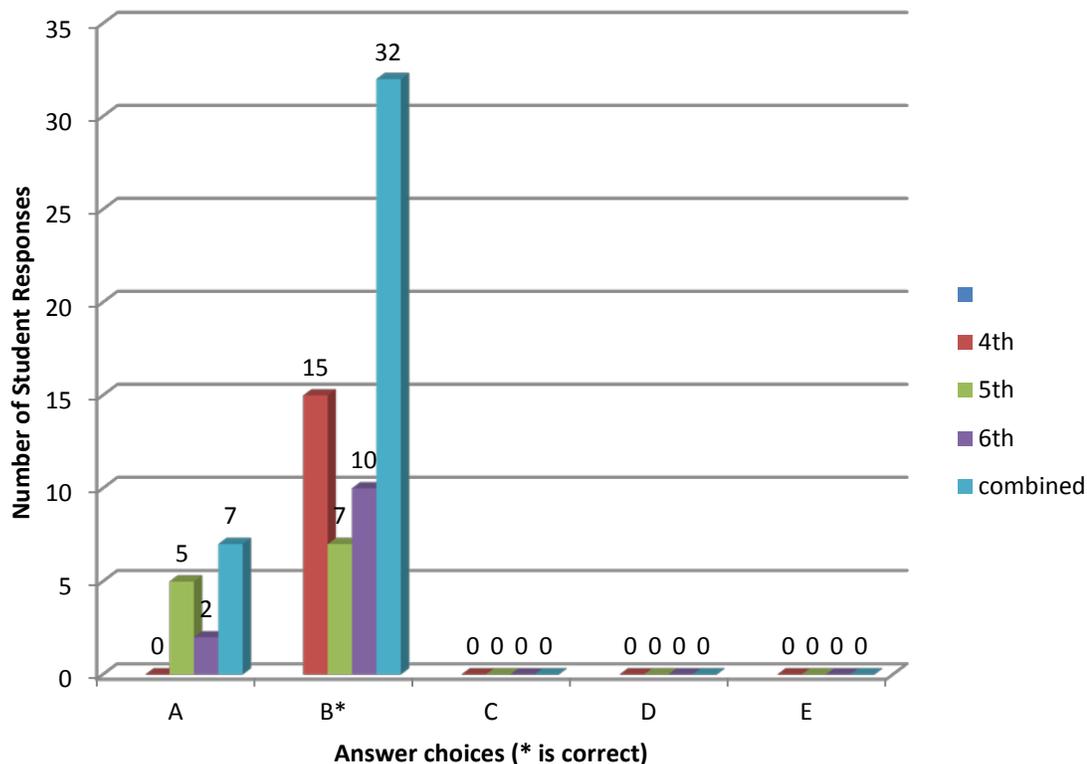


Figure 2. Results of ParNoMA Question 13, ($N=39$)

From Figure 2 you can see that most students did quite well with this question, except for fifth period, which had 42% of the students saying the molecules would expand and 58% indicating a faster rate of movement. In each of the questions (#3 & #14, #6 & #19, #13) compared above, molecular size seems to be an area where a number of students have a potential misconception. A misconception such as this could interfere with students being able to truly understand the Law of Conservation of Mass, which is the foundation of so much of the chemistry taught at the beginning level.

The other group of questions that highlighted a potential area of concern was the group containing questions 5, 7, 9, 11, and 15. This set of questions was related to what happens to water during a phase change and the concept of whether phase changes are

physical or chemical. In each of these questions significant numbers of students indicated the belief that water changes into its elements, hydrogen and oxygen, during a phase change. In question 7 the students are asked directly,

“When water is vaporized, it is changed to ____.”

- A. Hydrogen and Oxygen
- B. Hydrogen only
- C. Gaseous water
- D. Air, hydrogen and oxygen
- E. Oxygen only

Out of the three classes analyzed, 46.2% of the students chose A. Hydrogen and Oxygen, while only 41.0% of the students chose the correct answer, C. Gaseous water. Because question 7 so directly asked about this phenomenon, I have chosen to cross-tabulate the results of question 7 with the other questions in the cluster (#5, 9, 11, and 15). For reading convenience, question 7 appears across the top of the table. Table 5, which follows, shows the comparison of question 7 with question 11.

The question stems are:

Question 11: A wet dinner plate is left on the counter after it has been washed. After awhile it is dry. What happened to the water that didn't drip onto the counter?

Question 7: When water is vaporized, it is changed to:

Table 5
Question 11 vs. Question 7, (N=39)

11↓ vs 7→	Hydrogen and oxygen	Hydrogen only	Gaseous Water	Air, hydrogen and oxygen	Oxygen only
It changes to carbon dioxide	0	0	0	0	0
It just dries up and no longer exists as anything	0	0	0	0	0
It goes into the air as molecules of water	5	0	12	3	0
It goes into the plate	0	0	0	0	0
It changes to oxygen and hydrogen in the air	13	0	4	1	1

In this comparison, as well as in the others (Appendix L, Tables L1-L3) we note the consistency of the students' beliefs that water, when converted to a gas, turns into hydrogen and oxygen rather than water vapor.

The first phase of treatments and subsequent data collection was related to water and the gases that make it up. The students participated in several lab activities, where either a portion of the lab or the entire lab was focused on some aspect of water, hydrogen, or oxygen. After the students had completed three of the lab related activities, they responded to the Lab Experience Survey (Appendix D). The first lab was on the reactivity of the group II metals in water, specifically magnesium and calcium. During the portion of the lab where calcium was tested, hydrogen gas was generated, collected in a test tube, and subjected to the "classic test" of a lighted splint to produce the popping

sound. In the student responses to the survey, specifically related to this lab activity, a very large number of the students (86.5%) said they remembered how to test for hydrogen, and a significant number of the students (75.0%) could provide the correct elaboration on how to perform that test. At the time the survey was completed, the students had seen a demonstration on how to test for oxygen and two students who responded that they remembered how to test for hydrogen confused it with the oxygen test. Following the test for hydrogen, in a class during which we were studying different types of chemical reactions, I demonstrated the electrolysis of water to form hydrogen and oxygen with a Hoffman apparatus. For this particular demonstration a smaller number of students (57.7%) were able to recall the experience with 44.3% of the students able to describe some portion of the demonstration set up and resulting amounts of hydrogen and oxygen. These numbers I expected to be a little lower than those for the hydrogen test, because of three reasons: it didn't make noise, the changes the students saw were not dramatic in rate of production, and the equipment was old and one tube was a bit leaky. Interestingly though, one student did mention, in his response, the cracked piece of glass; and another mentioned the fact that the hydrogen vs. oxygen production was not a perfect 2:1 ratio, which was related to the leaky tube. The third and final lab activity included in this treatment set was the previously mentioned Microscale Generation of Hydrogen and Oxygen. During this lab, the students generated hydrogen and oxygen in separate syringes and then blew soap bubbles with each of the gases, as well as with a 2:1 ratio of hydrogen to oxygen. The bubbles were then lit to assess the quality of the "pop." While the students were working on their questions, one young man asked why the "hydrogen and oxygen didn't explode on their own," leading me to believe

that he was really thinking about the situation. We had a short discussion about activation energy being required to get a reaction started, relating it to the Bunsen burner or a candle. The Lab Experience Survey revealed that 49.0% of the students enjoyed the lab “Quite a lot” and another 28.6% enjoyed it at least “Somewhat.” While reading through responses about what they learned about water, I noticed that my highest and lowest performing students from the same class period both indicated “Quite a lot” of enjoyment, both were able to express something that they had learned from the lab [“that hydrogen burns more intensely in the correct ratio with oxygen” (high performing) and “when the gases hydrogen and oxygen have been combined they can be ignited” (low performing)], and both students indicated that the ratio of hydrogen and oxygen must be 2:1 for the best reaction. Of the eight students (16.3%) that responded that they got “Not Much” enjoyment or enjoyed it “Not at all,” there were four who elaborated with remarks such as “seeing liquids become 2 gases” or, “Hydrogen was separated (sic) from oxygen” that led me to believe they were responding about the Hoffman demonstration rather than the microscale generation lab. Additionally, two of the eight students responding that they didn’t enjoy the lab very much wrote that they had problems with their lab and did not get it to work correctly. With the confusion that seemed to be part of the responses in this last section of the survey, I was forced to pause for reflection; it may have covered too many topics at once, required the students to remember for too long of a time span, or perhaps the wording was unclear.

As previously mentioned in my discussion of the ParNoMA results, I found that many of my students had a pretty well established misconception about molecular size and how it might or might not be affected during phase or temperature changes. In order

to see if that misconception was holding true, I administered a knowledge probe that I entitled, “What’s Going on During Freezing?” I wanted a probe with the style adopted by Keeley, Eberle, and Farrin (2005) in their knowledge probes and was unable to locate one, so I wrote one myself (Appendix E), modeling it as closely as possible to the format of those in the published book. The general question related to an explanation of the expansion of water as it froze, deforming and splitting a plastic jug in the process. Students were asked to choose the best explanation and justify their answer. None of the participating students chose the first or last choice; while the middle three choices, shown below, all attracted student responses.

Bubba’s dad said, “Water molecules get larger when they freeze and they take up more space, which is why the bottle split.”

Aunt Bee said, “Water molecules get larger when they freeze and plastic molecules get smaller when they get cold, so when the water grew and the plastic shrunk, it was not a good combination.”

Bubba’s sister Betty said, “The shape of the water molecules caused them to line up in a specific pattern that took up more space when they were frozen.”

As with the ParNoMA, I found a large cluster of students (64.7%) who believed that Dad’s explanation of expanding molecules was correct. Another smaller cluster of students (13.7%) believed Aunt Bee was correct –again showing the belief that molecular size would change; and barely more than 1/5 of the students (21.6%) indicated that Bubba’s sister Betty was the most correct in her explanation. Following the aforementioned treatment involving Water Kits from 3-D Molecular Designs™, I interviewed nine students about the activity (Appendix F). Every one of the interviewed students enjoyed the activity and felt similar activities would be helpful in the future. One student said he would like to see this type of activity “very much, because it connects to

the diagrams and gives it life.” Another student said, “I never get it until I do the lab. When I do the lab, magically it comes to my mind.” When asked about how the activity caused them to rethink their answer and what caused that “rethinking” three of the students interviewed said it caused them to rethink their answer and the specific cause of that “rethinking” was the fact that the ice crystal we built “didn’t fit in the cup.” Those same three students, along with 5 others indicated that they were somewhat surprised by the space (hole) between the molecules in the ice crystal.

The test following this activity had one question that was particularly geared toward this very concept and of the interviewed students, four of the nine (44.4%) answered in such a way that it indicated that an improvement in their conceptual understanding. One of the interviewees, who chose the Dad’s explanation as being correct on the probe, indicated that his father had told him the very same thing. In his interview he said the activity caused him to rethink the way water was structured and that he was surprised by the space between the molecules; but on his test he did not make any correction to his personal concept. This indicates to me that his concept is fairly strongly held and highly influenced by language, as reference by Gabel in her 1989 article. Another interviewee, who did correct his concept, indicated that “building helps me learn better because I can see it.” That same student asked me, the day after the interview, “Did I sound dumb?” to which I responded, “No, you sounded like a student.” He then responded that he liked being interviewed, “It was fun.” For this particular student it may be that the interview process itself could have been part of his reworking of his concept. As a student with a relatively short attention span, the chance to discuss his thoughts in a one-on-one format in addition to the building activity may have cemented his thinking.

Overall, the four classes tested showed improvement with 59.2% of the students indicating that molecular arrangement was responsible for the expansion of water when it freezes, rather than molecular expansion (22.4%). An additional cluster of students (18.4%) chose an answer related to packing of the molecules but it was one which caused greater density, indicating that they had moved toward a concept accommodating molecular arrangement, but hadn't quite repaired everything.

The Conceptual Change Model (CCM) illustrated by Stepan (1994) afforded me the opportunity to both identify and try to rectify misconceptions. As I was teaching a unit on solutions I used an adaption of his first activity, entitled "How Much Matter?" (Stepan, 1994, pp.24-25) I adapted the activity by switching the order of types of solutes dissolving in water (liquid vs. solid solute) and then adding on a section related to electrolytes. In the first part of the activity, there were very few surprises for the students, as most of them knew that the solutes would not take up the same amount of space when dissolved as when separate from the solvent. There was, however, an interesting discussion that took place in at least one group in every class: The students seemed to know the alcohol was less dense than water and mentioned that, as well as previous learning about rates of evaporation. As a result, they predicted, that a mixture of 25 mL of water with 25 mL of alcohol would result in 40 – 45 mL rather than the 48-49 mL that actually occurred. At the end of the activity, I did use ball and stick models of the alcohol and water to help with visualization. The second part of the activity, which focused on conductivity and electrolytes, resulted in most students (62%) predicting that pure water would light up a conductivity tester. The students did better on their predictions about salt water (96% correct) and sugar water (70% correct); however the water and alcohol

mixture predictions were similar to those of pure water. Student comments as to their reasoning varied from no comment to a paragraph, with several students indicating the presence of metals and/or non-metals would affect the conduction. Only one student, who is not classified as GT, used the word electrolyte in any prediction/explanation combination and he was correct in his predictions. Following the investigations, I showed the students two animations from the North Carolina School of Science and Mathematics (2002) website about: dissolving salt in water and dissolving sugar in water. [The website does require one to register and get a password, both of which are free (Appendix M)]. One student said that she was “looking forward to the animations” and when I asked why she said, “I like demonstrations better than lab because you can get it wrong in lab and not know it. The demonstration and explanation makes sure you get it right.” Class discussion after the animations indicated that several students had found the animations helpful to their understanding of the dissolving process and electrolyte function.

During the interviews (Appendix H) following the CCM activity I focused on two major areas of interest: the CCM process and the animations. Because I had never used the CCM process in a lesson before, I was interested in how helpful the students perceived it to be. All of the students interviewed liked the type of lesson and thought that they would like to have more of that type of lesson in the future, with the exception of one student who avoided the question by responding with a comment about what she didn't understand about the dissolving as it pertained to how much of the salt and sugar did or did not dissolve. That student though, when asked about whether we should have future lessons of that style, said “maybe, depends on the subject. If I didn't know anything about it, it might be confusing.” When asked if the process of committing to an

outcome was helpful, all of the students responded that it had, except one young man who said, “Not for me, I got them wrong. But I did use my brain to think about it.” Even the student who avoided the earlier question about the lesson said, “Yeah, it made me think about what might happen.” This, to me, was significant because the student in question has been diagnosed with Asperger’s syndrome, a high functioning form of autism that affects social skills and awareness; she was finding something useful in a process that was requiring social interaction. In fact, seven of the nine indicated that the thinking about the outcome and then discussing it with their group members was helpful. One student, who sometimes has difficulty focusing, said that it helped him to focus; he also wrote my absolute favorite observation of all the papers I read regarding the testing of distilled water, “OMG, Why??” Apparently the water being a poor conductor got his attention! The second part of the interview was related to the students’ perceptions about the helpfulness of the animations. Seven of the nine students interviewed indicated that, in their opinion, the animations were helpful in their learning. Comments such as “yeah definitely, it gave me a visual picture” and they were “helpful, and they were cool too” reinforced those responses. When asked about how their knowledge changed regarding matter at the molecular or atomic level, the students generally felt like they knew more, with some referencing the affect that polarity had on the dissolving process with the pulling apart of the ions of salt and the spreading out of the particles. The final question of the interview asked them to pick, if they had to, between the committing to an outcome vs. the animation as far as helpfulness; only two picked the animations, both girls. One of girls said she picked animations “because if you did something wrong in lab, it could be a problem. The animation is right.” This was the second student (and second girl) to

vocalize that concern. Those students who chose the committing to an outcome cited reasons such as “discussion was helpful” and “it was more hands on.” Three students reluctantly picked, but expressed a preference for both.

The last part of the treatments was during our discussion of solutions and colligative properties, and spiraled back to both our discussion of water and electrolytes. First we did a Conceptual Change Model activity on boiling, using syringes and the same solutions that Calik (2008) had used. As a part of that process, in the Confront Beliefs section, I had the students draw pictures of what they believed had happened, when the water boiled. Many students expressed concern that they weren't sure they were right; so after completing the lab activity I had the students pull out the blue and green models, as well as a couple of water molecules from the Water Kits from 3-D Molecular Designs™, and allowed them a few seconds of play followed by Think-Pair-Share to determine which would represent the sodium ion and which would represent chloride. Class discussion quickly resulted in agreement of the correct representation. They were then asked to compare the attraction between water molecules to those between water and the sodium or chloride ions; and then to model for me two things: first, the water as a liquid and second, the water as a liquid that was in the process of boiling. As I walked among the groups I found that most were able to model the boiling correctly the first time, and I was able to help those who weren't correct make the appropriate adjustments. Following that activity, students were doing a lab where they made solutions and then evaporated other solutions to determine concentration. To reinforce the idea that steam is really water vapor, I gave the students cobalt chloride paper, which turns pink in the presence of water. My hope was that they might make that connection of boiling not being a chemical

change. Many students commented on how the paper turned pink in the steam, but went back to blue as it was removed from the steam and allowed to dry. Lastly, the students performed a lab on the electrolysis of water, where they collected the hydrogen and tested it with the previously learned hydrogen test. Most of the students recalled the test for hydrogen without prompting, which was a good sign of retention, since it had been two or three months since they last tested hydrogen. All of the students but four in the study were able to write the correct equation for the decomposition of water. Two of the students who had the wrong equation had not balanced it correctly, while the other two (who were both very low performing) had the water not undergoing a change at all. In the final round of interviews I chose, because of scheduling, to do small groups according to class period; keeping the student group the same, just clustering the students for efficiency and potential interaction. Each cluster of students could tell me that the cobalt chloride paper turned pink when they tested that and each group had at least one student who immediately tagged water vapor as the reason for the color change. There was one set of students who debated whether it was hydrogen or water vapor from the boiling solution and water vapor was eventually the victor. In a way this surprised me, because two of the students in this group of four had incorrectly chosen that water vaporizes into hydrogen and oxygen on their post-test and one of them said that water vaporized into oxygen only. Was the word “vaporize” the root cause of an issue in this question? Additionally, each group was able to suggest that when we modeled liquid water and then boiling water with the Water Kits we had more space between the molecules and the molecules did not change size or makeup. The last activity to be discussed in the interview process was the electrolysis of water. All were able to recall what gas we tested

(hydrogen) and how we knew what it was (the “pop” test). One group of students very specifically mentioned that the electrolysis was different from boiling because electrolysis was “a chemical change,” where the “boiling water still had the H and O together.” Another group mentioned the “other terminal had bubble too, not as much” indicating the distinct breakdown of the molecules of water into their parts.

Earlier I mentioned the possibility that the word “vaporize” may have been the culprit in some wrong answers on the pre- and post-assessments. It is possible that the word “vaporize” did not mean “to turn into a gas,” rather, it may have been a more comic-book like intimation. I say that because the final question of my interviews, other than offering final thoughts, was about wording on questions. I had them describe to me what mental picture came with the following two sentences:

When water boils, the water molecules separate from one another.

Water molecules break apart into their elements when they decompose.

Most of the students interviewed indicated that the first sentence brought to mind a picture of water molecules moving around, but not necessarily touching one another; while the second sentence indicated, in one child’s words, “H over there, O over here.” There was one set of boys, though, that indicated the first and second sentences were too similar and their descriptions were almost identical. When asked what would be a better way of saying separate, one young man said “getting farther apart.”

The final data collection was a post-assessment, again using the ParNoMA and incorporating five additional questions from the Chemical Concepts Inventory. In comparing the pre-assessment and post-assessment results, aside from overall

improvement, there were a few items that really stood out. The first was the group of questions (#s 3, 6, 13, 14, 19) that had students evaluating molecular size and or weight, and how that might be affected by phase change or temperature change. Figure 3 reveals that there was almost a 180° shift in beliefs from the pre-assessment to the post-assessment with questions 3, 6, 14, and 19.

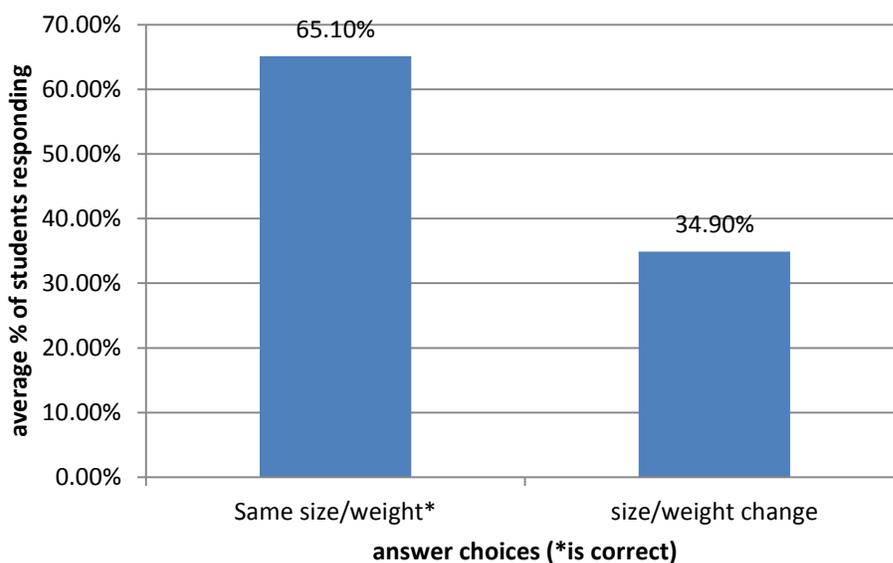


Figure 3. Student Beliefs about Molecular Size vs. Phase/Temperature Change (Post-assessment), (N=53)

In question 13, which earlier had shown a fairly significant guessing factor in the fifth period class, showed that in all classes all students but one were able to answer correctly.

My hope is that this indicates less guessing by that class, reinforced by the fact that the 5th period class improved their overall performance by nearly twenty-three percentage points (nearly 80% vs. nearly 57% correct). Additionally, to this cluster, two questions (24 & 25) from the CCI (Appendix N) were added to the end of the assessment that asked about solid iodine in a sealed tube that was turned to a gas. The focus was on

conservation of mass – in other words, the molecules would maintain the same mass. Overall 82% of the students answered those questions correctly, lending additional credence to the previous improvements.

The second group of questions (#5, 7, 9, 11, 15) was focused on what happens to water during phase changes; whether it changes physically or chemically. I also included question 23, which was added on to the post-assessment version and was originally question 6 on the CCI. In order to make a direct comparison I first looked at the class results for question 7, noting that the percentage of students indicating that water became gaseous water upon vaporization improved from 41% to 64% and the number of students indicating a belief that water, when vaporized, became hydrogen gas and oxygen gas went down from 46% to 30%. When the first period class was removed from the data pool (you might recall their preliminary data was not included due to a technology failure), the percent correct remained the same and the students choosing hydrogen and oxygen dropped to 25%. When cross-tabulating the other questions in the group against question 7 I found similar improvements. Question 11 and question 7 are compared in Table 6, with the remainder of the post-assessment cross-tabulations found in Appendix O.

Table 6
Question 11 vs. Question 7 of the ParNoMA Post-Assessment, (N=53)

11↓ vs 7→	Hydrogen and oxygen	Hydrogen only	Gaseous Water	Air, hydrogen and oxygen	Oxygen only
It changes to carbon dioxide	0	0	0	0	0
It just dries up and no longer exists as anything	0	0	0	0	0
It goes into the air as molecules of water	4	0	31	2	0
It goes into the plate	0	0	0	0	0
It changes to oxygen and hydrogen in the air	12	0	3	0	1

Although to me, there are still a fairly disconcerting number of students who believe that water turns into hydrogen and oxygen during a phase change, there is a large portion of the students who seem to have reworked their conceptual framework.

Finally, the overall scores of the students on the ParNoMA were compared, showing an average improvement from 60% to 82% correct for the three classes whose data were used in both the pre-assessment and post-assessment. This improvement includes two students who had no change and two students who actually went down. I know that at least one of the two students who had no change is not a native speaker, and perhaps there was a language issue on some of the questions. The two students who went down are not strong performers and there is the possibility that they either guessed on the

pre-assessment or got themselves confused about what they were thinking. Unfortunately, neither of these two students was in the interview pool, so any explanation would be pure conjecture. The difference in average score for my 4th period class, containing both GT and non-GT students, was a bit larger (10% vs. 7%) but that was offset by some very large gains by my non-GT students in my other classes. This was particularly true for my 5th period class, which had a leap from 58% to 85% correct. As a result, when the GT students were removed from the overall scores the improvement difference was from 57% to 80%, which seems to be an insignificant difference from the all inclusive group.

Upon reviewing the data collection and analysis processes I was able to determine that many of my students had misconceptions about matter, believing that water breaks down into its elements during phase changes, water molecules change size during phase change, and that water is a good conductor. The ParNoMA, knowledge probes, and Conceptual Change Model all proved useful for identification of potential misconceptions; and while both the hands-on activities and animations seemed to be helpful, the students expressed a preference for the hands-on activities or a combination of hands-on coupled with animations.

INTERPRETATION AND CONCLUSION

In the 1965 movie “The Sound of Music” there is a series of scenes, up on the mountain and continuing in the city, where Maria teaches the von Trapp children to sing. Once they have the Do-Re-Mi’s of music Brigitte says, “But it doesn’t *mean* anything.” For my students, that is also true; and as their teacher one of my jobs is to help them take

the “Do-Re-Mi’s” of chemistry and try to give them meaning. At this point in my project, with the data collected and analyzed, the next step is to try to generate some sort of meaning from the pool of data. To apply meaning, I think it would help to review the original questions I was trying to answer, namely:

- How can I identify some of the major misconceptions related to the particulate nature of matter that might act as barriers or detractors from learning in a first-year, high school chemistry class; and what can I do to facilitate students in a reconstruction of their understanding to a lasting, scientifically accepted conceptualization?
 - What are some methods I can use to diagnose misconceptions?
 - What are some treatments I can provide to help students to reconstruct their conceptualizations?
 - How can I effectively assess whether the remediation of the misconceptions has been successfully retained?
 - How will this experience change my approach to using different teaching techniques when teaching conceptually based material in chemistry?

From a teacher standpoint, the ParNoMA and questions from the CCI certainly seemed to be helpful in addressing the main question of how I might diagnose misconceptions and seemed to be useful in assessing for retention as well. Because of the clustered topics

within the assessments (both the CCI and the ParNoMA), the data from these questions provided me with a great look at persistence of thought on the part of the students. For example, the ParNoMA questions 3, 6, 14, and 19 were focused on the weight or size of molecules during temperature or phase change, and found 66% of the students believing that some sort of change in size or weight occurred during temperature or phase change compared to 34% that believe there was no change in size or weight. By using the CPS™ units, this data was quickly collected and had the added advantage of providing several types of reports that ranged from simple averages to comparing different questions for consistency. Consistency of student response was indicated as important to Mulford & Robinson (2002) and their design of the CCI was guided by that import. These reports and data were then used as a springboard for planning lessons and choosing activities, demonstrations, and labs that would address any identified misconceptions. From a student standpoint, the ParNoMA and CCI were not particularly helpful, because a) it was not instantaneous for them and b) the students didn't necessarily understand, from taking the assessment, that they had a misconception. The Conceptual Change Model and the knowledge probes seemed, based on student responses, to provide for the instantaneous or near-instantaneous feedback and identification for the students. Stepan (1994) indicates that student awareness of a misconception is a required condition for any change in concept to occur; and a chance for students to share and discuss their ideas is also supported by both Stepan (1994) and Keeley et al. (2005) as essential for students to reconstruct their thinking. In that way both the CCM and the knowledge probes served as not only assessment tools, but as part of a treatment process as well.

In the Conceptual Change Model, the students got immediate feedback by having the opportunity to commit to their ideas, share with a partner or group and then test or confront their beliefs. Once they had an opportunity to confront their beliefs they could reflect on what they had experienced and try to accommodate those experiences into their conceptual framework. I think it bears a reference here to something I have always been concerned about, and a few my female students mentioned earlier: in lab, you don't always know if you're getting it right. That was, and is, a huge concern for me with this particular model. It doesn't really provide for "fixing" something that doesn't seem broken. For example: A student says, "Salt water will be a good conductor because sodium is a metal" which has a correct belief with an incorrect explanation. When this student confronts his or her belief, they will be proven correct because salt water is a good conductor. However, they will not have any experience that contradicts the reasoning that the metallic nature of sodium is responsible; thus they could go away from class perfectly happy with their "correct answer" and not have any conceptual change. Thus, from what my students indicated in their interviews, I think it would be wise to include an additional portion to the lesson where the students can see a model or animation or demonstration that would get to the heart of *why* salt water is a good conductor and then follow that with class discussion so students can verbalize and reflect on their thoughts. Providing these opportunities is supported by at least two literature sources, Keeley et al. (2005) and Stepan (1994), which indicate that plausible explanations are required for students to accept new conceptual thinking. Having viewed several animations online, in my opinion those from the North Carolina School of Science and Mathematics are of good quality and really model the particulate nature of

matter very well. They don't last long, so you can show them more than once, in quick succession and make suggestions to the students about certain features to look for, as was done by Yeziarski & Birk (2006) when they provided guided discussion questions for animation viewing. As an example, during the NaCl Dissolving (NCSSM, 2002) animation I had my students pay close attention to the portion of the water molecules that was pulling on the different ions. This allowed class discussion to focus on charges of the ions as being important to the conductivity of the salt water.

The knowledge probe, What's Going on During Freezing, seemed to be a fairly effective diagnosis that reinforced what I knew previously from the ParNoMA, while allowing very quick feedback for the students. From a teacher perspective, the results of the knowledge probes are easy to analyze and lend themselves to providing a treatment or lesson that is very focused on a topic. From a student perspective, having responded to the probe at the end of a class period, the next day's lesson incorporating the Water Kits afforded them an opportunity to address their responses very quickly and to challenge their conceptual framework. For the students who were easily distracted, the kits provided them an experiential way to confront their thinking and keep focused. So many of the students commented on the large amount of space that was between the molecules when the water was in its crystal structure of ice, that I truly believe this activity was helpful in remediating molecular size issues. The improvement on the ParNoMA scores related to molecular size, in combination with the student comments reinforces that belief. In fact, the number of student who believed that molecules maintain their size or weight with a temperature or phase change increased from 34% to 65%.

In nearly every interview the students remarked about the hands-on activities, whether they were fairly strictly guided like the ice building or more free flowing like the CCM activities or lab; saying that the opportunity to *do* the science was helpful in their learning. As I reflected on the several lab activities related to the makeup of water, I found a couple of themes: first, having a thematic or repeating task that connects the labs is helpful, and second, if activities are connected, there needs to be a fairly short period of time between them in order for students to really put that connection into their minds, or additional reinforcing instruction needs to be supplied. I believe the thematic idea of testing for hydrogen helped with retention. The students did not all remember how to test for hydrogen during the first survey, but after completing additional labs with hydrogen most of them remembered how to run the test during the hydrolysis lab. One interesting side note on the testing process – many students, when writing up their very first lab where we tested the hydrogen, indicated that the hydrogen “poped” when the splint was introduced. I called them on the spelling, mentioning that “to pope” was not a verb, as far as I knew. We had a few laughs over the mental image of the hydrogen going around the lab, dressed like a pope, and “popping.” As we had other opportunities with hydrogen and oxygen and testing of gases, kids would often reference the “pope” test in jest. By creating a bit of humor around this very simple item, the kids remembered it. As far as connecting activities is concerned, I personally love the idea of spiraling instruction, giving the students many opportunities to master material; and I feel as though the labs and activities we did were beneficial. However, it was not as effective as I was hoping (only 58% mastery). One reason that this might be was the time between activities; the other is that many of the students didn’t know that they had the misconception about

water and physical vs. chemical change. I feel as though I made a big mistake in not telling them where they stood after I had their data. I was worried that they might feel bad about not knowing something that they theoretically learned in junior high school, but in retrospect, sharing that misconception with them might have given them more focus. That way, each time we returned to the theme we could have had a brief discussion or update to get us refocused. This discussion and additional focus might have mitigated the time factor that seemed to be an issue. One notable exception to the change in student beliefs as it pertained to water was question 15 of the ParNoMA, where decomposition was the correct answer as to how hydrogen and oxygen gases may be formed; although the total percentage of students who were correct, was actually lower than other questions in that topic cluster (49% vs. 58%) the improvement for question 15 was much greater (42%) as compared to questions 5, 7, 9, and 11 (27%). This is supported by Gabel (1989) who referenced language and instruction as two of the three contributing factors in student learning of conceptual material. Chemistry is first place in the Katy ISD science curriculum where students are truly held responsible for the term “decomposition” as it pertains to chemical reactions.

As far as diagnosing misconceptions then, I believe that the ParNoMA and CCI type assessments are great for teachers because they provide a tremendous amount of data and make effective planning aides; however, from the student perspective the instantaneous nature of a knowledge probe, such as those suggested by Keeley et al. (2005) or a lesson styled in the format of the Conceptual Change Model, ala Stepan (1994) is probably more effective. The Conceptual Change Model is helpful as well for students making changes to their conceptual framework, in that it provides for the vital

discussion and the hands-on aspect of learning (mentioned in 2 separate journal entries); but caution may be in order to avoid the happily “correct” misconception that can occur if students don’t encounter an experience that would conflict with any faulty reasoning. Carefully chosen animations, such as those used in the ParNoMA study by Yeziarski & Birk (2006), and models serve to provide a visual image for the students to reflect on; and interviews, or small, intimate discussions such as those touted by Nakhleh et al. (2005), Stepan (1994), and Keeley et al. (2005), seem to help the students put their “Do-Remember’s” together to give a concept full meaning.

VALUE

Meaning is certainly important, but it is not always valuable. There are many definitions of *value* including those related to money, art, intrinsic worth and relative worth or importance; and in this case relative worth or importance is probably the more appropriate definition. So, going back to my final sub-question I asked myself “What did I get out of this process that was useful to me, and might affect my teaching or be useful to others?” Perhaps the single most important result to me was how important it is to students to be able to verbalize their thinking and have a chance to reflect on what they have learned. During the Conceptual Change Model activities and in the knowledge probe the students had a chance to commit to what they thought was the correct explanation and the chance to talk about it with me and their peers. During the interview process they expressed that the commitment and discussion were helpful to their learning. Interestingly, in the very last interview I asked the students if they had anything extra that they’d like to share. One student, who does have trouble focusing, said that participating

in the interviews “was fun” and “it helped me a little to understand.” Another student said the interview process was “kind of like a review, it helped clarify my thinking.

Additionally, a third student, during the final interview said that “the electrolysis lab was helpful and the background with hydrogen helped when we did the lab,” which brings me to another result.

Although the design of the treatments including labs and activities related to water was flawed, the comment about the hydrogen background does indicate to me that there is potential value in the thematic (or spiraling) approach to teaching conceptual material. The caveat is that the students need to know why the theme is important, and likely they need to be reminded each time they return to the theme. This is very much supported by both Stepan (1994) and Keeley et al. (2005). So as I look to developing future units of study and the related lab activities I will need to be mindful of making sure that the students are aware of our goal. By this, I don’t mean simply putting the day’s learning objective on the board, but making sure to share why it’s an important learning goal and giving them time to discuss and reflect on what that means to them. Creating this additional focus may help the students to be more aware of what they should be looking for, in terms of learning.

Lastly, I believe that the use of models can be particularly helpful when students are learning about the particulate nature of matter. Matter is a very conceptual topic and it’s difficult to give them a visual image to go with their notes and terms, supported by 6 of 8 student interviews. My students said, in both interviews and class commentary, that the models of water gave them a good mental image and I will definitely use the Water Kits in the future. Although they are somewhat expensive, if well cared-for they will last

a very long time and I believe they would be a worthy investment for any high school chemistry department. And while the models are useful, sometimes a good animation is a great visual into the *why* of something. I'm always on the lookout for a good animation, and I have found those from the North Carolina School of Science and Mathematics to be very well done. One concern I do have is the lack of good animations about matter at the particulate level, during phase changes. They tend to show movement and contact quite well, but don't show the arrangement and crystal structure very well. So one area on which I will focus in the future will be to continue searching for good animations on phase changes.

The value here, then, is threefold: give the students time to commit to and discuss an idea (become aware of their misconception), provide hands-on opportunities and lab experiences to make the new concept plausible, and supplement their experiences with models and well-researched animations that help them understand the "OMG, Why???"

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APPENDICES

APPENDIX A

PARTICULATE NATURE OF MATTER ASSESSMENT (PARNOMA)
VERSION 2

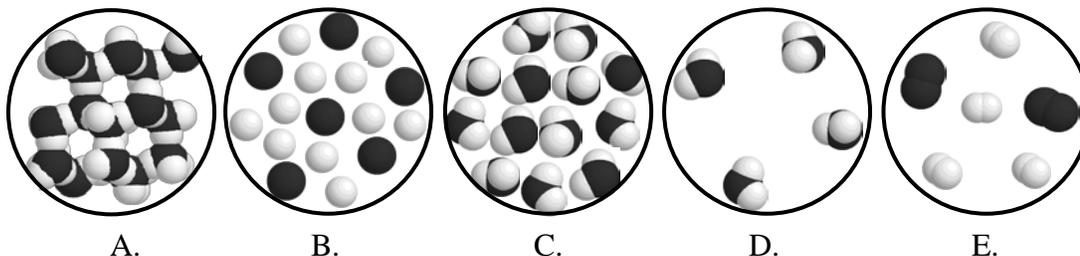
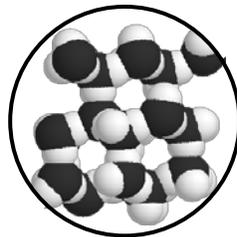
PARTICULATE NATURE OF MATTER ASSESSMENT (PARNOMA)
VERSION 2

Instructions:

Carefully read each question and choose the best answer.

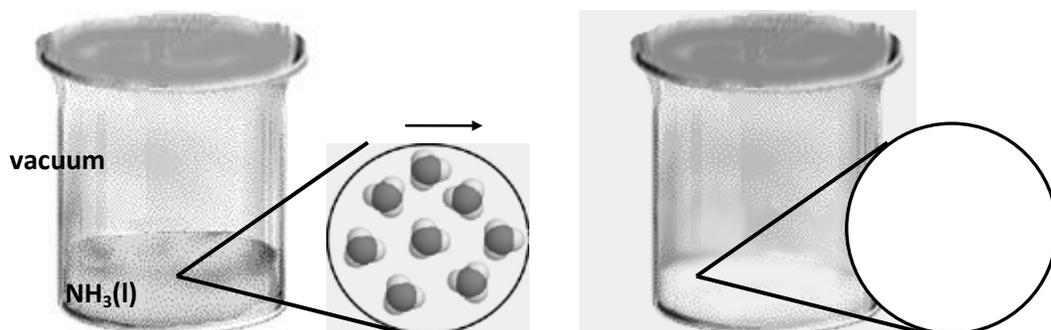
1. A diagram representing water molecules in the solid phase (ice) is shown below.

Which of these diagrams best shows what water would look like after it melts (changes to a liquid)?

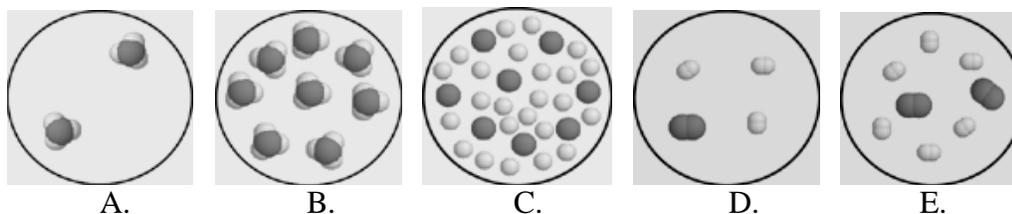


2. Consider three samples of water in three phases. The first is solid water (ice) at 0°C , the second is liquid water at 24°C , and the third is gaseous water at 100°C . The water molecules in the liquid phase _____ the water molecules in the gaseous phase.
- A. move faster than
B. move slower than
C. move at the same speed as
D. move more randomly than
E. travel in the same direction as
3. Which of the following processes will make water molecules larger?
- A. freezing
B. melting
C. evaporation
D. condensation
E. none of the above

4. A sample of liquid ammonia (NH_3) is completely evaporated (changed to a gas) in a closed container as shown:



Which of the following diagrams best represents what you would “see” in the same area of the magnified view of the vapor?



5. When water changes from a liquid to a gas through evaporation or vaporization, energy is required to
- break the bonds between the hydrogen atoms.
 - form new bonds between the atoms.
 - break the bonds between the oxygen and hydrogen atoms in the molecules.
 - break the water molecules away from other water molecules.
 - form new bonds between the molecules.
6. A water molecule in the gas phase is _____ a water molecule in the solid phase.
- smaller than
 - lighter than
 - heavier than
 - larger than
 - the same weight as

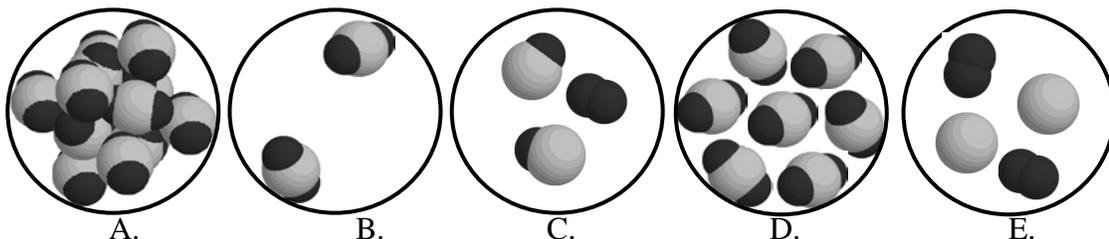
7. When water is vaporized, it is changed to
- hydrogen and oxygen
 - hydrogen only
 - gaseous water
 - air, hydrogen, and oxygen
 - oxygen only
8. A pot of water is placed on a hot stove. Small bubbles begin to appear at the bottom of the pot. The bubbles rise to the surface of the water and seem to pop or disappear. What are the bubbles made of?
- heat
 - air
 - gaseous oxygen and hydrogen
 - gaseous water
 - none of the above
9. A pot of water on a hot stove begins to boil rapidly. A glass lid is placed on the pot and water droplets begin forming on the inside of the lid. What happened?
- The lid became sweaty.
 - Steam cools and water molecules moved closer together.
 - Water from outside leaked into the pot.
 - Hydrogen and oxygen combined to form water.
 - Steam combined with the air to wet the inside of the lid.
10. Consider three samples of water in three phases. The first is solid water (ice) at 0°C , the second is liquid water at 24°C , and the third is gaseous water at 100°C . The water molecules in the liquid phase _____ the water molecules in the solid phase.
- move faster than
 - move slower than
 - move at the same speed as
 - move less randomly than
 - travel in the same direction as
11. A wet dinner plate is left on the counter after it has been washed. After awhile it is dry. What happened to the water that didn't drip onto the counter?
- It changes to carbon dioxide.
 - It just dries up and no longer exists as anything.
 - It goes into the air as molecules of water.
 - It goes into the plate.
 - It changes to oxygen and hydrogen in the air.

12. Which of the following processes does **NOT** require heat energy?
- A. evaporating water
 - B. melting ice
 - C. boiling water
 - D. vaporizing water
 - E. condensing water
13. When water molecules in the gas phase are heated, the molecules themselves
- A. expand.
 - B. move faster.
 - C. become less massive.
 - D. change to a liquid.
 - E. release air.
14. Which of the following processes will make molecules smaller?
- A. freezing
 - B. melting
 - C. evaporation
 - D. condensation
 - E. none of the above
15. Oxygen and hydrogen gases may be formed from liquid water through the process of
- A. vaporization.
 - B. evaporation.
 - C. decomposition.
 - D. freezing.
 - E. boiling.

16. A diagram representing carbon dioxide molecules in the solid phase, also known as dry ice, is shown below.



Which of these molecular diagrams best shows what dry ice would look like after it melts (changes to a liquid)?



17. When water at 25°C is heated and changes to a gas at 110°C , the water molecules
- become more organized.
 - move farther apart.
 - stop moving.
 - move closer together.
 - move more slowly.
18. Which of the following processes requires heat energy?
- condensation
 - freezing
 - evaporation
 - cooling
 - none of the above
19. A water molecule in the liquid phase is _____ a water molecule in the solid phase.
- smaller than
 - lighter than
 - heavier than
 - larger than
 - the same weight as

20. When water at 24°C is cooled to 0°C and freezes, the water molecules
- A. become less organized.
 - B. move much faster.
 - C. stop moving.
 - D. break apart.
 - E. move much more slowly.

APPENDIX B

PERIODIC TRENDS FOR REACTIVITY IN THE GROUP 2A ELEMENTS

PERIODIC TRENDS FOR REACTIVITY IN THE GROUP 2A ELEMENTS

Problem

How does the reactivity of metals change as you move down a group or across a period?

Background

The elements in Group 2A of the Periodic Table are called the Alkaline Earth Metals. Like the elements in Group 1A or the Alkali Metals, the elements in Group 2A are chemically active and are never found in nature in the elemental state. Like all members of a group, or family, the elements in Group 2A share common characteristics. Both Group 1A and 2A elements can react with water. An example of such a reaction would be:

**Pre-lab Questions**

1. List the alkali metals.
2. List the alkaline earth metals.
3. After watching the video clip, summarize your observations about the reactivity of the alkali metals with placed in water.

APPENDIX C

MICROSCALE GENERATION OF HYDROGEN AND OXYGEN

MICROSCALE GENERATION OF HYDROGEN AND OXYGEN

- Objectives:**
1. To predict, through identification of the limiting reagent, the volume of gas that can be generated during a chemical reaction.
 2. To investigate, and report on, the effect of different stoichiometric proportions of gases in a reaction.
 3. To determine a % error for the reaction.

Materials: Chemicals

solid magnesium powder	solid potassium iodide
1.0 M HCl	6% hydrogen peroxide
distilled water	

Equipment

60 mL syringe with cap	vial cap	balance
rubber tubing	small beaker	ear plugs (optional)

- Safety:**
1. Wear goggles.
 2. The acid and peroxide solutions are extremely irritating and can burn your skin.
 3. Caution should be used when removing the syringe cap. Gas pressure may result in liquids being sprayed out of the syringe. Hold the syringe vertically, with cap pointing up, when removing the cap.
 4. All materials may be safely disposed of in the sink. The gas may be safely released into the atmosphere.
 5. The explosions with hydrogen and oxygen will be loud. You should protect your ears with either earplugs or by covering your ears with your hands.

Procedure:

Make a data table for recording the following information: The mass of magnesium, the volume of the hydrogen generated, mass of potassium iodide, the volume of oxygen, observations about the 'intensity' of the hydrogen explosions and the relative amounts of hydrogen and oxygen.

Part I - The Generation of Hydrogen

1. Weigh 0.06 g of powdered Mg in a vial cap.
2. Keep the syringe in a vertical position while performing the following steps:
 - a. Remove the plunger from the syringe.
 - b. Place your finger over the tip.
 - c. Fill the syringe completely with water.
3. Carefully float the vial cap with the magnesium on the water in the syringe.
Allow the water to drain and the vial cap to rest on the bottom of the syringe.
4. Insert the plunger all the way so that it fits snugly against the vial cap.
5. Carefully draw in 5 mL of HCl and seal the syringe with the end cap.
6. Shake the syringe up and down to mix the reagents, allowing the reaction to take place. As the gas is generated the plunger will move up the barrel.
7. When the reaction appears to be over, invert the syringe and carefully remove the cap. Rotate the syringe 180 degrees and carefully discharge the liquid in the syringe. Replace the cap and measure and record the volume of hydrogen gas generated.
8. Wash the gas by drawing in 5 mL of distilled water, replacing the cap and mixing thoroughly by shaking it up and down. Discharge the water carefully, again trying not to push out any of the gas.
9. Seal the syringe by putting the cap back on the end. Set the syringe aside.

Part II - The Generation of Oxygen (new syringe)

1. Weigh 0.10 g of KI in a vial cap.
2. Keep the syringe in a vertical position while performing the following steps:
 - a. Remove the plunger from the syringe.
 - b. Place your finger over the tip.
 - c. Fill the syringe completely with water.
3. Carefully float the vial cap with the KI on the water in the syringe. Allow the water to drain and the vial cap to rest on the bottom of the syringe.
4. Insert the plunger all the way so that it fits snugly against the vial cap.
5. Carefully draw in 5 mL of H_2O_2 and seal the syringe with the end cap.
6. Shake the syringe up and down to mix the reagents, allowing the reaction to take place. As the gas is generated the plunger will move up the barrel. (this reaction is slower than the one to produce the hydrogen gas)
7. When the reaction appears to be over, invert the syringe and carefully remove the cap. Rotate the syringe 180 degrees and carefully discharge the liquid in the syringe. Replace the cap and measure and record the volume of oxygen gas generated.
8. Wash the gas by drawing in 5 mL of distilled water, replacing the cap and mixing thoroughly by shaking it up and down. Discharge the water carefully, again trying not to push out any of the gas.
9. Seal the syringe by putting the cap back on the end.

Part III - Experimenting with the "Bang for your Buck"

1. Fill a small plastic weighing boat with bubble solution.
2. Obtain a splint and lighter for introducing a flame source.
3. Remove the cap from the syringe containing hydrogen (opening should be pointing down) and affix the rubber tubing to the end.

4. Place the free end of the tubing into the boat of bubble solution. Slowly discharge about 20 mL of hydrogen to make a small mound of bubbles. Replace the cap on the syringe.
5. Light the splint and bring the splint to the mound of bubbles. Record your observations about the explosion.
6. Draw 5 mL of air into the hydrogen syringe.
7. Reattach the tubing to the end of the syringe. Blow bubbles with 20 mL of the gas mixture.
8. Light the splint and touch the bubbles. Record your observation about the explosion. Compare it to the previous explosion.
9. Release the rest of your gas. Rinse the hydrogen syringe.
10. Regenerate some hydrogen gas using the steps from earlier.
11. Wash the hydrogen as you did before.
12. Expel all but 15 mL of the oxygen in its syringe.
12. Expel all but 30 mL of the hydrogen. Connect the tubing from the hydrogen to the oxygen syringe, holding the hydrogen syringe slightly higher than the oxygen syringe.
13. Pull back on the plunger of the hydrogen syringe to the 45 mL mark. At the same time, your partner should be pushing the 15 mL of oxygen with the plunger. You should now have a mixture of hydrogen (30 mL) and oxygen (15 mL) totaling 45 mL of volume.
14. Use your tubing now attached only to the hydrogen syringe to blow bubbles with 20 mL of the gas mixture.
15. Touch the bubbles with a lighted splint and record your observations about the explosion and its relative intensity.

Analysis:

1. Using the 0.06 g of magnesium and the volume of 1.0 M HCl, determine your limiting reagent and calculate the volume of hydrogen gas you should have been able to generate. (You need a balanced equation first) You may assume STP.

(1.0 M HCl = 1.0 mol HCl)

1 L HCl

2. Using the volume of hydrogen you calculated in analysis #1 as your theoretical yield, determine a percent yield for the volume you measured in the activity.

Conclusion:

Compare your 3 explosions of hydrogen bubbles to one another. Discuss the differences you observed and how they might be related to the ratios of reactants you used to produce water from its elements. $(2\text{H}_2(\text{g}) + \text{O}_2(\text{g}) \longrightarrow 2\text{H}_2\text{O}(\text{g}))$

Be sure to indicate when, in your procedure, each material was present or not present and what caused the change.

If your percent yield was not exactly 100%, try to explain why, based on what you know about the reactions and from real life.

APPENDIX D

LAB EXPERIENCE SURVEY

APPENDIX E

KNOWLEDGE PROBE – WHAT’S GOING ON DURING FREEZING

What's Going on During Freezing?



Bubba was planning on going camping for the weekend and thought he would make some large pieces of ice for the cooler. To keep the cooler from filling with water as the ice melted, Bubba decided to make the large pieces of ice in half-gallon sized, empty plastic milk jugs. He carefully washed and rinsed the jugs and filled each one to the top with water, screwed on the cap and put each of them in the bottom of the freezer on Thursday night. On Friday afternoon, Bubba came home from school to help pack the truck and cooler. He opened the freezer to get the jugs and much to his surprise the caps had been partially pushed off and the jugs were deformed and had split down the sides. How did that happen? Bubba asked his friends and family and this is what they said:

Nana said, “The plastic got brittle when it was cold. The molecules weren’t attracted to one another because they were moving so slow, so the bottle split.”

Bubba’s dad said, “Water molecules get larger when they freeze and they take up more space, which is why the bottle split.”

Aunt Bee said, “Water molecules get larger when they freeze and plastic molecules get smaller when they get cold, so when the water grew and the plastic shrunk, it was not a good combination.”

Bubba’s sister Betty said, “The shape of the water molecules caused them to line up in a specific pattern that took up more space when they were frozen.”

Bubba’s friend Bob said, “The plastic molecules shrunk more than the water molecules when they got cold. So the plastic was too small for the water and it split.”

Which of Bubba’s friends and family do you think is correct, and why?

APPENDIX F

ICE PROBE AND ICE BUILDING ACTIVITY INTERVIEW QUESTIONS

ICE PROBE AND ICE BUILDING ACTIVITY INTERVIEW QUESTIONS

- Can you believe it's already time for spring break?
- How are things going for you this semester?

- Did you enjoy the activity with the magnetic water molecules?
 - Probe: What was it about that particular experience that made it enjoyable?
 - Probe: Would you like to see, view, or experience more of this type of lesson style?

- Thinking back to the question we answered about what happens during freezing, did the activity where we built the ice cause you to go back and rethink your answer?
 - Probe: What specifically caused the “rethinking” of your answer, or did it simply reinforce your answer?
 - Probe: How did it change what you know about the particulate nature of matter?
 - Probe: Do you think this type of activity would help you learn in other lessons about scientific topics?

- What did you see or learn in the activity that was surprising to you?
 - Probe: How was that surprise helpful to your learning?

APPENDIX G

MAKING SOLUTIONS – HOW MUCH MATTER?

Making Solutions – How Much Matter?

A. Salt in Water and Sugar in Water

1. Commit to an Outcome

Suppose you have two graduated cylinders, and one is filled halfway with table salt and the other halfway with table sugar. If you added water to both cylinders until the water reached the top measurement (full), then let the cylinders sit for awhile, what do you predict will happen to the water level? Predict what will happen to the levels of the salt and sugar. Explain the reasons behind your prediction.

2. Expose Beliefs

Share with others in your group your predictions and explanations about what will happen to the water levels with the salt and sugar, as well as the levels of each the salt and the sugar. Choose someone from your group to share with the class.

3. Confront Beliefs

Go to your lab station and use the graduated cylinders, salt, sugar, and water to test your predictions. What really happens when you add the water to the cylinders and wait for a few minutes?

Set aside a small sample of the salt water and sugar water for later use. Use the medicine cups provided. Then clean your graduated cylinders.

B. Alcohol in Water

1. Commit to an Outcome

Suppose that you have 25 mL of water and 25 mL of alcohol. If you added the water to the alcohol, predict approximately how much liquid would result.

2. Expose Beliefs

Share your beliefs about how much liquid will result and your explanations with the other members of your group. Choose someone from your group to share with the class.

3. Confront Beliefs

Go to your station and use the alcohol and water supplied to test your predictions. After making your observations, make any appropriate changes in your explanations.

Don't clean your graduated cylinders yet.

4. Accommodate the Concept

Take a moment to think silently about your observations. Based on your observations in Activities A and B above, what statement can you make about this behavior of matter? How do you think A and B are similar and how are they different? Now that you've written down your statement and thinking, share your statements with others in your group.

5. Extend the Concept

What are some examples related to the phenomenon observed in A and B with which you are familiar?

6. Go Beyond

What questions, problems, and projects related to this concept would you like to pursue? Be ready to share with the class.

Testing the Solutions

Now that you've made some observations and had a chance to think about the concept of the space that matter occupies, let's turn to looking at the properties of the mixtures you made.

A. Testing Pure Water

1. Commit to an Outcome

Suppose that you inserted a conductivity tester into a sample of distilled (pure) water. What do you think would happen to the light bulb on the tester?

2. Expose Beliefs

Share your beliefs about what will happen and your explanation about why it will happen with members of your group. Choose someone to share with the class.

3. Confront Beliefs

Go to your station and rinse your conductivity tester with distilled water. Wipe it dry with a clean piece of paper towel. Turn on your tester and test the distilled water sample. Record your observations. Turn off your tester and rinse/dry it again. Make any appropriate changes to your explanation.

B. Testing Salt Water and Sugar Water**1. Commit to an Outcome**

Suppose you inserted a conductivity tester into a sample of salt water? What do you think would happen to the light bulb on the tester? What if you tested sugar water?

2. Expose Beliefs

Share your beliefs about what will happen and your explanation about why it will happen with members of your group. Choose someone new to share with the class.

3. Confront Beliefs

Go to your station and rinse your conductivity tester with distilled water. Wipe it dry with a clean piece of paper towel. Turn on your tester and test the salt water sample you saved from earlier. Record your observations. Make any appropriate changes to your explanation. Repeat with the sugar water, being sure to rinse the tester with distilled water and wiping it dry.

C. Testing the Alcohol/Water Mixture**1. Commit to an Outcome**

Suppose you inserted a conductivity tester into a sample of alcohol and water? What do you think would happen to the light bulb on the tester?

2. Expose Beliefs

Share with your group, your beliefs about what will happen when the alcohol/water mixture is tested with the conductivity tester. Be sure to include your explanation.

3. Confront Beliefs

Go to your station and rinse your conductivity tester with distilled water. Wipe it dry with a clean piece of paper towel. Turn on your tester and test the alcohol/water sample you saved from earlier. Record your observations. Make any appropriate changes to your explanation.

4. Accommodate the Concept

Take a moment to think silently about your observations. Based on your observations in Activities A, B, and C above, what statement can you make about this behavior of matter? How do you think A, B, and C are similar and how are they different? Now that you've written down your statement and thinking, share your statements with others in your group.

5. Extend the Concept

What are some examples related to the phenomenon observed in A, B, and C with which you are familiar?

6. Go Beyond

What questions, problems, and projects related to this concept would you like to pursue? Be ready to share with the class.

Vocabulary to Consider

Solute	Soluble
Solvent	Insoluble
Solution	Dissolve
Electrolyte	Non-electrolyte

APPENDIX H

CCM AND ANIMATIONS INTERVIEW QUESTIONS

CCM AND ANIMATIONS INTERVIEW QUESTIONS

- How are things going this week?
- Can you believe we only have 10 weeks of school left?
- Last week we did the activity where you had to commit to an outcome, share your thoughts and then test your thoughts. Did you think that type of lesson helped you to learn something about what happens during dissolving?
 - Probe: What was it about that particular experience that made it helpful to you (or not helpful)?
 - Probe: Did it help you to commit to what you thought would happen before you tested it?
 - Probe: Why do you think it helped/didn't help?
 - Probe: Did any of the results surprise you? Which ones? Why were they surprising?
 - Probe: Would you like to see, view, or experience more of this type of lesson style?
- After the activity where we committed to an outcome, I showed you some animations on Dissolving? Did you find the animations helpful or informative?
 - Probe: What specifically about it was helpful or informative...?
 - Probe: How did it change what you know about how matter behaves at the molecular or atomic level?
 - Probe: What insight, if any, did it provide for you about the process of dissolving?
 - Probe: Did it matter that there was no sound?
 - Probe: Do you think this type of activity would help you learn in other lessons about scientific topics?
- If you had to pick between the committing to an outcome activity and the animations on dissolving, which do you think was most helpful to your learning?
 - Probe: Why was it most helpful?

APPENDIX I

POST-TREATMENT INTERVIEWS

POST-TREATMENT INTERVIEWS

- I want to thank you for participating in the study. I really appreciate your time and input.
- Did you get through your TAKS test okay? (Did you sleep in since you didn't have TAKS?)
- Starting in first semester, and many times throughout second semester we have done activities that are related, in some way, to water; its make up and behavior. I want to ask you a few questions about some of them.
 - In our solutions lab we used the cobalt chloride paper to test the make up of steam. Do you remember what the paper did in the steam?
 - Why did it turn color?
 - After we did the boiling in the syringes, we used the magnetic model kits with the Na⁺ ions and Cl⁻ ions, along with water. I had you model the water as both a liquid and during boiling. How were the models of the liquid and boiling different?
 - Did the amount of space the molecules occupied change during the process?
 - Did the molecules themselves change size during the process?
 - Did the molecules break up into the parts that made them (H and O)?
 - Describe, as best you can, what happened when we did the electrolysis lab with the battery.
 - What gas did you verify?
 - How was electrolysis different from boiling?
- Do you think wording can make a big difference in how you answer a question?
 - How are the following different or the same? How is what happens to the water the same or different?
 - Water molecules separate from one another when it boils.

- Water molecules break apart into their elements when they decompose.
- Any last thoughts you'd like to share?

APPENDIX J

CHEMICAL CONCEPTS INVENTORY

CHEMICAL CONCEPTS INVENTORY

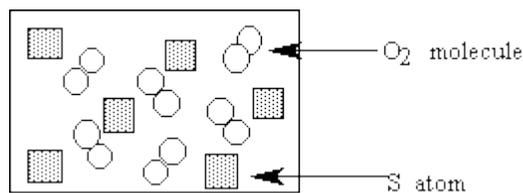
1. Which of the following must be the same before and after a chemical reaction?
 - a. The sum of the masses of all substances involved.
 - b. The number of molecules of all substances involved.
 - c. The number of atoms of each type involved.
 - d. Both (a) and (c) must be the same.
 - e. (e) Each of the answers (a), (b), and (c) must be the same.

2. Assume a beaker of pure water has been boiling for 30 minutes. What is in the bubbles in the boiling water?
 - a. Air.
 - b. Oxygen gas and hydrogen gas.
 - c. Oxygen.
 - d. Water vapor.
 - e. Heat.

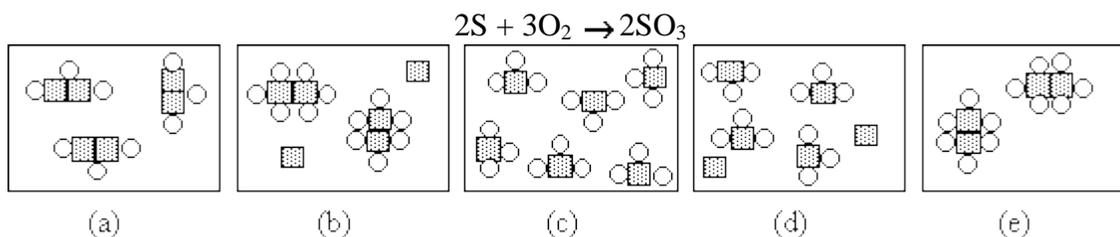
3. A glass of cold milk sometimes forms a coat of water on the outside of the glass (Often referred to as 'sweat'). How does most of the water get there?
 - a. Water evaporates from the milk and condenses on the outside of the glass.
 - b. The glass acts like a semi-permeable membrane and allows the water to pass, but not the milk.
 - c. Water vapor condenses from the air.
 - d. The coldness causes oxygen and hydrogen from the air combine on the glass forming water.

4. What is the mass of the solution when 1 pound of salt is dissolved in 20 pounds of water?
 - a. 19 Pounds.
 - b. 20 Pounds.
 - c. Between 20 and 21 pounds.
 - d. 21 pounds.
 - e. More than 21 pounds.

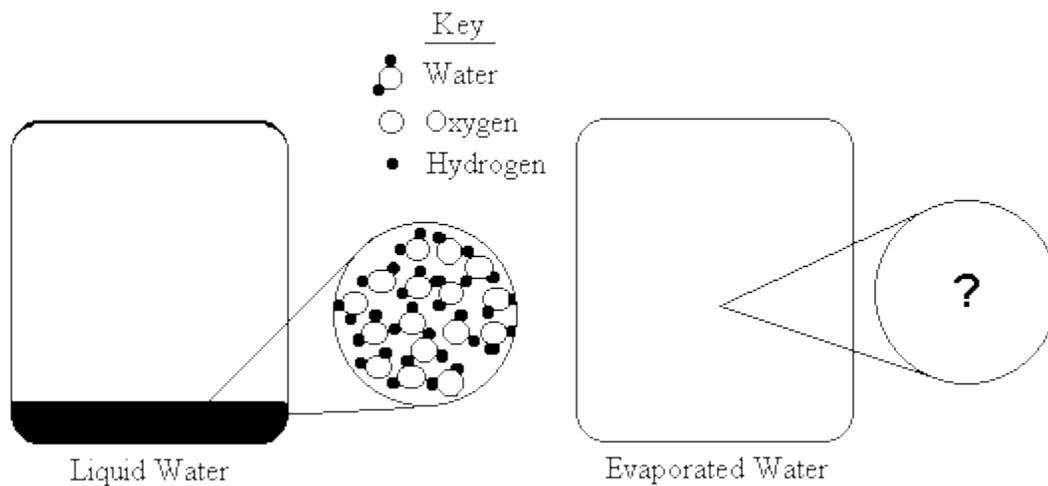
5. The diagram represents a mixture of S atoms and O₂ molecules in a closed container.



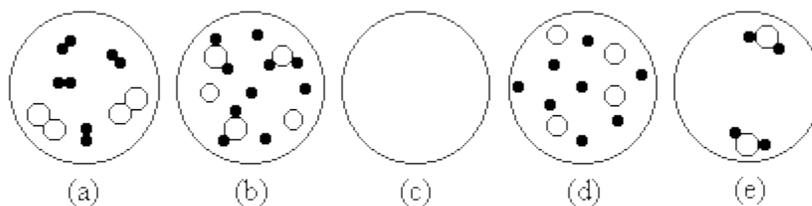
Which diagram shows the results after the mixture reacts as completely as possible according to the equation:



6. The circle on the left shows a magnified view of a very small portion of liquid water in a closed container.



What would the magnified view show after the water evaporates?



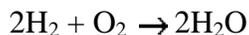
7. True or False? When a match burns, some matter is destroyed.

- a. True
- b. False

8. What is the reason for your answer to question 7?

- a. This chemical reaction destroys matter.
- b. Matter is consumed by the flame.
- c. The mass of ash is less than the match it came from.
- d. The atoms are not destroyed, they are only rearranged.
- e. The match weighs less after burning.

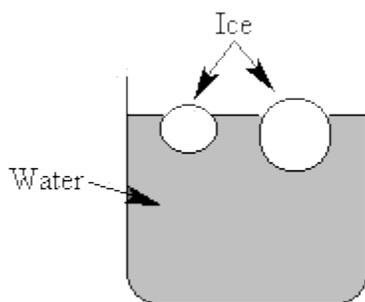
9. Heat is given off when hydrogen burns in air according to the equation



Which of the following is responsible for the heat?

- a. Breaking hydrogen bonds gives off energy.
- b. Breaking oxygen bonds gives off energy.
- c. Forming hydrogen-oxygen bonds gives off energy.
- d. Both (a) and (b) are responsible.
- e. (a), (b), and (c) are responsible.

10. Two ice cubes are floating in water:



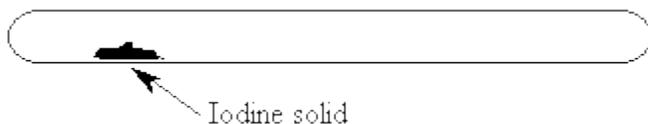
After the ice melts, will the water level be:

- a. higher?
- b. lower?
- c. the same?

11. What is the reason for your answer to question 10?

- a. The weight of water displaced is equal to the weight of the ice.
- b. Water is more dense in its solid form (ice).
- c. Water molecules displace more volume than ice molecules.
- d. The water from the ice melting changes the water level.
- e. When ice melts, its molecules expand.

12. A 1.0-gram sample of solid iodine is placed in a tube and the tube is sealed after all of the air is removed. The tube and the solid iodine together weigh 27.0 grams.



The tube is then heated until all of the iodine evaporates and the tube is filled with iodine gas. Will the weight after heating be:

- a. less than 26.0 grams.
- b. 26.0 grams.
- c. 27.0 grams.
- d. 28.0 grams.
- e. more than 28.0 grams.

13. What is the reason for your answer to question 12?

- a. A gas weighs less than a solid.
- b. Mass is conserved.
- c. Iodine gas is less dense than solid iodine.
- d. Gasses rise.
- e. Iodine gas is lighter than air.

14. What is the approximate number of carbon atoms it would take placed next to each other to make a line that would cross this dot: •

- a. 4
- b. 200
- c. 30,000,000
- d. 6.02×10^{23}

15. Figure 1 represents a 1.0 L solution of sugar dissolved in water. The dots in the magnification circle represent the sugar molecules. In order to simplify the diagram, the water molecules have not been shown.

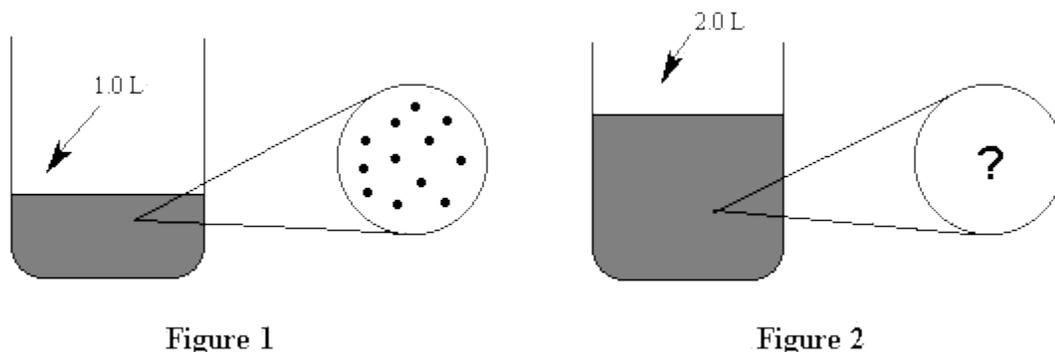


Figure 1

Figure 2

Figure 1

Which response represents the view after 1.0 L of water was added (Figure 2).

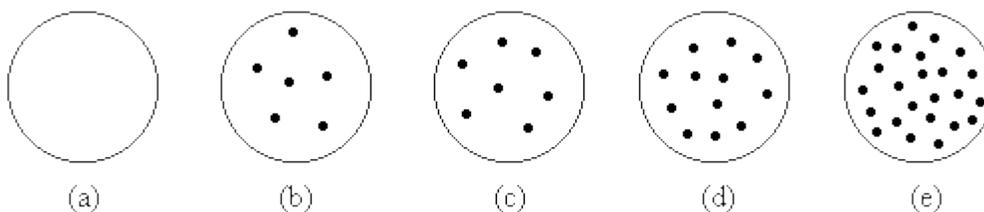


Figure 2

16. 100 mL of water at 25°C and 100 mL of alcohol at 25°C are both heated at the same rate under identical conditions. After 3 minutes the temperature of the alcohol is 50°C. Two minutes later the temperature of the water is 50°C. Which liquid received more heat as it warmed to 50°C?

- The water.
- The alcohol.
- Both received the same amount of heat.
- It is impossible to tell from the information given.

17. What is the reason for your answer to question 16?

- Water has a higher boiling point than the alcohol.
- Water takes longer to change its temperature than the alcohol.
- Both increased their temperatures 25°C.
- Alcohol has a lower density and vapor pressure.
- Alcohol has a higher specific heat so it heats faster.

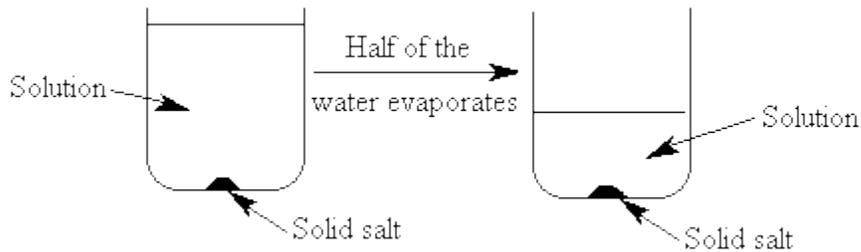
18. Iron combines with oxygen and water from the air to form rust. If an iron nail were allowed to rust completely, one should find that the rust weighs:

- a. less than the nail it came from.
- b. the same as the nail it came from.
- c. more than the nail it came from.
- d. It is impossible to predict.

19. What is the reason for your answer to question 18?

- a. Rusting makes the nail lighter.
- b. Rust contains iron and oxygen.
- c. The nail flakes away.
- d. The iron from the nail is destroyed.
- e. The flaky rust weighs less than iron.

20. Salt is added to water and the mixture is stirred until no more salt dissolves. The salt that does not dissolve is allowed to settle out. What happens to the concentration of salt in solution if water evaporates until the volume of the solution is half the original volume? (Assume temperature remains constant.)



The concentration

- a. increases.
- b. decreases.
- c. stays the same.

21. What is the reason for your answer to question 20?

- a. There is the same amount of salt in less water.
- b. More solid salt forms.
- c. Salt does not evaporate and is left in solution.
- d. There is less water.

22. Following is a list of properties of a sample of solid sulfur:

- i. Brittle, crystalline solid.
- ii. Melting point of 113°C .
- iii. Density of 2.1 g/cm^3 .
- iv. Combines with oxygen to form sulfur dioxide

Which, if any, of these properties would be the same for one single atom of sulfur obtained from the sample?

- a. i and ii only.
- b. iii and iv only.
- c. iv only.
- d. All of these properties would be the same.
- e. None of these properties would be the same.

APPENDIX K

PARNOMA RESULTS FOR QUESTIONS 3, 6, 14, AND 19

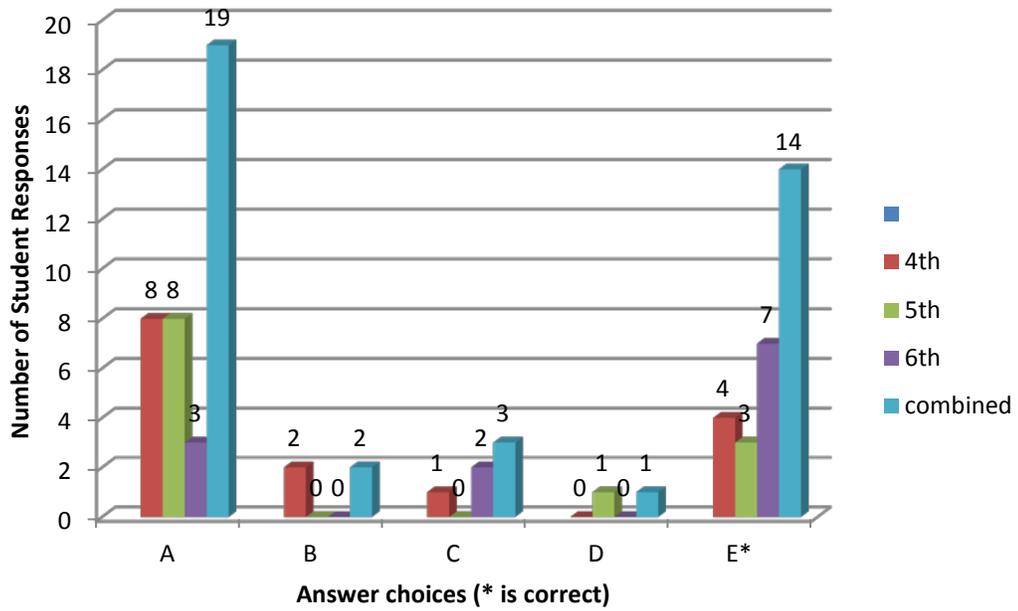


Figure K1. ParNoMA Question 3 Results. (N=39)

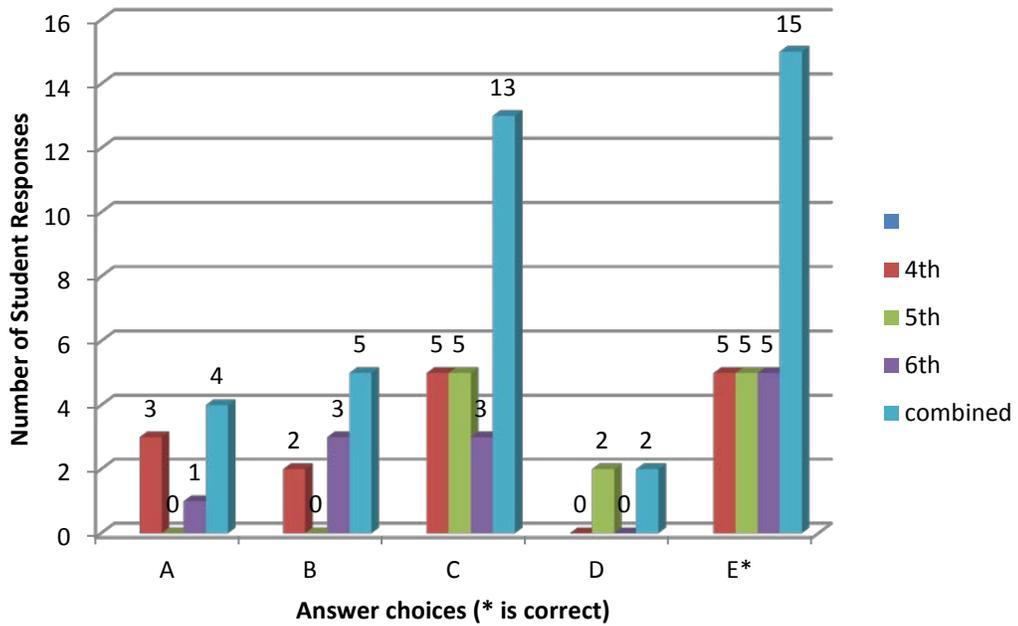


Figure K2. ParNoMA Question 14 Results. (N=39)

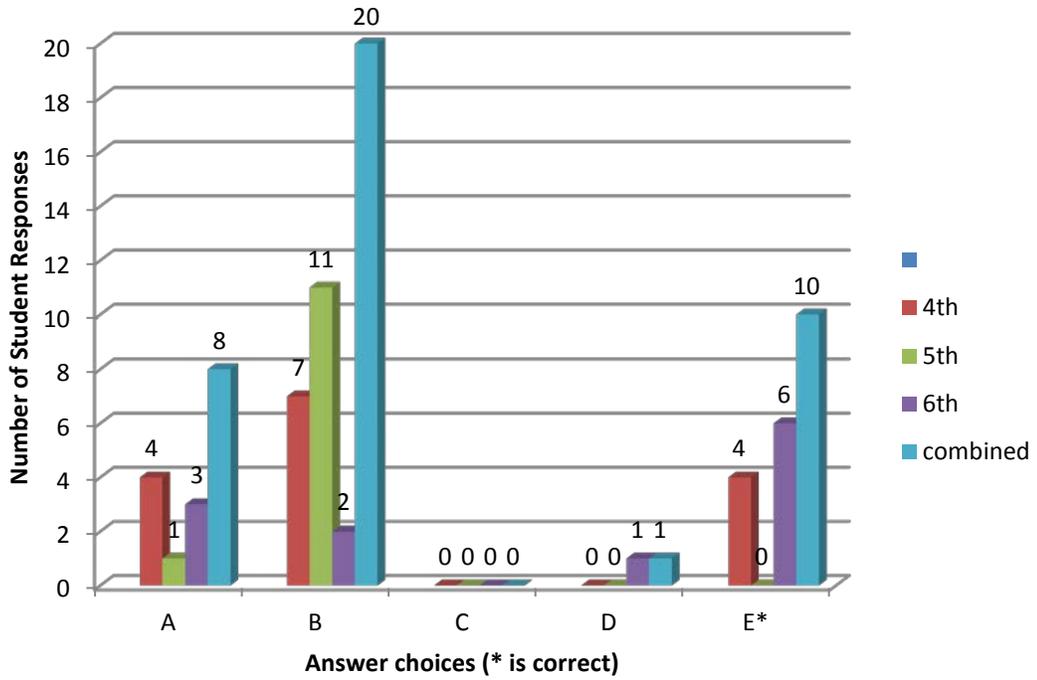


Figure K3. ParNoMA Question 6 Results. (N=39)

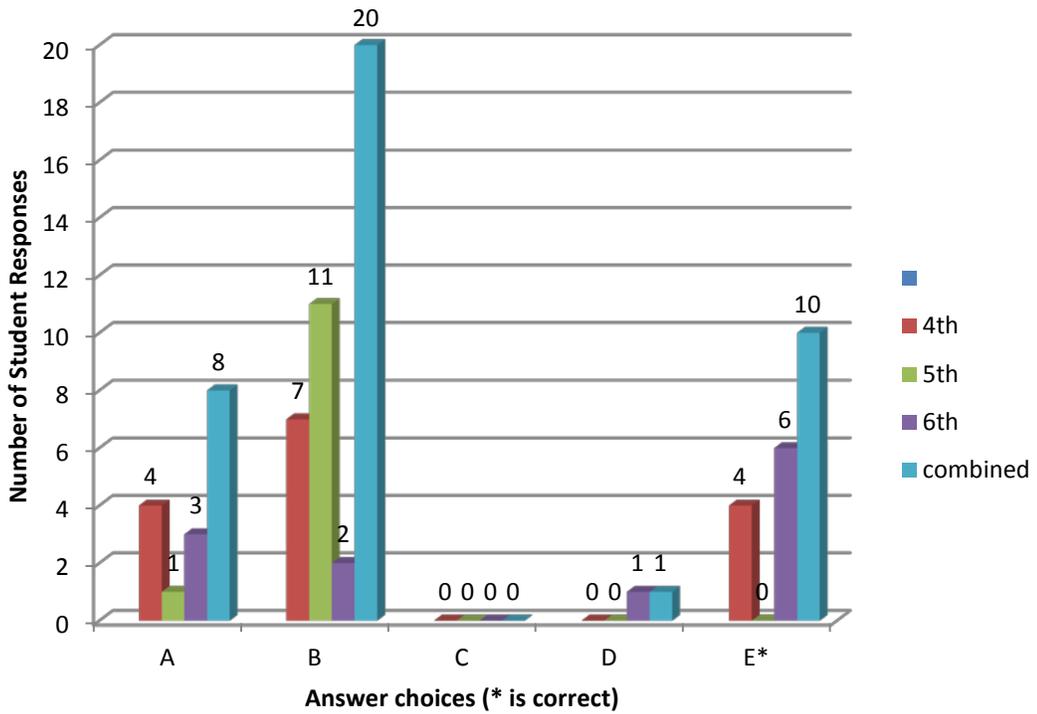


Figure K4. ParNoMA Question 19 Results. (N=39)

APPENDIX L

CROSS-TABULATION TABLES FOR PARNOMA PRE-TEST

Table L1
Question 5 vs. Question 7, ParNoMA. (N=39)

5↓ vs 7→	Hydrogen and oxygen	Hydrogen only	Gaseous Water	Air, hydrogen and oxygen	Oxygen only
break the bonds between the hydrogen atoms	2	0	4	0	0
form new bonds between the atoms	0	0	0	0	0
break the bonds between the oxygen and hydrogen atoms in the molecules	9	0	4	2	0
break the water molecules away from other water molecules	6	0	7	2	0
form new bonds between the molecules	1	0	2	0	0

Table L2
Question 9 vs. Question 7, ParNoMA. (N=39)

9↓ vs 7→	Hydrogen and oxygen	Hydrogen only	Gaseous Water	Air, hydrogen and oxygen	Oxygen only
The lid became sweaty	0	0	0	0	0
Steam cools and water molecules moved closer together	7	0	11	3	1
Water from outside leaked into the pot	0	0	0	0	0
Hydrogen and oxygen combined to form water	10	0	2	0	0
Steam combined with the air to wet the inside of the lid	1	0	3	2	0

Table L3
Question 15 vs. Question 7, ParNoMA. (N=39)

15↓ vs 7→	Hydrogen and oxygen	Hydrogen only	Gaseous Water	Air, hydrogen and oxygen	Oxygen only
vaporization	4	0	3	0	0
evaporation	21	0	5	0	1
decomposition	1	0	3	0	0
freezing	2	0	1	1	0
boiling	0	0	4	3	0

APPENDIX M

PASSWORD INFORMATION FOR NORTH CAROLINA SCHOOL OF SCIENCE
AND MATHEMATICS

PASSWORD INFORMATION FOR NORTH CAROLINA SCHOOL OF SCIENCE
AND MATHEMATICS

Below is the information on requesting a login and password from the North Carolina School of Science and Mathematics. Once you receive your free login and password, you can use the animations referenced in this paper.

This folder contains restricted content.

The contents of this website are copyrighted. Access is available to not-for-profit institutions for purely educational purposes.

To request access, please email warshaw@ncssm.edu.

In your email, please include the following information:

- Name of your institution.
- Is your institution either non-profit or not-for-profit? (yes or no)
- Will you use the NCSSM product(s) for educational purposes only? (yes or no)
- Will you give credit to the North Carolina School of Science and Mathematics when using these materials? (yes or no)
- Will you adhere to the following statement of non-discrimination in any use(s) of the NCSSM product(s)? (yes or no)

In administering its affairs, the North Carolina School of Science and Mathematics is committed to equality of opportunity. It is the policy of the School to be fair and impartial in all its relations with its students, employees and applicants for employment and to not discriminate against any person on the basis of race, color, creed, national origin, sex, sexual orientation, religion, disability, age or honorable service in the armed forces of the United States.

- Will you refrain from modifying the materials? (yes or no)

We will process your request and email you with credentials allowing access to this content.

APPENDIX N

CHEMICAL CONCEPTS INVENTORY – SELECTED QUESTIONS

CHEMICAL CONCEPTS INVENTORY – SELECTED QUESTIONS

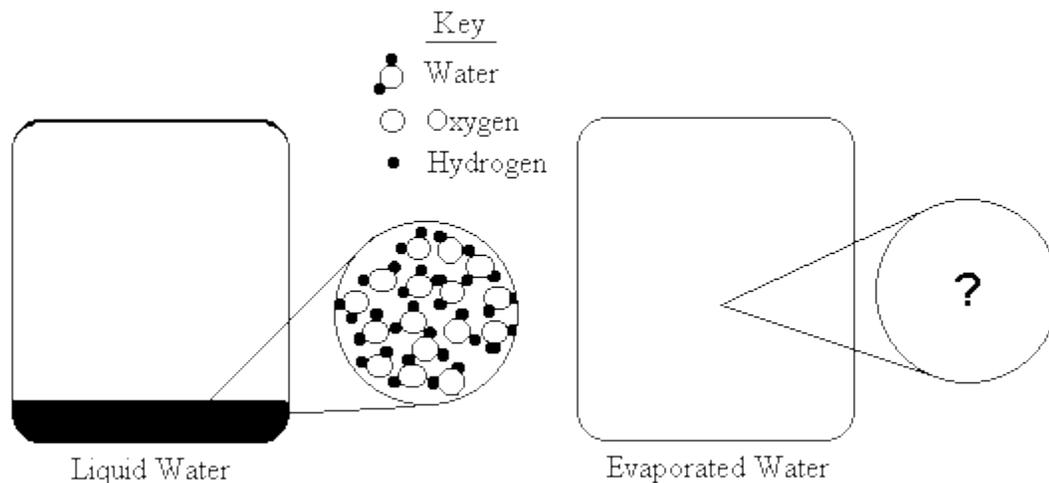
21. Assume a beaker of pure water has been boiling for 30 minutes. What is in the bubbles in the boiling water?

- f. Air.
- g. Oxygen gas and hydrogen gas.
- h. Oxygen.
- i. Water vapor.
- j. Heat.

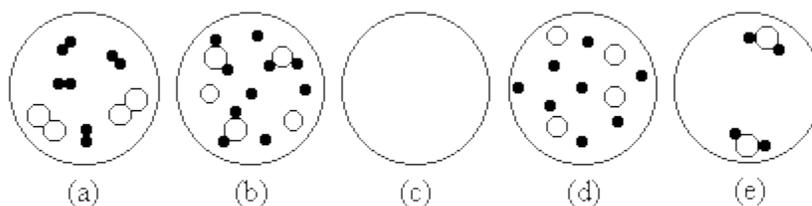
22. A glass of cold milk sometimes forms a coat of water on the outside of the glass (Often referred to as 'sweat'). How does most of the water get there?

- e. Water evaporates from the milk and condenses on the outside of the glass.
- f. The glass acts like a semi-permeable membrane and allows the water to pass, but not the milk.
- g. Water vapor condenses from the air.
- h. The coldness causes oxygen and hydrogen from the air combine on the glass forming water.

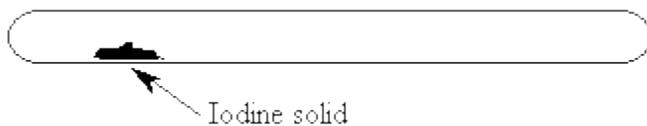
23. The circle on the left shows a magnified view of a very small portion of liquid water in a closed container.



What would the magnified view show after the water evaporates?



24. A 1.0-gram sample of solid iodine is placed in a tube and the tube is sealed after all of the air is removed. The tube and the solid iodine together weigh 27.0 grams.



The tube is then heated until all of the iodine evaporates and the tube is filled with iodine gas. Will the weight after heating be:

- f. less than 26.0 grams.
- g. 26.0 grams.
- h. 27.0 grams.
- i. 28.0 grams.
- j. more than 28.0 grams.

25. What is the reason for your answer to question 24?

- f. A gas weighs less than a solid.
- g. Mass is conserved.
- h. Iodine gas is less dense than solid iodine.
- i. Gasses rise.
- j. Iodine gas is lighter than air.

APPENDIX O

CROSS-TABULATION TABLES FOR PARNOMA AND CCI POST-TEST

CROSS-TABULATION TABLES FOR PARNOMA AND CCI POST-TEST

Table O1

Question 5 vs. Question 7, Post-test. (N=53)

5↓ vs 7→	Hydrogen and oxygen	Hydrogen only	Gaseous Water	Air, hydrogen and oxygen	Oxygen only
break the bonds between the hydrogen atoms	1	0	2	0	0
form new bonds between the atoms	0	0	0	0	0
break the bonds between the oxygen and hydrogen atoms in the molecules	10	0	7	1	1
break the water molecules away from other water molecules	5	0	25	1	0
form new bonds between the molecules	0	0	0	0	0

Table O2
Question 9 vs. Question 7, Post-test. (N=53)

9↓ vs 7→	Hydrogen and oxygen	Hydrogen only	Gaseous Water	Air, hydrogen and oxygen	Oxygen only
The lid became sweaty	0	0	0	0	0
Steam cools and water molecules moved closer together	7	0	25	1	1
Water from outside leaked into the pot	0	0	0	0	0
Hydrogen and oxygen combined to form water	9	0	5	0	0
Steam combined with the air to wet the inside of the lid	0	0	4	1	0

Table O3
Question 15 vs. Question 7, Post-test. (N=53)

15↓ vs 7→	Hydrogen and oxygen	Hydrogen only	Gaseous Water	Air, hydrogen and oxygen	Oxygen only
vaporization	6	0	2	0	0
evaporation	7	0	4	0	1
decomposition	0	0	26	1	0
freezing	1	0	1	0	0
boiling	2	0	1	1	0

Table O4
Question 23 vs. Question 7, Post-test. (N=53)

23↓	vs	7→	Hydrogen and oxygen	Hydrogen only	Gaseous Water	Air, hydrogen and oxygen	Oxygen only
	a		1	0	0	0	0
	b		2	0	1	1	0
	c		1	0	0	0	0
	d		7	0	4	0	1
	e		5	0	29	1	0