# “I didn’t know chem can be fun”:

# Teaching Practices for Engaging Underperforming Students to Learn a Practical Understanding of Chemistry

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Abstract

This action research study sought to identify instructional strategies that were engaging and effective in fostering an understanding of the real-world relevance of chemistry for underperforming chemistry students. The teacher-researcher investigated student-centered learning experiences, including hands-on activities and popular culture references, to measure their effect on student engagement and learning. A project- and theme-based strategy called group concept presentations was designed and implemented to increase conceptual and applied understanding around a single chemistry concept. Results showed that both engagement and learning increased over a seven-week period, with students reporting increased engagement by 20% and diagnostic exam scores increasing by 24% at the end of the study. Deeper learning and content mastery occurred when students continually revisited key concepts, felt responsible and accountable for their learning, and linked new knowledge to existing schemas. This study has applications for secondary teachers who are interested in improving the engagement and learning environment of their chemistry students.

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# Teaching Practices for Engaging Underperforming Students to Learn a Practical Understanding of Chemistry

My own passion for chemistry stems out of my fervent belief that it enables learners to understand what is happening in the world around them. Chemistry is at the heart of all scientific inquiry. It provides answers to the whys and hows that stimulate curiosity, fascination, and wonder. Chemistry explains how fireworks can be different colors, why food changes as it is cooked, how soap and shampoo make people clean, why humans typically do not develop allergies to gold or other noble metals, and how many things in nature work and why they work the way they do. Chemistry explains rainbows, light, explosions, and pollution. Unfortunately, chemistry by its very nature is math-based and highly conceptual, and students are often deterred by what they believe to be a difficult subject that is too abstract, too decontextualized, and too irrelevant to their lives. The magic of chemistry is too often lost in the tumble of equations, numbers, and rules.

During my student teaching experience, I was continually challenged by attitudes of reluctance, frustration, and disinterest toward chemistry. Because so much of my own educational background in chemistry was conducted using traditional methods of instruction, I struggled to teach my students in a manner that both allowed me to share my passion for chemistry and fostered their reception to that passion and passing of knowledge. I asked myself what I could do to help my students feel, even for a short while, the enchantment with chemistry that I experience every day. Thus, the focus of my research was to identify instructional strategies that capture students' engagement and interest in chemistry and are effective in promoting a practical understanding of chemistry concepts that are often difficult to grasp.

## Rationale for the Research Study

### Context of the Study

This study takes place at the School of Media Arts (SMA), which is one of four small campuses at an urban educational complex in San Diego, CA. The student population consists of approximately 480 students in grades 9 through 12 and draws primarily from the surrounding urban lower-middle class neighborhoods, though a percentage of the students are bussed in from lower-income areas. The demographic of the student population at SMA is 38% Hispanic/Latino, 23% Caucasian, 18% African American, 20% Asian, and 1% American Indian or Alaskan Native. SMA receives Title I funding, and 75% of the student body is eligible for free or reduced lunch. Additionally, 18% of the students are English Language Learners, 64% of which are native Spanish speakers. For the 2010–2011 school year, SMA achieved an Academic Performance Index (API) score of 807, placing the school in the top 70$^{th}$ percentile in the state of California. Additionally, SMA met four out of six criteria for Annual Yearly Progress during 2010–2011. In September 2010, SMA was named a National Blue Ribbon School by the U.S. Department of Education in recognition of SMA's attainment and maintenance of high student achievement, especially among disadvantaged and minority students, and for narrowing the achievement gap.

Based on school-wide results from the 2011 California Standards Tests (CSTs), the student population as a whole has shown growth in English language arts, history, and the life sciences (biology and earth science), but still struggles to find significant gains in chemistry and math. All students at SMA are required to pass chemistry in order to receive a high school diploma, and to increase student achievement in a math-based science, chemistry students at SMA in years past were required to have taken or be concurrently enrolled in Pre-Calculus.

Figure 1 shows that the percentage of students to achieve Advanced on the CST Chemistry has risen from 0% in 2009 and 2010 to 8% in 2011, and Proficient scores have risen from 4% in 2009 and 24% in 2010 to 31% in 2011. Unfortunately, the number of students scoring Basic, Below Basic, or Far Below Basic on the CST Chemistry remains well above 50%. In particular, the large number of students scoring Basic on the CST Chemistry indicates that only small to moderate gains are needed in skill development and conceptual understanding to reach proficiency in chemistry.

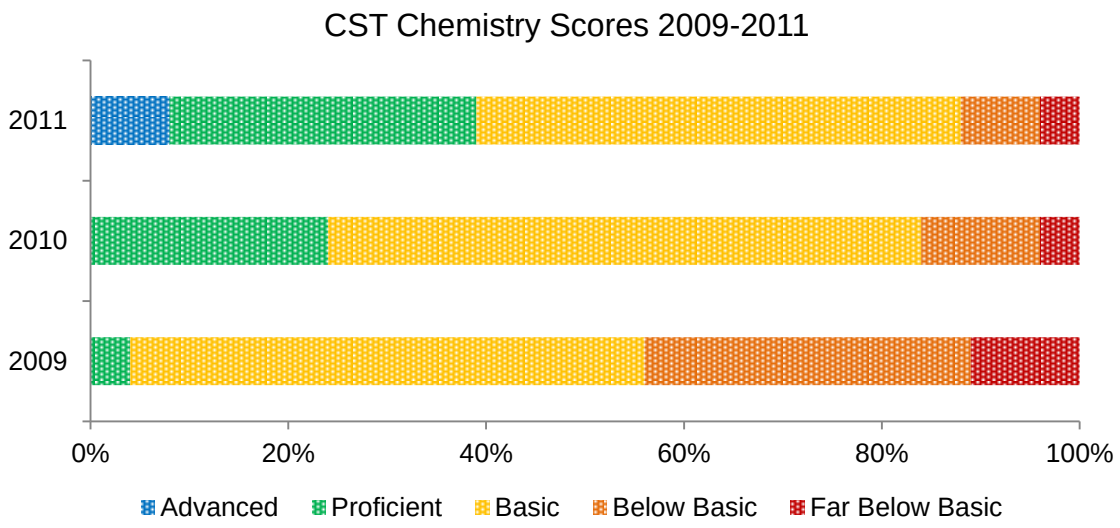


*Figure 1.* California Standardized Test in Chemistry scores for students at the School of Media Arts from 2009 to 2011.

The subjects of this study were 10th–12th grade students enrolled in my chemistry class, which is usually taken during the junior year at SMA. In my class of 24 students, there was one sophomore, 15 juniors, and eight seniors; the lone 10th grader was consistently high-achieving and high-performing all year, and her scores on every exam represented extreme outliers (95% or above) in the class data. My class also included five designated English Language Learners (ELLs) and three students with Individualized Education Plans (IEPs). Due to the ability tracking

that occurs within grade levels at SMA, the majority of my students were those who typically score less than Proficient on both the math and English CSTs. Additionally, the prerequisite for pre-calculus in order to study chemistry was removed for this year's students, so I anticipated increased difficulty and allocated more time for teaching math concepts for this particular group. Regardless, there was still a range of ability among my students, and some students certainly exhibited more of an inclination for and interest in chemistry than their peers.

Finally, the theme of media and design is the center of education and curriculum at SMA, with a focus on project-based learning. Teachers in each grade level collaborate to provide an interdisciplinary and project-based curriculum that requires students to master both academic and industry standards by engaging in an authentic media project. I was on the 11$^{th}$ grade team, whose client-based project focused student experience on real-world expectations of media design and production. Throughout the school year, this project influenced and shaped the order in which I presented each unit of the chemistry curriculum. Despite my efforts to help students understand how chemistry related to the project and can be applied in real-life situations, I felt there was a continual disconnect between chemistry and other subject areas, and between chemistry and the project.

**Statement of the Problem**

From essentially the first day of school, I struggled with my students' lack of motivation and excitement to learn chemistry. Any initial enthusiasm was soon supplanted by frustration and then indifference in the face of highly abstract or math-based concepts, such as electron configuration and stoichiometry. After the apathy settled in, many of my students expressed a great concern for maintaining a grade of at least a "C" but appeared unwilling to exert the effort required to develop the thinking skills necessary to learn, understand, and appreciate chemistry—

that is, to demonstrate the minimum skills and knowledge that are customarily representative of the average student with a “C” grade. The result of these prevailing attitudes—the reluctance to grapple with abstract concepts and higher-order thinking, and the devaluation of knowledge and learning—was an inability to grasp the relevance of chemistry to other content areas and the real world, which only compounded the resistance to mastery of chemistry concepts.

To identify the roots of my students’ disinterest, I first turned to my methods of instruction, which were often teacher-centered and lecture-based. I realized that though I disliked the note-taking that characterized much of my own chemical education, I was imposing this same experience on my students. I didn’t realize that I was marching through the standards, spending too much time thinking about how to effectively talk about chemistry and not enough time developing effective activities for my students to learn by actually doing chemistry. I further recognized that the way I was teaching failed to match up with my vision of who I wanted to be as a teacher—a facilitator of learning, someone who brought chemistry to life and made students want to know more. Famed comedian Groucho Marx once said, “If you’re not having fun, you’re doing something wrong.” I finally understood that in my classroom, if I wasn’t having fun teaching, my students probably weren’t having fun learning. Therefore, changes need to be made in the way I taught chemistry.

My realization that a shift was imminent if I wanted my students to enjoy their time in my classroom was supported by my observations of a return to interest and engagement particularly during units in which I was able to make ready connections with students’ daily observations of the world around them. For example, the unit on gas laws inevitably led to a sharing of experiences about shrunken plastic bottles, bloated potato chip bags, and shriveled balloons, which all came about as a result of changes in temperature or pressure. I saw that when

chemistry concepts were made applicable to contexts that students were familiar with and understood, even in a lecture-based setting, there was an astounding leap in their willingness to learn chemistry and the content understanding that followed. The goal of my action research, then, is to identify the teaching strategies that both engage students' interest and effectively help them gain an applied understanding of chemistry concepts, which are often challenging to master and highly abstract.

**Needs Assessment**

A needs assessment was implemented to measure students' initial engagement in my class and to identify instructional strategies for Phase I interventions. A diagnostic exam was administered at the beginning of the needs assessment to establish a baseline of content understanding over the entire chemistry curriculum. At this point, my class had covered about 75% of the chemistry material, so I expected the average on the diagnostic exam to be lower than usual (in reference to typical scores on unit tests). The questions pertaining to the missing concepts on the diagnostic accounted for less than 20% of the exam questions. The mean score on the exam was a 47%, which I found indicative not only of the concepts yet to be learned but, more importantly, weak mastery of the concepts already covered.

The first part of my needs assessment consisted of two pre-surveys (available in Appendices A and B) that sought to gain a deeper understanding of how and what motivates students to learn. These surveys also asked students to identify the measures that both I and they could take to assist their learning and understanding of chemistry. In the surveys, 71% of students explicitly identified "labs" and "hands-on" activities as effective learning experiences. 54% of students also said it is helpful when their teacher finds "different ways of explaining" or gives "real-life situations" and examples that pertain to the concept. Motivations for learning

included primarily the desire and/or necessity for good grades in order to pass core classes and graduate from high school (83%) and topics that spark their interest and “make learning fun” (35%). Only one student in the class identified “college” as a motivation for learning, and two students said that they were motivated to learn simply for the sake of acquiring knowledge. Areas of need that my students identified about their learning experiences with me as their teacher included 1) a desire for a slower, more thorough pace of instruction (39%) and 2) more “fun” labs and in-class activities (39%). When asked what they could do to become better students, 74% of students admitted they could be more diligent outside of the classroom, e.g. by completing homework, studying for exams, and coming for tutoring, while 43% of students said they could be more proactive in class by paying attention or asking clarifying questions. The data I gathered from the pre-surveys in Part 1 of the needs assessment led me to ask the following questions: How can I provide rich learning experiences that will stimulate my students’ interest, curiosity, and wonder? My students identified hands-on activities and different ways of explaining as teaching structures that help them learn, so how can I implement these strategies in a way that will match their desire for good grades with a drive to learn chemistry and hold themselves responsible for completing the work required? I saw through my students’ responses that the shift I was seeking lay in the direction of more learner-centered instruction in which my students felt deeply involved in their learning. I also realized that I needed to be more in tune with my students’ concerns and should address what they felt were my shortcomings as a teacher. This included offering slower-paced instruction, particularly for my English Language Learners, supporting all students’ efforts to develop better study habits both in and out of my classroom, and providing different measures and methods of teaching to cater to their different learning modalities and interests.

Part 2 of the needs assessment was designed to measure student engagement against a variety of instructional techniques outside of the traditional lecture. Students completed exit slips for a two-week period on which they ranked their engagement on a scale of 1-5 and answered questions that connected that day's learning with their engagement with the activity. The template for the exit slips is available in Appendix C. Each of the four classes of instructional technique identified for evaluation during the needs assessment were implemented several times over the two-week period. These instructional techniques included hands-on activities, in-class demonstrations, video clips of science experiments, and interactive lectures. As a class, students identified hands-on activities and in-class demonstrations as the most engaging learning experiences. In-class practice and active note-taking were also ranked more engaging than watching a video of someone else conducting an experiment. The results for Part 2 were tabulated as class averages and are shown in Figure 2.

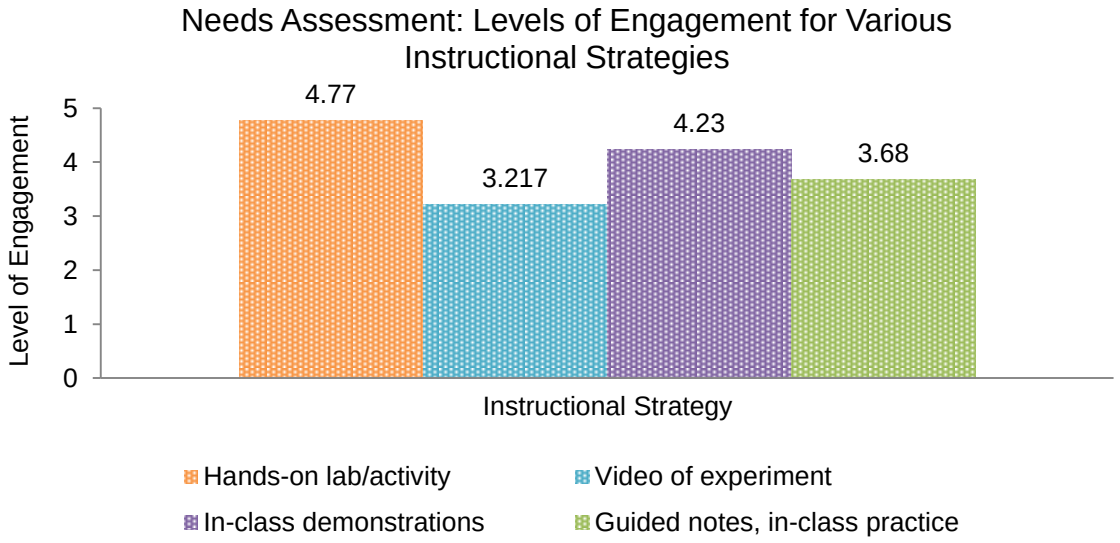


*Figure 2.* Self-reported levels of engagement for various instructional strategies.

Part 2 of the needs assessment revealed to me that it would be worth exploring non-lecture based methods of instruction for their effect on student engagement. On the exit slips,

students exhibited heightened interest and engagement when the gap between theory and practice began to close—that is, students reported more engagement when they saw an experiment in person or actually conducted an experiment themselves than when they were listening to me explain concepts or when they took notes, even with guided notes worksheets. I also noticed that engagement did not always correlate to true learning. For example, one student stated, "[Making ice cream] was fun, but I didn't get what it has to do with chemistry… Like I get the transfer of energy thing because [the bag of ice cream] got cold, but when would you ever need to make something hot or cold in real life?" Though this student later understood the relevance of endothermic and exothermic reactions in the creation of hot and cold packs, she was unable to independently exercise a practical understanding of chemistry. Therefore, I also considered how I could make these interactive learning experiences more effective in helping students synthesize an understanding of the application and relevance of chemistry concepts.

**Research Question**

The recognition of several needs in my classroom—namely, the desire for engaging, non-traditional learning activities and the inability of students to contextualize chemistry—led me to ask the driving research question: How can I effectively engage my students in a practical understanding of chemistry concepts?

**Significance of the Study**

The foundational aim of this study is to foster a deep learning of chemistry. Deep learning delivers the higher-order cognitive skills that students will need to succeed in a world that is constantly evolving. These skills, including metacognition, problem-solving, analyzing, and synthesizing, are necessary to construct long-term understanding beyond the initial acquisition of knowledge. In subjects that require students to build on prior knowledge, such as

science, the ability to recall information from past learning segments is important in order to maintain a working foundation of fundamental concepts on which to strengthen existing skills and develop new ones. One of the goals of this study is to promote students' ability to build connections between chemistry concepts and their prior knowledge and past experiences. For those who struggle to appreciate knowledge for the sake of knowledge, deep learning can spark the development of self-reliant learners who reflect on the personal significance of what they are doing and have high metacognitive and learning skills. By identifying strategies that can motivate students to learn, and more importantly, to learn challenging and highly theoretical concepts, this study has the potential to bring about a conceptual change in students' perception of the world. For both my class and chemistry learning in general, it is thus necessary to shift toward learner-centered methods of instruction in which students are active constructors of knowledge who search for meaning instead of facts and who understand that knowledge is not a "thing," but an ongoing, endlessly fruitful process.

## Literature Review

### Overview

An abundance of literature is available about the global shift toward learner-centered methods of instruction, particularly those methods that kindle engagement in the learning of chemistry and strive to make highly abstract content more relevant and accessible for students (Bowen, 2000; Gallet, 1998; Holbrook, 2005; Marks & Eilks, 2009; Ochonogor, 2011; Shachar & Fischer, 2004; Sirhan, 2007). The purpose of this literature review is threefold. First, a brief overview of traditional, teacher-centered methods of instruction is given, as well as a look at the movement toward active, student-centered learning and the effect of these methods on students in secondary chemistry classrooms. The second purpose is to examine difficulties that students

encounter both in and out of the chemistry classroom, including the high conceptuality of the subject matter and external influences such as parent involvement and socioeconomic background. This section closes with a discussion of the practices that have been undertaken to engage students in the learning of chemistry, to not only help students enjoy the classroom experience but also add to their ability to learn the material.

Key premises that emerged from a thematic analysis of the literature involved the significance of an active learning model in chemistry classrooms to promote students' awareness and appreciation of chemistry. This can be accomplished if instructors strive to see the subject matter from the point of view of the student learner and develop innovative methods of instruction that captivate student interest, help students make real-world connections, and motivate students to take control of and be accountable for their own learning. Additionally, because chemistry curricula commonly incorporate many abstract concepts (Sirhan, 2007), effective chemistry teaching will allow students to develop higher-order cognitive skills that transfer to other content areas as well as help them make connections between concepts and real-world experiences.

## Description of Previous Research

**Shift from teacher-centered to learner-centered instructional methods.** Research shows that chemistry classes in most international education systems use the traditional, whole-class method of instruction (Marks & Eilks, 2008; Ochonogor, 2011; Shachar & Fischer, 2004). Traditional chemistry teaching typically emphasizes lectures and note-taking, in which the presentation of chemical concepts and equations are scribed, memorized, and reproduced by students. Unfortunately, the depth and breadth of knowledge gleaned is typically limited to students' ability to understand their teacher's lectures and the content of their textbooks.

Similarly, laboratory teaching methods under the traditional approach typically involve a "cookbook formula" in which students are presented with years-old procedures that allow students to obtain expected and reproducible results regardless of their actual understanding of chemistry (Gallet, 1998). Therefore, the transfer of information from teacher to student in traditional instruction is often characterized by the simple accumulation of raw knowledge that does not "develop the students' critical sense or judgment, nor does it permit them to think for themselves when placed in an unknown terrain" (Gallet, 1998, p. 72). When presented with the clear restrictions of traditional teaching, then, what can teachers do to facilitate deep learning and higher-order thinking in their students? More importantly, how do they accomplish this when it requires them to "teach in a way that they themselves have never been taught" (Czerniak, Lumpe, & Haney, 1999, p. 123)?

Gallet (1998) conducted a study on the merits of problem-solving teaching (PBT) that grew out of his objections to traditional teaching. According to Gallet, traditional teaching is more concerned with "the ends to achieve than on improving the means of reaching them" (p. 72) and when teachers underestimate the inherent challenge of preparing students to think for themselves, they also deprive themselves of the pleasure of assisting students in their intellectual evolution. The model of traditional teaching further implies that information can be memorized and assimilated independently from its use, which results in the creation of superficial learning that disables students from applying what they know. The ultimate drawbacks to the aforementioned objections is that students experience low motivation and a general lack of interest in chemistry (Marks & Eilks, 2008), which has led to alarming failure, dropout ratios, and mediocrity of academic results (Gallet, 1998). These findings validate my own experiences. Not only is my own educational background in chemistry heavily characterized by lectures, note-

taking, and direct presentation of the material, but the manner in which I ran my classroom toward the beginning of the school year was characterized in much the same way. I personally experienced the struggle of learning to teach in a way that I myself was never taught. The previously posed question is therefore an important one—how do teachers break the mold and adopt new curriculum and more effective teaching strategies?

Since the advent of progressive education, which can be traced back as far as the 19th century, there has been a slow but marked shift toward active learning and student-centered methods of instruction. Student-centered, or learner-centered, teaching models focus on students more than teachers and on learning instead of teaching (Wohlfarth et al., 2008). The central question in the classroom shifts from "How can I improve my teaching?" to "How can I improve my students' learning?" The result of this paradigm shift is that teachers become co-learners in their own classrooms, in which everyone who contributes to or participates in the learning process is limited only by their own capabilities on when and how they will learn. This model encapsulates the education world's current understanding of the best practices in teaching, including an emphasis on active learning, collaborative learning, cooperative learning, and problem-based learning (Wohlfarth et al., 2008; Prince, 2004). There is extensive empirical support in the literature for active learning. Bonwell and Eison (as cited in Prince, 2004, p. 3) concluded that active learning leads to better student attitudes and improvements in students' thinking and writing. For chemistry in particular, effective teaching using the active learning model embraces the nature of scientific inquiry and culminates in "curiosity, creativity, spirit of healthy questioning, promotion of aesthetic values and avoidance of dogmatism among the learners" (Ochonogor, 2011, p. 645). Students who learn chemistry via active learning are more engaged in and more likely to develop a deep understanding of the content.

Cooperative learning as an active learning strategy has been extensively tested in chemistry classrooms. According to Johnson, Johnson and Smith (as cited in Bowen, 2000), the five key components of cooperative learning are positive interdependence, face-to-face interaction, individual accountability, interpersonal skills, and group processing. When this set of components is included in cooperative learning strategies, the study of science and other subjects in secondary schools is distinctly enhanced and students acquire superior outcomes compared to those achieved by peers in classes conducted with the traditional whole-class method (Shachar & Fischer, 2004). Students who engage in cooperative learning experience increased achievement, motivation, and have more positive perceptions of their classroom experiences. A study conducted by Ochonogor (2011) field-tested a special form of cooperative learning coined the "goat and sheep method" that combined heterogeneous grouping and small learning groups with extra activities, such as animations and simulations. The results of this study were that up to 87% of learners exhibited remarkably improved pass rates both in quantity and quality on a post-assessment. Additionally, the topics covered became more learner-friendly and chemistry educators achieved higher confidence and proficiency.

This study seeks to help me, as a teacher, experiment with learner-centered teaching and shift away from teacher-centered methods of instruction. As a researcher, I hope to field-test specific active learning strategies in my classroom in order to elucidate their effect on my particular group of students. My rationale for field-testing active learning strategies in my class of relatively low-achieving students is based off the results from the Shachar and Fischer (2004) study, in which they found the following:

> Students who displayed a low or middle level of achievement prior to their participation in cooperative learning classes benefited from their experience more than did those

> students with an initially high level of achievement… [The slower learners] are apparently freer to ask questions of their peers than they are in the traditional classroom setting. (pp. 82-83)

Based on my students' poor early performance in my class and widely below-average CST scores in math and English language, discussed elsewhere in this paper, I believe the adoption of active learning in my classroom will be effective in demanding "a higher level of thinking, more involvement, and a deeper comprehension" (Shachar & Fischer, 2004) than the traditional lectures I offered prior to this study.

**Factors that affect student achievement in chemistry.** Several factors other than method of instruction were discussed in the literature as having measurable effects on student performance in chemistry. This section of the literature review will examine 1) the inherent difficulties of learning chemistry, due to the nature of the subject matter and the nature of the learning process, and 2) factors external to the classroom that affect student achievement, such as culture, community, and level of parental involvement.

In an assessment of the literature regarding the difficulties of learning chemistry (Sirhan, 2007), five main areas of concern were identified for students of chemistry: (a) curriculum content, (b) overload of students' working memory space, (c) language and communication, (d) concept formation, and (e) motivation. According to Sirhan, the first learning difficulty in chemistry stems out of the presentation of concepts in the curriculum—that is, the logic represents that of the experienced academic chemist and is not psychologically accessible to the learner. For example, highly abstract concepts such as atomic theory and electron orbitals may be seen by chemists as the fundamentals of chemistry, but are often too daunting for beginning chemistry students to grasp. To this end, the highly conceptual nature of chemistry provides an

inherent obstacle to learning as real understanding requires “not only the grasp of key concepts but also the establishment of meaningful links to bring the concepts into a coherent whole” (p. 8). Compounding this difficulty is the great deal of new and often conceptually complex material that is presented to students in short periods of time. Because many students have not yet developed the skills necessary to organize their ideas and reduce the load of the working memory space, they experience “difficulty selecting the important information from the other less important information” (p. 6). This new information includes unfamiliar or misleading vocabulary, as well as familiar vocabulary that changes meaning as it moves into the field of chemistry. For example, the word “volatile” is generally understood to mean “unstable” or “explosive,” but has a scientific definition of “easily vaporized.” Therefore, more opportunities are needed for the learner to discuss ideas as they are presented and for misunderstandings, confusions, and misconceptions to become more apparent. The final area of concern identified by Sirhan was student motivation to learn difficult concepts. Resnick (as cited in Sirhan, 2007) found that students will engage more easily with problems that are embedded in challenging but relevant real-world contexts, but as discussed previously in this section, the complex nature of much of chemistry hinders students’ ability to place it in real-world contexts as well as their ability to develop deep understanding and appreciation of the material.

Sirhan’s work (2007) showed that the key to teaching chemistry is to see the subject matter from the point of view of the student learner. In order for this to happen, teachers need to know what their students already know and how they came to acquire that knowledge—are there confusions, wrong ideas, or misconceptions that need to be addressed? It is also important to take into account learning theory and to understand how the learner gains knowledge. How can difficult material be presented in a manner that is consistent with patterns of human learning?

Does the presentation of the curriculum allow for the development of links between seemingly disparate concepts? Finally, student attitudes and motivation, which are both influenced by teacher quality and curriculum quality, are significant for meaningful learning. It is in the teacher's hands to ensure that the learner perceives what is being taught as relevant to their lifestyle. When designing my action plan for this study, I tried to keep in mind what seemed to me an underlying theme in Sirhan's literature review: What is taught is not always what is learned. By attempting to understand how students may view the subject of chemistry and crafting interventions around the perspective of the student learner, I hoped to devise effective strategies for teaching that would sync students' experience in my classroom with my perception of their experience in my classroom.

The link between teachers' perception of students' learning and actual student performance was studied by Lin, Lee, and Treagust (2005). Because chemistry teachers do not understand their students' learning difficulties, there is often a great degree of inconsistency between the teachers' estimation of their students' learning achievement and students' actual academic performance. Lin et al. found that chemistry teachers often overestimate their students' level of achievement. On a t-test, teachers overestimated their students' academic achievement by two times more than student actual performance. To bridge this gap, more steps need to be taken to promote student conceptual understanding and teachers' pedagogical content knowledge. Teachers should provide more opportunities for students to discuss, explain, and present their ideas, which will boost their conceptual understanding of chemistry and provide a platform on which misconceptions and misunderstandings can emerge. In addition, teaching as a profession requires constant learning and continual reflection. Teachers should be seen and view themselves as intellectual and reflective practitioners rather than as technicians (Lin et al., 2005).

The overestimation of student achievement by teachers in the study came about because teachers lacked adequate understanding about their students' difficulties in learning. Therefore, continual and systematic reflection on student learning is likely to result in new knowledge and strategies for teaching.

There are several external factors to the classroom that also affect student achievement in chemistry. Alvaera, Bayan and Martinez (2009) found that teaching approach, whether teacher-centered or learner-centered, has no effect on student academic achievement in Philippine public schools if there is "inefficiency of poor quality of teaching" in those schools. The implications of these results in regard to teacher quality and training are beyond the scope of this study. However, Alvaera et al. also found that parental involvement can be used to predict student achievement especially in cultures in which families are at the center of the social structure. In the Philippines, mothers are viewed as the primary caretakers of their children, and Alvaera et al. found that mother involvement proved a significant predictor of Philippine students' scholastic performance. Cultural background, parental involvement, and parental socioeconomic status have all been shown to have a profound influence on academic achievement (Oloruntegbe, Ikpe, & Kukuru, 2010). These factors can be used to predict student learning outcomes and influence students' perceptions of their teachers' interpersonal behavior and classroom learning environment (Oloruntegbe et al., 2010). In particular, Pedrosa et al. (as cited in Oloruntegbe et al., 2010) proposed that socioeconomic status drives students' ability to make connections between science concepts and home activities. Students coming from disadvantaged backgrounds and lower-income homes are often involved in domestic activities such as cleaning, cooking, and gardening. Oloruntegbe et al. found that students from low socioeconomic backgrounds struck a better relationship between school and home science than their

counterparts from high socioeconomic backgrounds. It was postulated that academic performance would be enhanced even more if teachers could specifically cite relevant home experiences as examples and illustrations in their teaching.

The findings reported by Alvaera et al. (2009) and Oloruntegbe et al. (2010) suggest that my study, and the quality of my teaching in general, will benefit greatly from an interest in and understanding of my students' backgrounds, in addition to a concerted effort to make use of that knowledge to elicit conceptual understanding. Along with the obvious implications of being familiar with students' home environments and familial relationships, an awareness of how culture and socioeconomic status may shape perspective will make it easier for the teacher to view chemistry through the eyes of the student learner. For example, Oloruntegbe et al. pointed out the applications of science to domestic activities, so it is of value to think about how these real-world links can be used to tap into and make use of students' existing understandings of scientific phenomena. Finding creative ways to bring students' out-of-school experiences into the classroom may allow for a more comprehensive and engaging learning experience and pave the way for providing the relevant real-world contexts that Sirhan (2007) says will engage students to learn difficult concepts.

**Making chemistry accessible to all learners.** The unpopularity and irrelevance of chemistry in the eyes of students (Holbrook, 2005) is at the root of many of the concerns discussed previously in this literature review. The emphasis on conceptual understanding tends to be geared to internal concepts within chemistry itself and tends to be irrelevant for functionality in our lives, i.e. relevant to the home, environment, future employment, and for future societal changes and developments (Holbrook, 2005). To raise awareness and appreciation for chemistry, it is important to stress what Holbrook terms "education through chemistry"

instead of “chemistry through education”; that is, promoting necessary educational and cognitive skills to be acquired through the learning of chemistry instead of learning chemistry as a body of knowledge that is often detached from other content areas or real-world applications.

Efforts to increase the relevance of chemistry to students and to foster an understanding of how chemistry fits into the real world include the employment of popular culture such as books, films, and television shows (Clauss, 2009; Copes, 2006; Goll, Wilkinson, & Snell, 2009; Matson, Fitzgerald, & Lin, 2007; Wally, Levinger, & Grainger, 2005; Wink, 2001), analogies (Orgill & Thomas, 2007), and thematic instruction (Czerniak, Lumpe, & Haney, 1999). These measures engage students more effectively and allow them to form obvious connections between chemistry concepts and the portrayal of science in mainstream culture. Copes (2006) and Wally et al. (2005) reported the successful use of books, such as J. K. Rowling’s popular literary series of Harry Potter adventures, to excite students and teach chemistry concepts found in the books, such as spectroscopy (colored flames), solutions and chemical reactions (potions), and pH (color-changing inks). Goll et al. (2009) and Wink (2001) presented studies on the use of movies and film to anchor discussions of chemistry concepts in real-world or dramatic scenarios. Video clips were also used by Matson et al. to create customized safety videos specific to the student population. The use of popular culture in these studies allow for the presentation of material that students often find difficult or dry in a much more engaging manner.

The effective use of analogies in chemistry instruction has been studied by Hanes (2004), and in the 5E model of instruction by Orgill & Thomas (2007). Analogies “motivate students, clarify students’ thinking, help students overcome misconceptions, and give students ways to visualize abstract concepts” (Orgill & Thomas, 2007, p. 40). By using analogies within the framework of constructivist learning theory, students’ conceptual understanding, problem-

solving skills, communication skills, and creativity can be powerfully enhanced. Thematic units were also found to foster a perception of relevance for students. Czerniak et al. (1999) found that thematic science "increase[s] student understanding of science, make[s science] more interesting, and make[s] it motivating to learn" (p. 139). In that study, teachers generally exhibited positive attitudes toward thematic units but felt that more resources, support, professional development, and less stress on test scores were necessary to implement lasting reform. Nevertheless, those teachers also expressed that a systematic approach to adopt thematic science would be well worth the profound efforts required to make thematic units a standard feature of K-12 science classrooms.

In this study, I will employ several strategies described in the literature to help my students reach a more comprehensive understanding of and developed interest in chemistry and the sciences in general. Though I have used analogies in my instruction prior to this study, those instances were scarce, unrehearsed, and sometimes equally as incomprehensible to my students as the concept I was attempting to explain. In Phase I, I plan to investigate the effectiveness of introducing pop culture references into my classroom and elucidating the effect that those discussions will have on my students' engagement, learning of chemistry, and understanding of how chemistry fits into differential societal infrastructures. I hope that by taking measures to increase this applied understanding, I will also be able to cultivate a drive to learn challenging concepts that my students believe will be of value and relevance to their lives.

**Position of the Research Question**

The established literature on the teaching of chemistry in K-12 schools suggests that it is becoming increasingly necessary to employ learner-centered methods of instruction, particularly to address the concerns of the inherent difficulties of learning chemistry and to overcome

external factors that affect students' ability to succeed in the chemistry classroom or find relevance in the subject matter. Several researchers have discussed effective strategies to engage students and make chemistry accessible to a variety of learners, including how to help students understand that chemistry does fit into the context of the real world. However, there are few reviews available that discuss the actual measurement of students' practical understanding of chemistry concepts. How do we know that students have developed an applied understanding of chemistry? Can they relate their understanding of chemistry concepts to situations and phenomena that are seemingly unrelated to science? What teaching practices or classroom activities can be used to measured students' ability to contextualize chemistry? Because math skills are central to learning chemistry, can students in my particular classroom, who are math-deficient and already underperforming in chemistry, be engaged and motivated to develop that applied understanding? Though conclusive answers to these questions may be out of the grasp of this study, I hope to explore the links between these concepts and their implications in my classroom.

## Methodology

### Positionality

In my dual capacity as a teacher-researcher, I was presented with a unique set of challenges and opportunities under which to conduct my study. Though my primary responsibility as a teacher was to provide a quality, standards-based education for my students, on the research end of my study I also sought to identify what actions I needed to take to stimulate similar levels of excitement and interest for the students in my classroom that I myself experience toward chemistry. The undertaking of this study provided me with the opportunity to address the specific needs of my students in an area of personal interest—a deep learning of

chemistry. For the most part, the aims of my disparate roles of teacher and researcher enhanced and served one another, but it was nonetheless necessary for me to maintain as much objectivity as possible in my interpretations and analyses of my students' actions, work output, and academic performance. I worked to maintain neutrality by 1) using a triangulation of data, which supported the development of unbiased data analyses, 2) keeping my students abreast of my research and encouraging honest, straightforward responses to which I would not retaliate in any manner, which was also an asset in my endeavor to design personalized interventions, and 3) cultivating an open, collaborative relationship with my mentor teacher, who graciously offered support and guidance throughout the action research process.

**Methods of Data Collection Description and Rationale**

I used a triangulation of data sources, including both quantitative and qualitative methods, to strengthen the validity of my study and allow me to view the results of my interventions from a variety of perspectives, thereby enhancing the quality of the inferences resulting from the study. It was necessary to develop methods of data collection that would both objectively track my students' learning and shed light on more intangible aspects of their overall learning experience, including their engagement with the material and the ease with which they were able to make connections between the classroom and the world outside of it.

**Surveys.** I used surveys extensively throughout the action research process as a source of qualitative, student-reported data. In an effort to involve my students as co-researchers, I sought their feedback once a week about the interventions being implemented in each phase. On these surveys, students reported their levels of learning and engagement as a percentage of time using Harvey Balls ideograms. I chose to use Harvey Balls because they presented, a quick and simple way for students to visually communicate qualitative information. The surveys were also used to

collect answers in response to questions regarding students' engagement with specific activities, the identification of three new facts, concepts, or ideas learned over the course of the week, and occasionally an elucidation of how their learning or understanding of a particular chemistry concept changed as a result of the intervention or developed since the initial introduction of the concept in class. Toward the end of the study, especially, I began to ask more focused survey questions to probe deeper into my students' engagement and learning. The survey used most often during the study can be seen in Appendix D.

**Scores on assessments.** I used student scores and responses on both summative (diagnostic and unit exams, lab write-ups, presentations) and formative (quick writes, warm-ups, homework) assessments to collect measurable, quantitative data about student learning and understanding. Data collected as scores on summative assessments were of particular use in assessing student understanding over the course of the action research process in comparison to students' previous demonstrations of content knowledge on exams they completed prior to the study. Diagnostic exams were administered at the beginning of the needs assessment and before and after Phase I (three in total). Peer scoring sheets in Phase II were analyzed to evaluate the quality of students' presentations and their peers' understanding of the material as a result of being taught concepts by their peers. Additionally, written student responses in this source of data were used to validate data collected using other methods. For example, verifying whether the high levels of learning reported on surveys matched up with students' written explanations of chemical phenomena in lab write-ups or verbal descriptions during presentations.

**Teacher field log and reflection journal.** The final method of data collection was my field log, which dually served as my reflection and observation journal. During class time, I recorded student comments about my study, responses to the activity at hand, any

misconceptions or cleared misunderstandings, and anything else that I deemed of relevance or value to my analysis of the study. In this log, I attempted to separate my unbiased record of events taken during class from my personal reflections and observations about the interventions, lessons, and my students' reactions and responses to classroom activities. More importantly, I hoped to shed light on aspects of my students' experience that were not revealed in the surveys or exit slips. This log served as a source of qualitative data from the teacher's perspective, and was also used to gain a deeper understanding and more effective analysis of data collected from students and from assessments.

**Summary of Implementation Phases**

This study consisted of two phases. A summary chart of the pertinent details, including the essential activities, methods of data collection, and timeframe of the needs assessment and each implementation phase can be found in Table 1 below.

Table 1

*Time Frame and Essential Activities for Each Implementation Phase*

| Phase | Essential Activities | Data Collection | Time |
|---|---|---|---|
| Needs Assessment | Various instructional strategies to establish baseline of student engagement and identify Phase I interventions | Two pre-surveys, exit slips, field log | 2 weeks |
| Phase I | CST Chemistry review: Reteach and review chemistry concepts using 1) active learning experiences and 2) pop culture references | Surveys (Harvey Balls), diagnostic exam scores, field log | 3 weeks |
| Phase II | Group concept presentations: Great Gas Geyser and Dry Ice Magic | Surveys, peer scoring, exam scores, field log | 4 weeks |

**Phase I**

An analysis of the data from my needs assessment revealed the demand for active learning opportunities as well as opportunities for my students to make real-world connections and understand that chemistry is firmly woven into their daily observations and experiences. In the needs assessment surveys and exit slips, my students indicated greater interest, engagement, and anticipation for all non-lecture-based learning experiences. The needs assessment also revealed a deficiency in my students' content mastery and ability to contextualize chemistry—not even to understand how chemistry is applicable to real-world experiences but just to identify that it is relevant in the first place. For example, though we had discussed solutions extensively during the unit on mixtures, during the needs assessment my students were hard-pressed to identify that the ice cream they were making could be classified as a homogenous mixture, or solution. When prodded, they were able to define "solution," "mixture," and "homogenous mixture," but could not make the leap in thinking that would lead them to connect their theoretical understanding of a solution with the physical example of a solution in their hands. I hoped that a structured review of the material accompanied by interactive and hands-on learning experiences of those concepts in Phase I would address this disconnect and help students visualize and identify real-world chemistry.

As a result of these observations, I wanted to further explore the effect of active learning experiences on my students' engagement and content understanding in Phase I, as well as build their higher-order thinking and awareness of chemistry in the real world. To these ends, my interventions for Phase I were 1) the use of student-centered experiences such as demonstrations, hands-on activities, and laboratory experiments, and 2) the use of popular culture references. I hoped that by using television shows, books, and movies that my students enjoyed and were

familiar with, the knowledge that chemistry exists in everyday things would be easier to grasp and hold onto. Phase I took place during my two-week review of the entire year of chemistry concepts, in preparation for my students' sitting for the CST Chemistry. Phase I was thus well-suited to an exploration of how I could use student-centered activities and pop culture references to reteach chemistry concepts during my CST review, allowing me to compare students' new understandings as a result of the interventions to their initial experience with the same concepts that were learned through traditional instruction. To track any growth or progress in my students' content mastery, I administered a diagnostic exam prior to implementing any Phase I interventions and another upon completion of Phase I.

**Action plan description.** Phase I interventions occurred concurrently. The first intervention included hands-on and visual experiences such as laboratory activities (Gallet, 1998), animations (Yaron, 2000), simulations (Yaron, 2000), and demonstrations, which all hold great potential for engaging students and increasing student achievement. Performing science allows students to better construct meaning and acquire an understanding of more complex and abstract concepts. For example, my initial teaching of gas laws prior to the study was heavily lecture-driven, and student interaction entailed mostly discussions of how to use the various gas law equations to solve word problems. One discussion in particular (referred to earlier in this paper) was successful in drawing out students' prior knowledge as examples of water bottles and potato chip bags came into play, but this understanding did not extend to the entire class and remained largely conceptual. The review of gas laws during Phase I included two demonstrations—the "egg in a bottle" and "imploding can" experiments, which are common demonstrations in chemistry classrooms. After performing each demonstration, I walked students through an explanation of how each experiment pertained to and could be explained by one of

the gas laws by asking questions that facilitated their thinking and further helped them to draw on their existing knowledge, however limited or fragmented they perceived that knowledge to be.

Laboratory experiments were also used in Phase I to review concepts, such as eliciting a deeper understanding of reaction rates by conducting the famed Diet Coke and Mentos experiment made popular by Mythbusters in 2006. For this particular experiment, students identified the factors that affect chemical reaction rates (temperature, pressure, concentration, and presence of a catalyst) and brainstorm in groups how those factors would be tested. Throughout Phase I, I responded to what I perceived to be my students' conceptual weaknesses during our review sessions and designed classroom activities accordingly. A short list of the learning experiences provided in Phase I can be found in Table 2 at the end of this section.

The second Phase I intervention was the use of references to popular TV shows, books, and movies to illustrate the presence of chemistry concepts in mainstream media. As with the first intervention, pop culture references were used whenever I was able to locate a relevant reference and when I believed that these references would help students develop a deeper understanding of concepts. For example, a discussion about the various states of matter (solid, liquid, and gas) turned to sublimation and deposition, which are the phase transitions from solid to gas and gas to solid, respectively. These phase changes are uncommonly discussed in chemistry classrooms. To help students remember that melting occurs when a solid changes into a liquid and sublimation occurs when a solid changes into a gas, I broadcasted the scene from the 1939 film *The Wizard of Oz* in which Dorothy splashes water on the Wicked Witch of the West and the witch famously screams, "I'm melting! I'm melting!" By having students use both their eyes and ears to make observations about the clip—in particular, that when the Wicked Witch is

"melting" she is letting off steam or gas instead of forming a puddle of liquid on the ground—I was able to lead them into a discussion about whether the witch should really be saying, "I'm subliming! I'm subliming!" Another example of the use of pop culture was a clip from the 1991 film *Father of the Bride*, in which Steve Martin rants in a supermarket about hot dogs being sold in packages of eight and hot dog buns in packages of 12. This scene was used in the review about stoichiometry, balancing chemical equations and limiting reagents. A transcript of the video clip is available in Appendix I. A short list of the paired Phase I interventions described in this section can be found in Table 2 below.

Table 2

*Phase I Student-Centered Learning Experiences and Popular Culture References*

| Phase I Schedule | Chemistry Concepts Reviewed | Student-Centered Activities | Pop Culture References |
|---|---|---|---|
| Week 1 | Atomic Structure<br>Chemical Bonds | Bond-Type Lab | *Harry Potter* quotes and James Bond: "My name is Bond. Ionic Bond. Taken, not shared." |
| | Balancing Equations<br>Stoichiometry | Stoichiometry of S'mores | Supermarket scene in *Father of the Bride* |
| Week 2 | Gas Laws | Egg in a Bottle and Imploding Can Demos | *Mythbusters*: Exploding Toilet |
| | Acids and Bases | Cabbage Juice Indicator and Making Invisible Ink | Marauder's Map in *Harry Potter and The Prisoner of Azkaban* and *Good Eats:* Fudge Factor and Pretzel Logic |
| | Thermodynamics | Making Hot and Cold Packs | Wicked Witch of the West in *The Wizard of Oz* and *X-Men: The Last Stand* (Gambit and Iceman) |
| Week 3 | Reaction Rates | Diet Coke and Mentos (Coffey, 2008) | Walt's lecture about reaction rates in *Breaking Bad:* Crazy Handful of Nothin' (1.6) |
| | Equilibrium | Simulation: Throwing Paper Wads (Orvis & Orvis, 2005) | Ammonium thioglycolate in *Legally Blonde* |

*Note.* To inform a better understanding of the nature of the learning activities in Phase I, more detailed information for the Week 1 *Harry Potter* reference, transcript for the *Father of the Bride* video clip, and Stoichiometry of S'mores activity and the Week 2 thermodynamics activity, Making Hot and Cold Packs, can be found in Appendices F, G, H and I, respectively.

**Presentation and analysis of data.** As I progressed through my review for the CST Chemistry in Phase I, I was able to gather insightful information regarding how to engage my students and their learning needs in my classroom. At the end of each of the three weeks that comprised Phase I, I collected exit slips from my students on which they reported, using Harvey balls, the percentage of time over the course of the week that they were engaged and learning more about chemistry. Five examples of exit slip data are available in Appendices J–N. A summary of the class data from the Harvey Balls is provided in Figure 3 below.

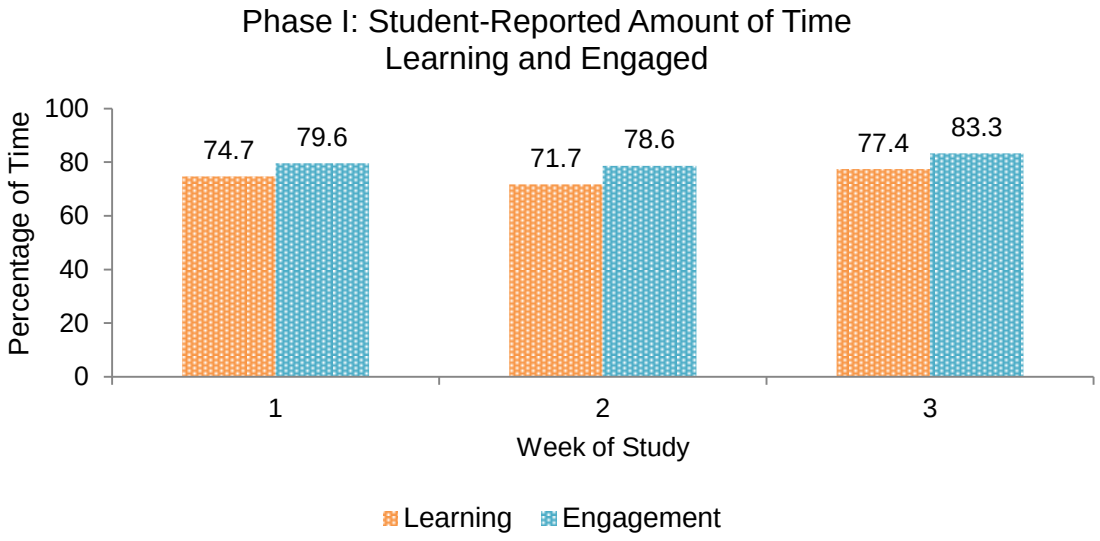


*Figure 3*. Student-reported learning and engagement as a percentage of time over the course of each week in Phase I, in response to Phase I interventions of learner-centered activities and popular culture references.

Phase I data revealed that both interventions were effective strategies for engaging my students and helping them understand the relevance and universality of chemistry. Figure 3 shows that, as class averages, learning and engagement decreased and increased in the same pattern over the three-week period. This trend suggests that whenever my students were engaged in the lesson, they were learning at the same time. In the all-class data of Week 1, 18 of 23 students (78%) who fell into this trend reported less than a 10% difference between the amount of time they were learning and engaged. This percentage holds for all three weeks of Phase I.

The students represented in Appendices J–N (these students will hereafter be referred to by the letter of their exit slip appendix) are illustrative of the range of ability and achievement in my class. The appendices are ordered from highest-performing to lowest-performing student. Students L and M were two of five students in the whole class during Week 3 who reported significantly disparate (>10%) amounts of time in which they were engaged and learning, with Student L conveying engagement at all times but learning for only 40% of the time. The data collected from Student N is more characteristic of the rest of the class in the association of high levels of engagement with effective teaching and thus the student's own increase in content knowledge. Despite the enduring learning that students reported in their Harvey Balls, however, their written responses on the exit slips were shallow and not indicative of greater content understanding. Of the appendix samples, only Student K responded with explicit points of learning, i.e. "learned how forward and reverse [reactions] can still be [at] equilibrium when [there are] less [moles] on one side". Most students wrote one or two words to declare that they learned something but were unable or unwilling to elaborate on what that understanding actually entailed. I noted in my field log one student's remark: "I love when learning is fun!" I believe that the exciting nature of the classroom activities stimulated my students' motivations to learn,

but a desire to learn and belief that one is learning unfortunately does not equate to actual knowledge attained. The flaw in this causal link between engagement and learning was further corroborated by the diagnostic exam scores. The trend in class average data on the three diagnostic exams, administered at the beginning of the needs assessment and Phase I and at the close of Phase I, is shown in Figure 4 below.

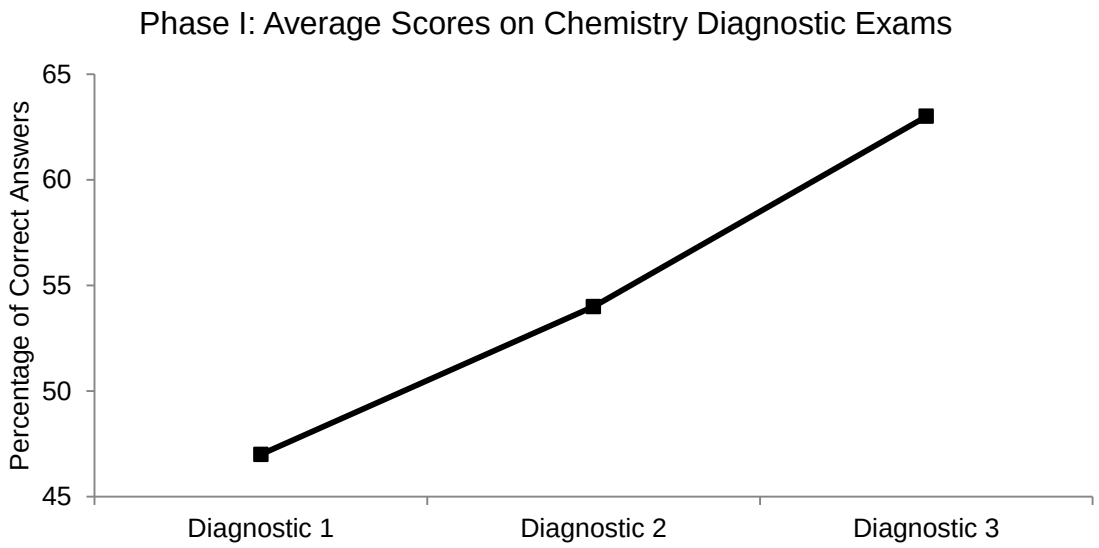


*Figure 4*. Progression of scores on chemistry diagnostic exams, presented as a mean of all class data.

Though the data suggests a great increase in content mastery between the first and third diagnostic exams, the score increase from exams 1 to 2 (seven-point increase up to 54%) is attributed mostly to where we were within the chemistry curriculum for the first diagnostic exam (recall that the first exam was administered at the beginning of the needs assessment, when 25% of the chemistry curriculum remained to be learned). A similar improvement was seen between exams 2 to 3 (nine-point increase up to 63%), but the mean score for exam 3 still falls very short of the minimum for a passing grade at 69.5% for a grade of C-.

The student-reported data and exam scores from Phase I suggest that the interventions in this phase were minimally influential on developing students' understanding of chemistry concepts. However, a solid first step toward increasing content mastery occurred in students' increased sense of the pervasiveness of chemistry in the world around them. Hands-on activities had a greater impact on their engagement than pop culture references, but it would be careless to ignore the influence that using pop culture specifically had on opening my students' eyes to the real-life application of chemistry and presence of chemistry in different media. After the first week of Phase I, students voluntarily approached me with pop culture references that they believed were relevant to our class. After my first reference to *Harry Potter* (Appendix F), for example, one student asked me if the disappearing ink used to write the Marauder's Map in *Harry Potter and the Prisoner of Azkaban* was a real invention. This sparked a trend of students seeking chemistry references from different sources, some of which I chose to implement during Phase I.

Nonetheless, students' ability to identify that references to chemistry are present did not necessarily equate to a deeper understanding of how it can be used to explain certain phenomena, which was present throughout my field notes in addition to the class's diagnostic exam scores. This disconnect was manifested primarily as an inability to draw connections between concepts or attach multiple concepts to a single event. For example, during the Diet Coke and Mentos experiment, which was presented in the review of reaction rates, I asked students questions that I intended to lead to other concepts, such as equilibrium, solutions, and gas laws. However, all of their answers referred back to reaction rates, as in the following exchange:

> *Teacher:* What happens when you uncap the bottle? What did you observe?
>
> *Student 1:* It hisses!

*Teacher:* Okay, so why is that happening? What causes the hissing noise?

*Student 2:* The carbon dioxide gas is undergoing a really fast reaction so it gets out of the bottle.

*Teacher:* Well, what do you mean it "gets out" of the bottle? Does this same thing, the hissing, happen when you open a water bottle?

*Student 1:* It does happen, but water doesn't react as fast as soda so you can't really hear it like with soda.

*Student 2:* No, I don't think there's carbon dioxide in water. But for this one, the gas makes the reaction go faster so it gets out fast and makes it hiss.

It was evident in this exchange that my students' attempts to find answers to my questions were leading them to draw faulty, illogical conclusions and make connections that were not there. Though we had discussed earlier in the lesson what happens for a reaction to take place—different reactant molecules collide—Student 2 erroneously said that carbon dioxide was undergoing a "really fast reaction" with itself, causing the gas to escape from the bottle. He was correct in saying that the hissing noise was caused by the rapid escape of gas from the bottle, but his explanation for why the gas was escaping should have included a discussion of pressure and equilibrium. My students knew that we conducted the experiment to discuss reaction rates, but were unable to expand their understanding of the experiment to other concepts that we recently reviewed. Additionally, the concept of a catalyst (which falls under the subject of reaction rates) was unclear to Student 2. He wanted to say that gas bubbles are catalysts (since catalysts are one of the four factors that affect reaction rates), but didn't realize that 1) opening a soda bottle does not initiate a chemical reaction and 2) catalysts are substances added to a reaction to make the

reaction proceed to completion faster. Because carbon dioxide bubbles are already part of the soda mixture, they cannot be catalysts even if a reaction was underway.

Throughout Phase I, I observed student conversations that revealed an enthusiastic class who unfortunately struggled to wield academic language, communicate conceptual understanding to me or other students, and otherwise demonstrate progressive content mastery to a minimum level of proficiency. However, there is something to be said for the engagement and excitement that the interventions in Phase I drew out of my students. For example, the conversation with my students described earlier in this section would have been met, prior to this study, with “I don’t know” and “I’m not sure” from several students in place of the convoluted but genuine responses that I received in Phase I. Unfortunately, toward the end of the phase it was becoming evident that my students’ excitement to learn chemistry and their efforts to participate in class were still being hindered by a lack of productivity outside of the classroom. In the face of their third diagnostic exam scores, my students began to get disheartened. What could I do to maintain their enthusiasm and support deep learning?

In response to Phase I, my guiding research question evolved from an investigation into effective instructional techniques to an exploration of learner-centered activities and their place in my classroom. How could placing learners at the center of my instructional design inform my effectiveness as a teacher? What is the effect of learner-centered instruction on students’ ability to understand the links between chemistry concepts, and also between chemistry and other subject areas? Having succeeded in increasing the student-centered character of my classroom, and more importantly, achieving student engagement when before I had very little, I sought to identify the weaknesses laid bare by Phase I and capitalize on my students’ newfound enthusiasm about chemistry and awareness of its place in the world. The shortcomings of Phase I

lay in my students' persisting inability to make connections across the curriculum and to equate their feeling and drive to learn with an actual acquisition of information. Additionally, many of the activities provided in Phase I, though learner-centered, were independent instead of collaborative between students. When planning an intervention for Phase II, I thus sought a design that would make my students even more central to the learning process. First, I aimed to focus on individual concepts so that my students' attention wouldn't be divided by multiple things they didn't understand—for example, learning only about reaction rates, instead of trying to force connections between reaction rates and equilibrium. I hoped that by narrowing their studies down to emphasizing a single concept, learning would grow in depth instead of breadth. I also wanted to increase the collaborative nature of the classroom environment, so that my students could communicate their understandings and misconceptions. Finally, in an attempt to solve for the disengagement that was occurring between school and home, I sought to increase my students' accountability, directed toward themselves as well as their peers.

**Phase II**

My intervention for Phase II was designed to address several needs that emerged out of Phase I. I hoped to aid students in developing content mastery through a fun and engaging activity that promoted student accountability, applied understanding of chemistry, and active group learning (cooperative and/or collaborative learning). To this end, I developed a mini-project inspired by thematic units, which focus learning on a big question or focus and demonstrate the interdisciplinary nature of real life (Czerniak et al., 1999). Crawley and Salyer (as cited in Czerniak et al., 1999) found that thematic science increases student understanding of science, makes it more interesting and motivating to learn, and helps students understand the "big picture." For this intervention, students worked in groups to create presentations (hereafter

referred to as “group concept presentations”) about a single chemistry concept with the intention of peer-teaching that concept to their classmates. Groups were also responsible for designing a demonstration, experiment, simulation, or animation that would link their concept to a real-world application of chemistry. I hoped that the potential for personal and creative experiences offered by this intervention would not only help my students enjoy chemistry but also add to their ability to learn the material (Furlan, 2007).

**Action plan description.** Phase II occurred in two parts. Part IIA began with a class discussion in which we examined and troubleshot the challenges of the Diet Coke and Mentos experiment conducted in Phase I and generated a list of chemistry concepts that could explain or be explained by the experiment. We ultimately chose four concepts—solutions, gas laws, reaction rates, and equilibrium—that I assigned to groups of four to six students. After conducting the experiment, which we called the “Great Gas Geyser” (GGG), each group of students analyzed the GGG through the lens of their specific concept. Students aimed to be experts of their specific concept and were told to disregard concepts that other groups were studying. Over two class periods, each group created presentations to teach the concept to their peers, through 1) explaining how their particular concept related to the GGG experiment and 2) bringing in a relevant, real-world connection using a demonstration, experiment, simulation, or student-created Flash animation to provide evidence of their own understanding and drive the point home for their classmates. The planning process was cooperative in nature, and students worked together to present a specific content standard related to their concept. To probe each group’s thinking and expertise on their chemistry concept, students were told that an open-ended Q&A session, open to me as well as the rest of the class, would take place immediately after their group presentations, and should therefore be as thorough as possible in their preparation

and planning. I closely monitored the progress of each group to make sure they were on task, sometimes suggesting roles for each student or providing literature when I felt they needed more specific guidance. During the presentations, the Q&A sessions lasted anywhere from five to 15 minutes, depending on the frequency and complexity of questions asked. Each presentation was peer-reviewed by the rest of the class using the scoring rubric in Appendix E. The timeline for Part IIA is shown in Table 3 below.

Table 3

*Timeline of Phase II Part A*

| Week | Day | Activity |
|---|---|---|
| 1 | 1 | Groups/concepts assigned, class discussion of experimental design |
| | 2 | Conduct Great Gas Geyser experiment, discuss observations |
| 2 | 3 | Group planning |
| | 4 | Group planning |
| | 5 | Group concept presentations and peer scoring |

The second part of Phase II was very similar to the first, with the exception of several minor changes that I made to give students more freedom, choice, and autonomy in the learning process. These changes were the result of a class discussion that took place on the first day of Part IIB. I suggested this discussion and was present for it, but my role was only that of an observer and I did not participate in the discussion. This discussion began with each table of students (not in presentation groups) discussing what they liked and did not like about the planning and presenting process, as well as aspects about the activity, including my role as a teacher, that they found helpful or limiting. Finally, a student volunteered to facilitate a discussion in which the class collaborated to listed the strengths and weaknesses of Part IIA and

propose solutions to address the weaknesses identified. The results of that class conversation are shown in Table 4 below:

Table 4.

*Class-Generated List of Strengths, Weaknesses, and Solutions to Weaknesses for Round 1 of Group Concept Presentations*

| Strengths | Weaknesses | Solutions |
|---|---|---|
| • Support within groups<br>• Shared responsibility<br>• Deeper understanding of the concept we studied<br>• Already have presentation skills; this was good practice<br>• Other groups had interesting experiments<br>• Hands-on presentations were engaging | • Unbalanced responsibility between group members<br>• Shyness; lack of confidence talking about our concept<br>• Lack of basic conceptual understanding (so can't have deep learning)<br>• Large group sizes made it hard to equally share responsibility | • Smaller group sizes<br>• Get rid of Q&A or give each group the questions in advance<br>• Choice of group members<br>• Choice of concept |

In response to the proposed solutions, I allowed each group to choose the concept to be studied and decreased the size of groups to three or four students. Many students reported that sharing responsibility was a positive aspect of the presentations, but that the large group sizes were unmanageable for allocating equal shares of responsibility within the group. I also gave students a voice in choosing their group partners, by having each student list three peers they would like to work with, one of whom had to be a person they did not interact with every day.

Using my knowledge of students' strengths and weaknesses, conceptually and behaviorally, I sorted students into groups, with every student being paired with at least one person they identified as wanting to work with. I also opened up the structure of group planning and presentation design to give students more responsibility and encourage them to answer to each other, instead of to me.

The experiment for Part IIB, "Dry Ice Magic," consisted of a rotating series of dry ice experiments. Short descriptions of these experiments are available in Appendix O. The timeline for Part IIB was slightly modified from what is seen in Table 3. The first day included both the experiment rotation and discussion of student observations, followed by three days of group planning and the presentations on the final day. I extended time for the group planning portion of Part IIB to three days, in order to make way for a shift from cooperative learning to group work that was more collaborative in nature. I also gave students more control and responsibility in Part IIB by giving them almost complete autonomy in shaping their presentation—students decided in their groups what aspects of their concept they wanted to present and the manner in which they packaged their presentation. Instead of checking in and directing each group's progress like I did in Part IIA, I assessed their progress, provided suggestions about their approach, and generally made myself available as a consultant and facilitator. Due to student feedback from the post-IIA class discussion and my own notes from the first round of group concept presentations, I also discarded the Q&A portion of the presentation, so that the evaluation of each group's content knowledge would be restricted to the information they chose to present. Students were not restricted to the state content standards in chemistry to inform the scope of their concept knowledge. As in Part IIA, the presentations were peer-reviewed using the scoring rubric in Appendix E.

**Presentation and analysis of data.** For Phase II, I continued my practice of collecting exit slips at the end of every week, on which students reported the percentage of time over the course of the week that they believed they were learning and engaged. The data on each exit slip therefore included either the experiment or presentation portions of Phases IIA and IIB. An average of the student-reported percentages of time spent learning or engaged for the four weeks that comprised Phase II is available in Figure 5 below.

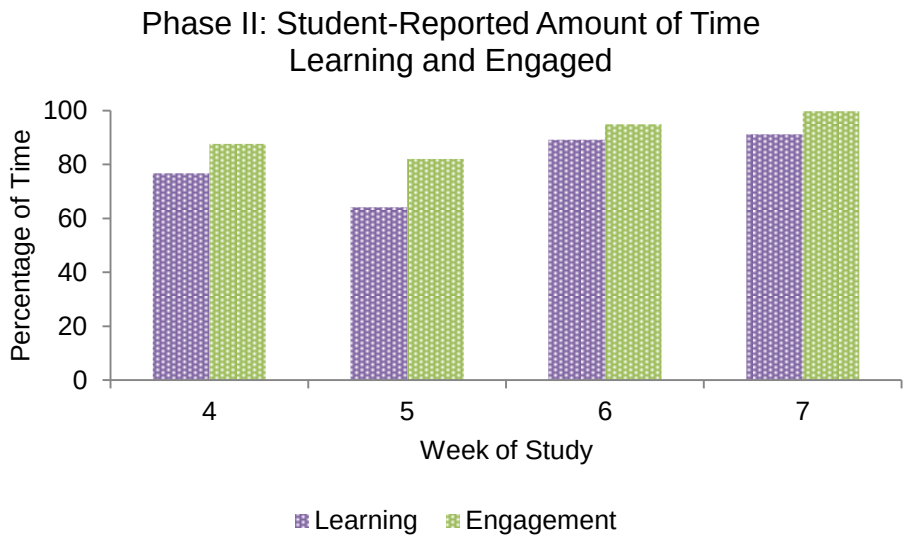


*Figure 5*. Student-reported learning and engagement as a percentage of time over the course of each week of Phase II, in response to the Phase II intervention of group concept presentations.

In Figure 5, Weeks 4 and 6 represent the Great Gas Geyser and Dry Ice Magic experiments, respectively, and Weeks 5 and 7 represent the two rounds of group concept presentations that followed. Students reported they were learning and engaged at least 75% of the time for each week of Phase II, with the exception of 64% of time spent learning during Week 5. The least amount of time during which students reported learning or engagement over Phase II occurred during Week 5, which also had the greatest difference between the mean

amounts of time spent learning or engaged within a week. Sixty-eight percent of students reported a significant difference (>10%) between the percentage of time they felt they were learning and the percentage of time they were engaged in Week 5. In an effort to understand in particular the drop in amount of time learning, I analyzed students' responses to the survey questions for that week. The survey questions on the Week 5 exit slips (collected on the day of the first group concept presentation) are as follows:

1. List 3 new things that you learned or understand better after today.
2. What feature of today's activity made you feel engaged and interested?
3. Why/how was today's lesson more informative/fun/effective than the first time you learned your group's concept?
4. Did having fun make you feel more motivated to learn and/or comfortable talking to your classmates about chemistry? How/why?
5. Improvements for next time?

Because the nature of the questions was specific to the day of the group concept presentations, the drop in learning during Week 5 (from both the Harvey Balls and survey responses) is not representative of the entire week. However, I hoped that a focused look at this particular day would still yield increased learning, so I examined student answers to the first Week 5 question in an effort to understand the data. One student wrote, "I didn't learn anything. Everything we went over I already knew." About a third of the class expressed this same sentiment, but I gathered from their responses and a review of my field log that many students did not differentiate between "learning" and "learning more." That is, for example, a student who claimed she learned 0% of the time during Week 5 wrote that she "already know[s] about reaction rates," but "learned that catalysts speed up the reaction after you add it to the reaction

mixture. I didn't know the catalyst had to be separate then [sic] the reaction." This student was cognizant of the concept of reaction rates, and though she admitted to learning more about reaction rates as a result of being taught by her peers, did not distinguish between "knowing about reaction rates" and "knowing more about reaction rates." I believe that this misconception accounts in large part for the decrease in learning that occurred during Week 5.

I also wanted to learn more about students' attitudes toward the group concept presentations, so I conducted a deep analysis into class-wide responses to Questions 2, 3 and 4 on the Week 5 exit slips. In general, students reported that, barring a few tweaks, the presentations were informative and interesting. In response to Question 2, students wrote, "having [chemistry topics] explained by peers is interesting," "the visuals and hands-on experiments were engaging and creative," and "different topics being presented made [learning] less boring." These answers indicate a high level of engagement. Students also wrote, in response to Question 3, "I had a better understanding of our topic… because we focused on just one topic and [did] not jump around on other topic [*sic*]." One student wrote that the lesson was effective for him because, "You need to be the expert on your concept. You also know how the experiment works because you came up with it." Finally, "Designing the presentation helped me understand the concept better because while doing the experiment for [the concept], [the experiment] made it easier for me to understand Boyle's law." Students found that because they were responsible for teaching their peers, it was helpful to focus on one concept that they could study extensively. The process of developing a presentation was also helpful in aiding students' visualization of concepts. Finally, in response to Question 4, many students generally felt that "it was interesting to see some of the experiments made and how it related to what they were teaching." One aspect of the group concept presentations that made them very interesting and

engaging for students was the opportunity to preview their peers' creative work and gain insights into how others interpret their own understanding of chemistry. The data suggested that, within a group, students learned more about their own concepts in the process of preparing for the presentation. However, though the general attitude of the class was that learning from their peers was interesting and effective, after looking at the data I remained unconvinced that the "teaching" intention of the presentations was fulfilled. This was corroborated by the class average on the fourth diagnostic exam, which I administered at the end of Part IIA. The trend in class average after the fourth diagnostic exam is shown in Figure 6 below.

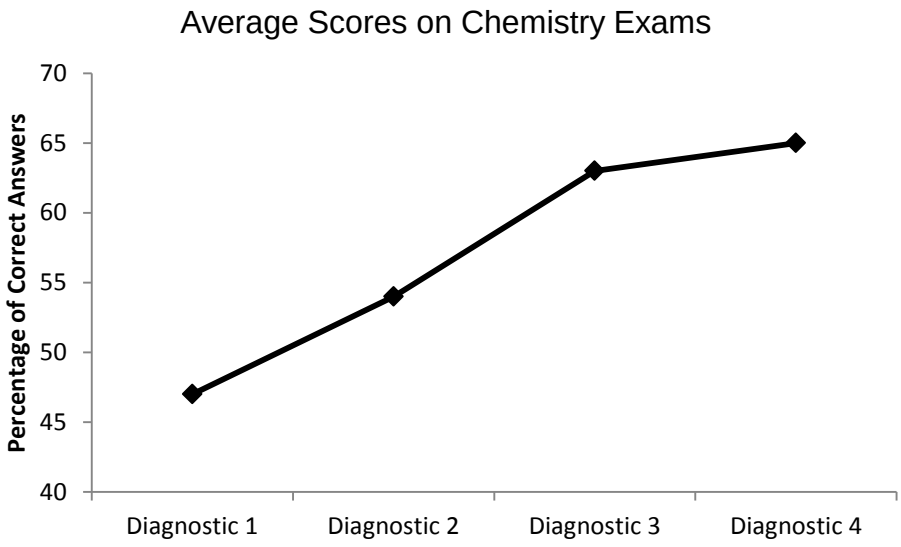


*Figure 6.* Progression of scores for four chemistry diagnostic exams through Phase IIA, presented as a mean of all class data.

Though my first preview of the Phase IIA data indicated that the group presentations were effective in increasing both student learning and engagement, the diagnostic exam average still fell below a passing grade, with a two-point increase from the third diagnostic exam to a 65%. In order to increase the effectiveness of the group concept presentations, I implemented the

changes for Phase IIB, described earlier in this section. The results of the peer scoring on five criteria for both parts of Phase II are shown in Figure 7.

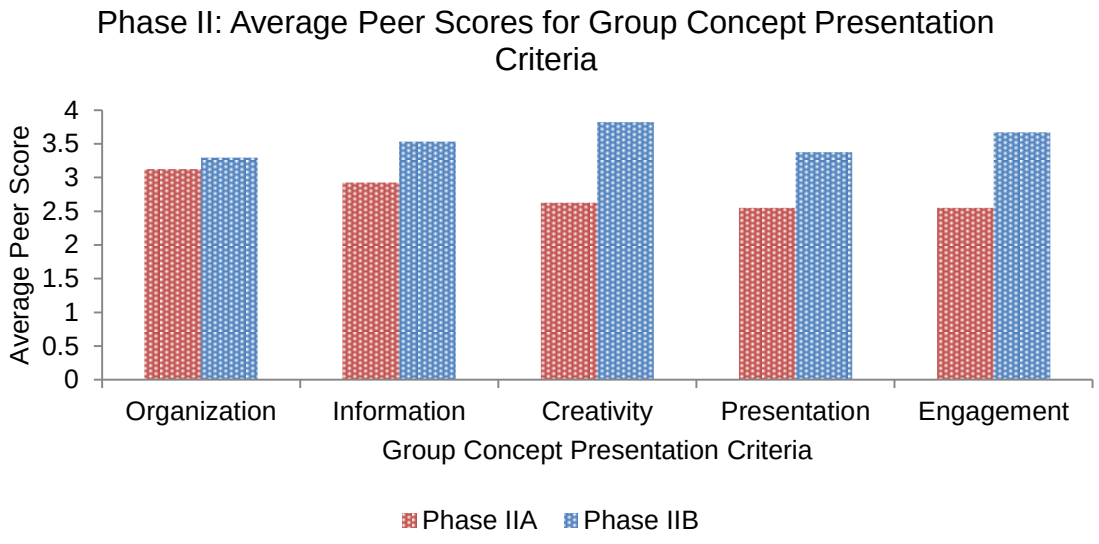


*Figure 7.* Class-averaged peer scores for five criteria on the group concept presentation rubric.

Figure 7 shows that the second round of group concept presentations yielded an increase across all five peer scoring criteria:

1. Organization, clarity, and preparation;
2. Accurate and adequate information;
3. Creativity;
4. Presentation elements, including projection, eye contact, confidence, and posture; and
5. Interest and engagement.

The greatest increases from the first to second parts of Phase II can be seen in the peer scoring averages for the criteria of creativity and engagement, which both increased by more than one scoring point. This suggests that the changes implemented for Phase IIB, of giving students more freedom and autonomy in researching their concepts and developing their presentations, were

effective in producing presentations and peer instruction of a higher quality. Removing myself as a manager of their work seemed to not only drive students to rely more on their group members in order to create the presentation, but allowed them to exercise more creativity, be more confident in their content knowledge, and teach their peers in an interesting manner.

The IIB group concept presentations further differed from the first round in that some students used schemas to understand and explain chemistry to their peers. Three groups out of four chose the concept they were most interested in, explained several elements of the dry ice experiments through that concept, and then in reverse fashion, re-explained the concept using an experiment or demonstration of their own design. The unanimous class favorite was the final presentation, for which a group of four girls who were the experts on chemical reactions collectively baked eight different batches of chocolate chip cookies to illustrate the effect of changing ratios or types of ingredients. One batch of cookies, for example, was much flatter and crispier than the others, which was explained by an increase in the amount of butter mixed into the cookie dough. Two cookies with the same ratio of ingredients but different sugars—brown and white—revealed that brown sugar makes a chewier cookie. After the presentation, the discussion that ensued inevitably led to questions that brought other, related concepts into play. For example, one student asked the cookie group, “What if you have less butter than the recipe says but you don’t want the cookie texture to change?” By knowing the ratio of ingredients, answered the cookie group, you’ll be able to use the amount of butter that you do have and convert backward to find out the rest of the ingredients. After a moment of silence, another student tentatively pointed out, “That seems kind of like stoichiometry, with the mole ratios and stuff.” It was so exciting for both me and my students to see all manner of chemistry connections spring into their minds. This particular group was well-organized, in terms of allocating equal

responsibility to group members and presenting a structured explanation of chemical reactions. Their clear passion for baking made them confident about the relevance of their concept and made way for a smooth and engaging presentation.

Students reflected about the second round of group concept presentations by telling me what they liked about the presentations and how the presentations informed a better understanding of chemistry. Students reported finding value in the presentations for a variety of reasons. The following responses were written by students of all achievement and performance levels, across the range of grade levels and language proficiency in my class:

a) I like group presentations because [they] related chemistry to real-world examples and they were fun to learn. I liked the creativity.
b) Group concept presentations help us understand [chemistry concepts]… because they are explainable in the way we understand.
c) [The presentations] helped me understand learning chemistry because we have the experiments that help us see concepts visually.
d) I liked the presentations because we could see that everything in this class is related but we don't see it.
e) The presentations were more fun to watch than just doing a lab because we learned more about the different ways [the experiments] explain chemistry.
f) I feel that the group presentations make it more interesting to learn the concepts. When we lecture I feel that I learn more but doing the presentations makes what I learn easier to apply or more memorable.
g) Working in groups helped us learn because we had each other if we needed help within the concept.

## Analysis of Results

### Summary of All Data

The data that I collected across Phases I and II suggested, most importantly, a gradual growth in my students' engagement and content understanding over the course of the study. This trend was evident both in qualitative student-reported data and in class average scores on diagnostic exams and group concept presentations. Exit slip data from Phase I, in which I sought to increase the student-centered character of my classroom by providing hands-on activities and pop culture references, showed a steady climb in the amount of time per week that my students were engaged in the classroom and believed that they were learning more about chemistry. A parallel increase in diagnostic exam scores corresponded to the reported growth in learning. However, the level of proficiency across the curriculum still did not meet the minimum standard of passing. In an effort to remedy the persistent struggle to gain mastery of content knowledge, I tried to increase the student-centered character of my interventions and explored thematic science, cooperative and collaborative learning, and measures to increase student accountability.

Phase II saw a growth in students' roles and responsibilities in the learning process. A drop in both engagement and learning during Week 5 may be accounted for the new activity introduced—group concept presentations—as well as students' misconceptions regarding "knowing" about a subject and "learning" more information about that subject. Additionally, the wording of the survey questions for that week may have led students to report only their engagement and learning for a single day. Nonetheless, there is a sharp increase in time spent both engaged and learning from the first round of group concept presentations in Week 5 to the second round in Week 7. Finally, the end-of-course exam results show that the class was able to obtain a minimum level of proficiency by scoring a mean of 71% on the final exam.

**Data Summary Charts**

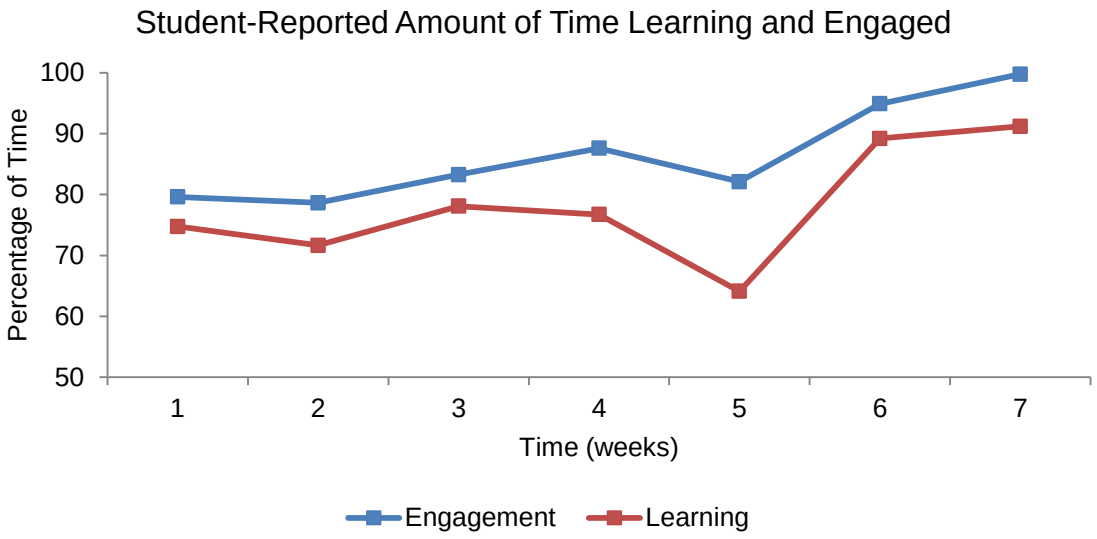


*Figure 8*. Summary of student learning and engagement across Phases I and II. Data was student-reported as percentages of time over the course of each week. There is a clear progression in both engagement and learning from Week 1 to Week 7 of the study.

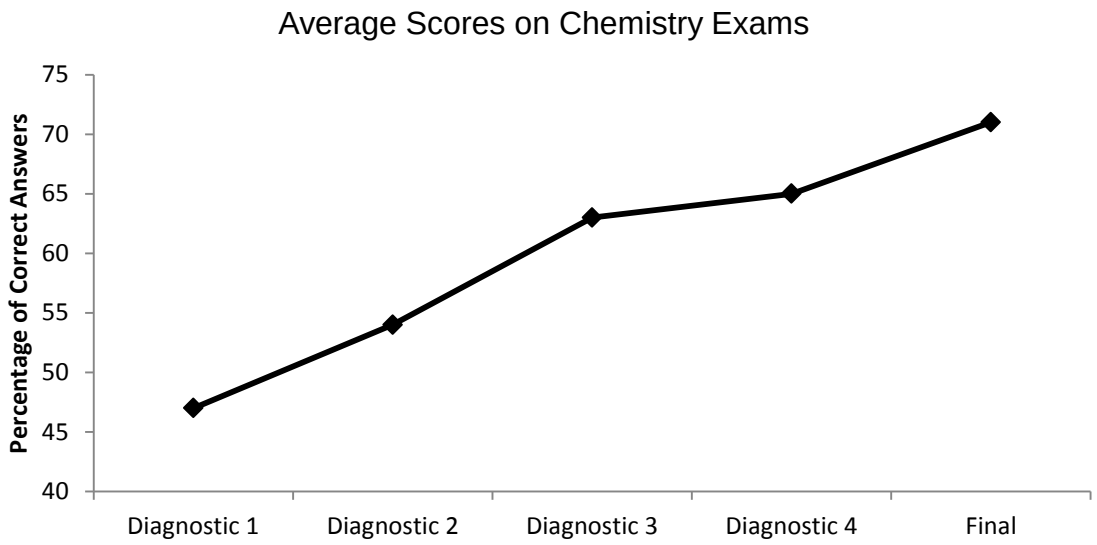


*Figure 9.* Progression of scores for four diagnostic exams and the final exam through Phases I and II, presented as a mean of all class data. Students obtained proficiency on the final exam with a mean score of 71%.

## Key Findings and Discussion

### Findings

**Revisiting key concepts promotes content mastery.** A recurring theme in my study was a revisiting of key concepts and the ensuing growth in content mastery. By the beginning of Phase I, my students had learned the entire chemistry curriculum and seen every concept at least once. The concurrence of the CST Chemistry review with Phase I interventions resulted in a return to each unit under a different light, in which students could reevaluate and make adjustments to their initial understanding. By the close of Phase II, some concepts were reviewed three times since the first learning and students were given several opportunities to ask questions, voice their understanding or lack of comprehension, and communicate with their peers about the topics in question. I believe that, at least in part, any success I achieved in the study regarding students' enhanced understanding of chemistry may be attributed to the continual return to fundamental concepts.

One area in which revisiting concepts seemed most helpful toward building students' content mastery was the clearing up of common misconceptions and misinterpreted chemical ideas. For example, several students persisted in thinking that because the net reaction rate at chemical equilibrium is zero, no reactions are occurring. This is a common misconception about equilibrium that, prior to this study, no amount of lecturing or variation in explanation on my part could demystify. Chemical equilibrium was one of the most demanding conceptual difficulties that my students faced all year, and more than one misconstruction arose around this concept. Finally, after participating in the "throwing paper wads" equilibrium simulation activity (Orvis & Orvis, 2005) in Phase I, students were more comfortable with the idea of a dynamic state in which the forward and backwards reactions are proceeding at the same rate. Deeper

comprehension of “dynamic equilibrium” was facilitated during the second round of group concept presentations. To illustrate static equilibrium, the presenting group started a tug-of-war game with equal strength on both sides of the rope—in this scenario, there really is no movement or change. “Dynamic equilibrium” was demonstrated by sending five students out of the room and having the rest of the class remain in the classroom. When students moved back and forth so that there were always five students outside and 19 students in the classroom, the presenting group pointed out that if every student looked identical, there would simply appear to be no movement. In reality, the constant back and forth rate ensured that there were always five people outside, even if they were different individuals, and 19 inside the classroom. Though each preview of equilibrium occurred in different ways, the fact of returning to the concept over and over helped students develop an understanding of dynamic equilibrium and clear up their previous misconceptions.

**Students use schemas to construct meaning about new ideas.** In Phase II, my students’ group concept presentations revealed an inadvertent reliance on schemas, or preexisting knowledge structures, to help them remember chemistry concepts and incorporate those new understandings into their worldview. In learning, schemas come into play when the brain compares new ideas or experiences to what the learner already knows and is familiar with as a tool to gain understanding. One of the ways that we can increase our effectiveness as teachers is to be aware of schema theory and understand the mental models that our students use to make sense of the world, as well as the assumptions and background information they use to support those models. An example of schemas being used to generate understanding of a new idea was seen in the group concept presentation about chemical reactions through cookies, described previously in this paper. In addition to this group, another group in Phase IIB studied their

concept of acids and bases by growing plants in different concentrations of acid water to study the effect of acid rain on plant life. All of the students in this group (seniors) worked with the Surfrider Foundation for their 11th grade project last year, one of whom is still very environmentally active in San Diego County. These students thus found it relatively easy to organize the concept of acids and bases into their existing framework of environmental science, in which acid rain plays an important role. Another construction of chemical meaning within a preexisting worldview was also seen during Phase I when I introduced popular culture into the classroom. When presented with the existence of chemistry among characters and storylines that students were already familiar with, they worked to draw parallelisms between the chemistry concept and pop culture reference.

**Student-centered instruction transforms the learning experience.** The last key finding of this study is the claim that student-centered learning rapidly enhances and transforms learning for students. In my classroom, placing students at the very center of instructional goals had a positive effect on student engagement, student motivation, peer communication, shared responsibility, and accountability.

***Student engagement.*** As a result of the learner-centered interventions that I implemented in Phases I and II, student-reported engagement and learning consistently increased and decreased concurrently throughout this study. As I postulated earlier in this paper, the direct correlation between these two variables suggests that my students associated learning with their perceived level of engagement, regardless of whether a true acquisition of knowledge was taking place. More frequently over the course of the study, students expressed their enthusiasm about the hands-on activities and demonstrations that increasingly became a natural part of our classroom environment. As one student described during Week 6, “Being interested [in the

experiment] made me want to know more about it, even though I knew it was hard." The sense of fun and excitement that my students experienced in the face of hands-on and learner-centered activities was accompanied by a desire to understand the phenomena that caused their mystification and wonder.

***Student motivation.*** The increase in student engagement and subsequent effect on learning has a direct link with a rise in student motivation. I believe that students want to be challenged, and that all students, regardless of their previous achievement or performance, when presented with something that makes them engaged and excited, will want to know more about it. They will actively seek information pertaining to that topic in a quest to gain meaning and understanding. For example, in Phase IIB of this study, I allowed students to choose their concepts instead of assigning them, which opened the door for students to study a phenomenon they were interested in, or at least believed they could be interested in. My choice to give students this freedom was an exercise in student-centered instruction, and the result of that freedom was students' concerted effort to learn more about a topic, locate an interesting and conceptually accessible real-world connection, and present that connection in an engaging way to their peers. By providing students with a personalized learning experience in which they were the center of my instructional goals, I saw a genuine upsurge in motivation to learn and understand chemistry.

***Peer communication.*** Another effect of using student-centered instruction was an increase in my students' comfort level to speak and interact with their peers beyond social issues. Particularly during Phase II, in which students worked in groups and personal communication was necessary, I saw an increase in students' voluntary interactions—this included email correspondence and after-school meetings in addition to verbal exchanges in class and other

school hours. Regardless of whether they spent time together outside of my classroom, for the most part, all students in my classroom developed over the course of the study a good rapport with me and good rapport among themselves. This transformed my classroom into a true community of learners in which students' varying language abilities and skill levels, among other characteristics, were equally supported and accepted. Students were also more willing to voice their confusion and ask questions of each other. At the end of Week 7, a student who has been characteristically quiet all year praised the group process: "Group presentations affected my learning a lot because it made me understand chemistry better. For example if I didn't understand something, my teammate would explain it better."

***Shared responsibility and accountability.*** The final effect of student-centered instruction was an increase in students' sense of responsibility and accountability. Particularly in Phase II, I saw students become responsible for their own learning. When they realized that I was not going to guide them as closely as I did during the first round of presentations, they took it upon themselves to regain control of the planning process. In some instances, I saw students step up as leaders within their groups and suggest or appoint roles for their group members. Additionally, just as the group as a whole shared responsibility for delivery of the final presentation, students held themselves and each other accountable for the results or outcomes of their specific roles. On the Week 7 exit slip, for example, one student wrote, "I was motivated to finish the poster because I knew my group were [*sic*] counting on me and I didnt [*sic*] want to let them down." Students were concerned not only with their individual grades but the effect that their individual work would have on the group outcome and final product. Especially toward the end of the study, this resulted in a concern to produce higher quality work than was previously submitted. Finally, and most importantly, I noted that whenever any student in a group failed to live up to

his or her peers' expectations of the individual's share of work, that individual accepted the consequences that arose in regard to the outcomes of his or her actions and decisions.

**Significance**

The results of this study are significant particularly in the context of the progressive education movement, which began in the late 19th century and promotes deep understanding through a student-centered philosophy. Though practitioners of progressive education have been touting the merits of learner-centered education since the late 1800s, the education system in the United States, as in many other countries, is still largely characterized by traditional, whole-class instruction (Marks & Eilks, 2008; Ochonogor, 2011; Shachar & Fischer, 2004). My personal experience in this study, which certainly cannot be generalized to every classroom or every teacher, nonetheless supports the claim that student-centered instruction is successful in the promotion of, among other qualities, deep, long-lasting learning, social skills, and critical thinking.

My students began the school year as underperformers in chemistry, and prior to this study I certainly wondered what more I could do to capture their interest and share my passion for the science they were disengaged with and disinterested in. This did not come as a surprise, however, because there is a great abundance of literature available on the many difficulties of learning chemistry (Sirhan, 2007; Holbrook, 2005). So why is our movement toward change so slow? What needs to happen to transform the way we teach chemistry and to make it more accessible and learner-friendly? Surely the goal of educators is to create confident and proficient students, but when faced with an overload of high conceptuality, it's no wonder that our students shy away from chemistry. Unfortunately, we really cannot afford to keep churning out students who are not skilled in science, who acquire knowledge without understanding.

The key findings I extracted from this study are largely in agreement with the literature on enhancing the learning process and strategies to accomplish that goal. Due to the working memory overload that is common in beginning learners of chemistry (Sirhan, 2007), it is important to support the formation of lasting knowledge by revisiting concepts. A large amount of memory is lost before it reaches long-term memory storage, so revisiting concepts helps learners retain information. Additionally, Oloruntegbe et al. (2010) discussed the importance of relating chemistry to students' at-home experiences and cultural schemas. Teachers, according to the study, "must use students' home experiences to consolidate learning in school." During Phase II of my study, I observed the greatest engagement and desire when chemistry fit into my students' schemas and frameworks of understanding. Finally, my finding that student-centered instruction enhances the learning process was corroborated by Bowen (2000), who found that "aspects of cooperative learning can enhance chemistry achievement," and Ochonogor (2011), who wrote that "applications of [the goat and sheep cooperative learning method] described in this study enhances chemistry educators' and learners' performances anywhere."

**Answers to Research Questions**

My driving research question was, "How can I effectively engage my students in a practical understanding of chemistry concepts?" However, this single, simply-phrased question branched out into several different inquiries over the course of my study: How do I know if my students have developed a practical understanding of chemistry? Are they able to relate their understanding of chemistry to situations and phenomena that seem unrelated to science? Finally, how do I engage and motivate the students in my particular classroom to develop that applied understanding?

At first glance, this study seemed to point to several different answers to my main research question. But in answer to that question, the most effective, engaging strategy to help students develop a comprehensive understanding of chemistry is, to put it simply, involve them deeply in the learning process. The profession of education is invariably dynamic and humanizing. Students learn from teachers they care about and who they believe care about them. In my chemistry classroom, this caring manifested itself as my fervent goal to teach my students that chemistry is interesting, magical, pervasive, and relevant. Though I helped students build connections, I did not make the connections for them—this is what's important, to guide students and give them tools to accomplish a goal. It wasn't enough for me to provide hands-on activities and reference things that fit into their schemas. They had to come up with hands-on activities; they had to fit things into their schemas. The answer to all the questions, then, is to give students enough of a foundation that, when given the tools, they can complete the building themselves.

**Limitations**

Though the results of this action research study yielded very insightful information regarding my students, their learning needs, and my ability to meet those learning needs, several limitations need to be addressed and discussed.

The most important limitation revolves around the definition of "action research," which is not by nature a fully scientific investigation. Action research is not about learning more about teaching or even about studying students. It is not about learning why teachers do certain things or teach a certain way; it is about how teachers can do things better and teach in different ways. With that in mind, the results and findings of this study are relevant specifically to my classroom, with my students, with me as their teacher. Qualitative research is very much about perception, and changing any of the perceptions in this study would produce very different results.

Nonetheless, is it sometimes valuable for people to test others' ideas and methods in their own practice, so though the results of this study are by no means conclusive, they may be of value in other settings.

Another limitation I encountered in this study was my loss of control as a student teacher. Due to the schedule at my student teaching site and within my grade-level team, there was a very short period of time I had in which to conduct the entirety of the study. It was challenging to make the most out of seven weeks, and often the need for flexibility meant last-minute changes and thinking on my feet. I also needed to closely monitor the progression of my study while still providing a rigorous curriculum, and fulfilling my other responsibilities as a student and student teacher. Additionally, my study did not take place over an uninterrupted period of time; there was a one-week break at the end of Phase I, and two separate one-week breaks in the middle of Phase II. For a full-time teacher in her own classroom, the constraints of space and time that I encountered in this study may not be as restrictive.

Finally, it is important to note that the specific population of students in my classroom was conducive to the design of group concept presentations, but this may not be the case in classrooms with students who benefit more from traditional or less student-centered methods. My student population also consisted of several designated English Language Learners and other designated English proficient students who had difficulty communicating fluently in my classroom, and it was communicated to me by my students that sometimes I "talk and teach too fast." Therefore, a heavily hands-on approach in which students could visualize and interact with chemistry worked very well in my classroom, but it is important to take into account that student demographics, learning styles, language abilities, and general classroom culture all have a huge impact on the extent of effectiveness than an intervention may have.

## Implications

**My teaching.** The implication of this study for my own teaching practice is that I now have more than one set of tools in my box of instructional methods. This study allowed me to develop as a learner-centered instructor, but it will be important for me in the future to identify when teacher-centered and learner-centered methods will be more effective or appropriate for that particular group of students. It was also incredibly fulfilling for me to empower my students to learn more about a content area they were initially very unhappy with, so in the future it will be important for me to recall this study and carry out additional investigations, if the need arises.

**The teaching profession.** This study also has meaning for other teachers of science. I believe that an exploration of action research as pedagogy could be transformative for all educators, but for science teachers in particular, it is our awesome task to lure in more brilliant minds that can tackle difficult and abstract concepts. In general, knowledge of and practice with various methods of instruction will inform any teacher's ability to be an effective educator for all students. It is also important to be aware that the typical science classroom, especially at the college level, is characterized by traditional, lecture-based instruction, which many science teachers (including myself) bring back to their high school students. This study shows the importance of understanding students' conceptual difficulties and making changes to match their learning needs.

**Policy.** I believe that policy makers at all levels need to consider student-centered instruction as a conduit for obtaining and developing students' interest in learning. In my study, increased engagement was followed by a desire to continue thinking and questioning about chemistry. Real education is more than just the regurgitation of facts and skills; it is the building of knowledge and dispositions for future generations of our nation's leaders, thinkers, and doers.

The United States, unfortunately, is in serious trouble in international education rankings, and the coveted spot at the top of the list fell out of our grasp decades ago. If we mean to return to first-class education, for all content areas and at all levels of education, a paradigm shift is necessary to transform the way we run our schools, the way we view and value our children and students, and the way our students view and value their education.

**Research.** Future research around this work may include an analysis into productive group dynamics as well as a study on the cognitive effect of revisiting concepts (both via the same and different methods) on content mastery. It may also be interesting to probe further into students' use of schemas when learning chemistry, and an effort to understand how students makes sense of chemistry when it is too abstract to fit into their preexisting schemas. These potential research questions may be more appropriate for undertakings at the university level with adjustments for students and teachers in high school settings.

## Reflection and Conclusion

My first foray into action research was a humbling and inspiring experience. Chemistry is not an easy subject to learn, especially for students who aren't particularly math or science-minded, but I realized again and again over the course of my study that it is an even harder subject to teach. As secondary teachers, we strive for content expertise, and often the irony of this evolution is that teaching becomes harder, not easier, since we lose sight of the conceptual difficulties that our beginning learners face. At the root of my study was the need to get back in touch with what it means to be a learner of chemistry so that I could be a thoughtful and effective teacher of chemistry.

In order to do this, I had to radicalize my notions of pedagogy. My own chemistry teachers used traditional instruction and helped me to love chemistry, so I thought that if I did the

same things in the right way, my students would love chemistry, too. This logic is flawed, of course. Lecture-based instruction is a conduit for rote memorization, and students don't want to learn via rote memorization. More importantly, for many students, memorization doesn't work. It doesn't facilitate deep learning or an understanding of fundamental concepts, and it doesn't facilitate the awe with which lovers of learning perceive their favorite subject areas. So how do we teach the students who aren't teaching themselves?

This study allowed me to discover what it truly means to be a teacher. I discovered what it meant for me, specifically, to take a child's learning, his or her cognitive development and intellectual livelihood, into my own hands and be responsible for it. Action research is not always a smooth process—there were plenty bumps in my road to completion—but I found that those bumps humanized the process and humanized my students.

For future action research projects, I hope to explore more specific areas of concern and be more organized and systematic in my design of the study, methods of data collection, and analysis of data. Occasionally during this study I thought I was feeling my way blindly. Though a loss of control on the teacher's part may be inherent in educational action research, I don't want this to equate to a loss of meaning as well. With the time constraints I was working under, it would have been easy to demand data, if not progress, from my students, with the aim of "getting things done," but I had to step back and remember that I was doing the study for them as much as for myself.

Whatever the challenges or shortcomings of my study, I certainly feel that very positive things, including new knowledge and skills, grew out of it. As a teacher, I learned to break the mold and explore new methods of instruction—in particular, to teach by questioning instead of telling. This was met with some resistance, but when my students saw that I genuinely cared

about their learning—not only in chemistry but in other content areas, including their ability to think critically and create meaning—the classroom environment was profoundly transformed. I experienced the most growth in my capacity as a researcher. My brain works by moving from hard evidence to hard conclusions, but qualitative research is less about crunching numbers and very much about perception. I thus developed an appreciation for triangulation and the ability to make sense of qualitative data. Finally, as a teacher-researcher, I started to understand the intricate links between content expertise, pedagogy, and classroom culture. I learned to pay attention to the needs of my classroom, and feel empowered to improve and understand my classroom by changing it and then learning how to improve it from the effects of those changes.

With more practice, I hope that action research will become a natural part of my approach to teaching. As a teacher, I hope to empower students as scholars and lovers of knowledge and to ready them for an ever-changing world; this can't be done if I try to run my classroom the same way from year to year. It is important for teachers to embrace their potential roles as teacher-researchers in order to uplift the teaching profession and restore meaning to educating children. This action research has helped me understand what it means to be an agent of change in schools, by viewing my own profession as reflective practice through which I will not only interpret situations, but influence and reshape the status quo.

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# Appendix A

## Needs Assessment Pre-Survey 1

Reflect on your experiences in this class since the beginning of the school year. Fill out the following chart by listing the things that you like and do not like (about this class and my lesson plans, not about me as a person!).

| Likes | Dislikes |
|---|---|
| | |

# Appendix B

## Needs Assessment Pre-Survey 2

1. What helps you learn?

2. What motivates you to learn?

3. What can Ms. Cruz do to help your learning of chemistry?

4. What can YOU do to help your learning of chemistry?

# Appendix C

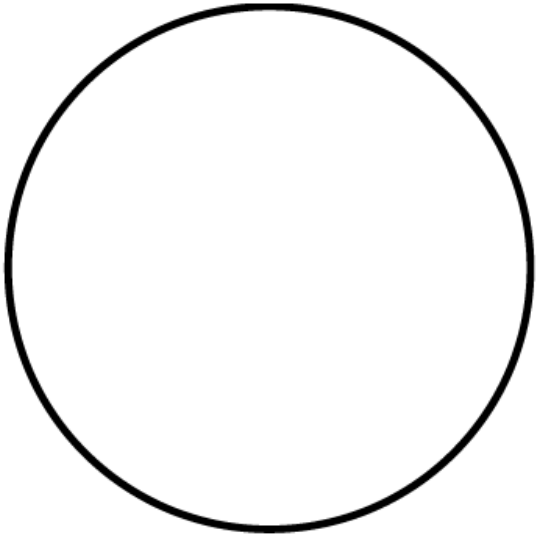
## Needs Assessment Exit Slips

| | |
|---|---|
| On a scale of 1-5, how engaged were you today? (circle one)<br>1 2 3 4 5<br>What did we do in class today that you found engaging?<br>What did we do that helped you understand chemistry?<br>What did we do that did not help you understand chemistry or made the material more confusing for you? | On a scale of 1-5, how engaged were you today? (circle one)<br>1 2 3 4 5<br>What did we do in class today that you found engaging?<br>What did we do that helped you understand chemistry?<br>What did we do that did not help you understand chemistry or made the material more confusing for you? |
| On a scale of 1-5, how engaged were you today? (circle one)<br>1 2 3 4 5<br>What did we do in class today that you found engaging?<br>What did we do that helped you understand chemistry?<br>What did we do that did not help you understand chemistry or made the material more confusing for you? | On a scale of 1-5, how engaged were you today? (circle one)<br>1 2 3 4 5<br>What did we do in class today that you found engaging?<br>What did we do that helped you understand chemistry?<br>What did we do that did not help you understand chemistry or made the material more confusing for you? |

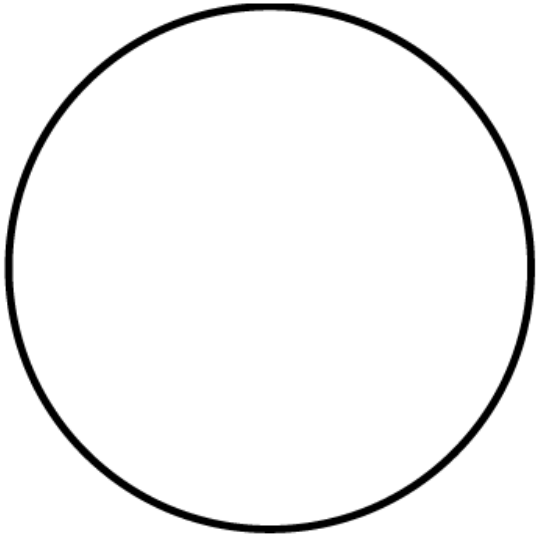
Appendix D

# Engagement and Learning Reflection

Indicate the amount of time you were ENGAGED in class this week by filling in the Harvey Ball below like a pie chart.



Indicate the amount of time you were LEARNING in class this week by filling in the Harvey Ball below like a pie chart.



| List three activities we did this week that you found ENGAGING. | List three new facts, ideas, or concepts that you LEARNED this week that you didn't know before. |
|---|---|
| 1. | 1. |
| 2. | 2. |
| 3. | 3. |

Appendix E

Phase II Peer Scoring Rubric

Your name: _____

Which group are you scoring? _____

What concept are they presenting? _____

*Complete the following table:*

| Criteria | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Organization, clarity, and preparation | | | | |
| Accurate and adequate information | | | | |
| Creativity | | | | |
| Presentation elements | | | | |
| Interest and engagement | | | | |

*Please provide additional feedback by answering the following questions:*
What did you learn from this group's presentation? Be specific.

Do you think you have a better understanding of the concept they presented? How has it changed? If not, what would have helped you understand it better?

What were some of the strengths of this group's presentation?

What were some of the weaknesses of this group's presentation?

Other comments and constructive criticism:

On a scale of 1–10, what overall score would you give this group?_____

# Appendix F

## Phase I Pop Culture Reference for Atomic Structure: Excited Electrons in *Harry Potter*

Read the following quotes from the *Harry Potter* series:

1. The day before Harry's first Quidditch match the three of them were out in the freezing courtyard during break, and [Hermione] had conjured them up a bright blue fire that could be carried around in a jam jar.
   - *Harry Potter and the Sorcerer's Stone*, p. 181

2. They stepped over the threshold, and immediately a fire sprang up behind them in the doorway. It wasn't an ordinary fire either; it was purple. At the same instant, black flames shot up in the doorway leading onward. They were trapped.
   - *Harry Potter and the Sorcerer's Stone*, p. 284

3. He took a pinch of glittering powder out of the flowerpot, stepped up to the fire, and threw the powder into the flames. With a roar, the fire turned emerald green and rose higher than Fred, who stepped right into it, shouted "Diagon Alley!" and vanished.
   - *Harry Potter and the Chamber of Secrets*, p. 47

4. Behind him, a group of haggard-looking Ministry wizards rushed past, pointing at the distant evidence of some sort of a magical fire that was sending violet sparks twenty feet into the air.
   - *Harry Potter and the Goblet of Fire*, p. 87

5. One by one, the Beauxbatons students stepped across the Age Line and dropped their slips of parchment into the blue-white flames. As each name entered the fire, it turned briefly red and emitted sparks.
   - *Harry Potter and the Goblet of Fire*, p. 262

On a separate piece of paper, answer the following questions to begin our discussion.

1. What do these passages have in common?

2. Can the phenomena you identified be explained in terms of chemistry? Explain.

3. In the *Harry Potter* books, magic is described as a natural force that can be used to override the laws of nature. For example, the Wingardium Leviosa spell causes objects to levitate and defy gravity! However, the story of magic has roots far back in human history. Several ancient and past societies believed in and practiced magic, including ancient Egypt, ancient Greece, the Middle Ages and Renaissance. With all this in mind, what does your answer to question 2 above tell you about the relationship between magic and knowledge? More importantly, what does science have to do with any this?

# Appendix G

## Phase I Pop Culture Reference for Stoichiometry: Transcript of supermarket scene in *Father of the Bride*

*Stock Boy:* Excuse me, sir, what are you doing?

*George Banks:* I'll tell you what I'm doing. I want to buy eight hot dogs and eight hot dog buns to go with them. But no one sells eight hot dog buns. They only sell 12 hot dog buns. So I end up paying for four buns I don't need. So I am removing the superfluous buns.

*Stock Boy:* I'm sorry, sir, but you're going to have to pay for all 12 buns. They're not marked individually.

*George:* Yeah. And you want to know why? Because some big-shot over at the wiener company got together with some big-shot over at the bun company and decided to rip off the American public. Because they think the American public is a bunch of trusting nit-wits who will pay for everything they don't need rather than make a stink. Well they're not ripping off this nitwit anymore because I'm not paying for one more thing I don't need. George Banks is saying NO!

*Stock Boy:* Who's George Banks?

*George:* ME!

Appendix H

Phase I Student-Centered Activity for Stoichiometry:
S'more Stoichiometry

**Introduction:** You have been invited to dinner with George Banks and his family, and as a kind gesture you have volunteered to bring materials to make S'mores. However, every time you make S'mores, you seem to run out of marshmallows, graham crackers, or chocolate.

**Problem:** Your goal is to find out how many bags of marshmallows, boxes of graham crackers, and chocolate bars will leave you with as little extra materials as possible. To do this:

1. Determine the maximum number of S'mores that can be made, given one bag of large marshmallows.
2. Determine the number of boxes of graham crackers and chocolate bars needed to make the number of S'mores determined in Task 1.

**Purpose:** To explore the principles of stoichiometry, balancing equations, and limiting reactants.

**Materials (per group):**

| | |
|---|---|
| Chocolate bars | Paper plate |
| Marshmallows | Napkins |
| Graham crackers | Electronic balance |

**Procedures:**

The following symbols will be used for each reactant.

| | |
|---|---|
| Graham cracker | S |
| Marshmallow | Mm |
| Chocolate piece | Or |
| S'more | $S_2MmOr_3$ |

1. Mass and record the unit mass of each reactant.
   S _____ g
   Mm _____ g
   Or _____ g

2. Calculate the unit mass of $S_2MmOr_3$.

3. Provide the balanced equation to synthesize a $S_2MmOr_3$. What do the coefficients represent?

4. Determine the number of unit marshmallows that are available in the bag. If there are 454 marshmallows in one bag, how many units do you have?

5. Determine how many unit graham crackers and chocolate pieces are needed to make as many products as possible.

6. In Question 5, you found the number of unit graham crackers and chocolate pieces needed to maximize your S'more count. However, when you go to the store you cannot quickly determine the number of graham crackers or chocolate pieces in a box. To make your shopping easier, you can use mass values to quickly determine how much you need to buy. Convert the number of graham crackers and chocolate segments found in Question 5 to mass values in grams.

7. If a box of graham crackers weighs 254 g, how many boxes do you need? Also, if one chocolate bar has a mass of 49.5 g, how many bars do you need?

**Post-Lab Questions (answer on a separate sheet of paper):**

1. Is there a relationship between the mass of a S'more and the masses of the reactants used to make it? If so, what is the relationship? What law have you studied in this course that might define this relationship?
2. A limiting reactant is the material responsible for a reaction reaching completion. In the reaction, what was the limiting reactant?
3. What reactants, if any, were in excess? Mass and record the total of each excess reactant.

**Extension Questions (answer on a separate sheet of paper):**

1. How many S'mores could you make if you had started with 100 g of each reactant?
2. What would be the limiting reactant?
3. How much of each excess reactant would result?

Appendix I

Phase I Student-Centered Activity:
Making Hot and Cold Packs

**Background & Purpose**

You are a chemist competing for a patent contract with a health company to determine the best chemicals to use for their new hot packs and cold packs. They will be marketing their products mainly to athletes with injuries and therefore need the most effective and fast-acting exothermic and endothermic reactions. Your purpose is to determine the best chemicals to use to achieve the above results.

**Pre-Lab Questions**

1. a) What is an endothermic reaction?

   b) How can you tell if an exothermic reaction has occurred?

2. a) What is an endothermic reaction?

   b) How can you tell if an endothermic reaction has occurred?

**Materials**

| | |
|---|---|
| Sodium bicarbonate ($NaHCO_3$) | Water |
| Calcium chloride ($CaCl_2$) | Thermometer |
| Ammonium chloride ($NH_4Cl$) | Beakers |
| Ammonium nitrate ($NH_4NO_3$) | Stir bars |

***All waste must be discarded into the Waste Container**

**Procedure**

Collaborate within your group to create a procedure to determine 2 exothermic reactions and 2 endothermic reactions using the reagents provided. You have 5 chances total; so plan out a procedure carefully. Write your procedure in clear steps on a separate sheet of paper.

NOTE: Use **no more than 6 grams of any chemical** and **no more than 15 mL of water** for each trial.

**Data Table**

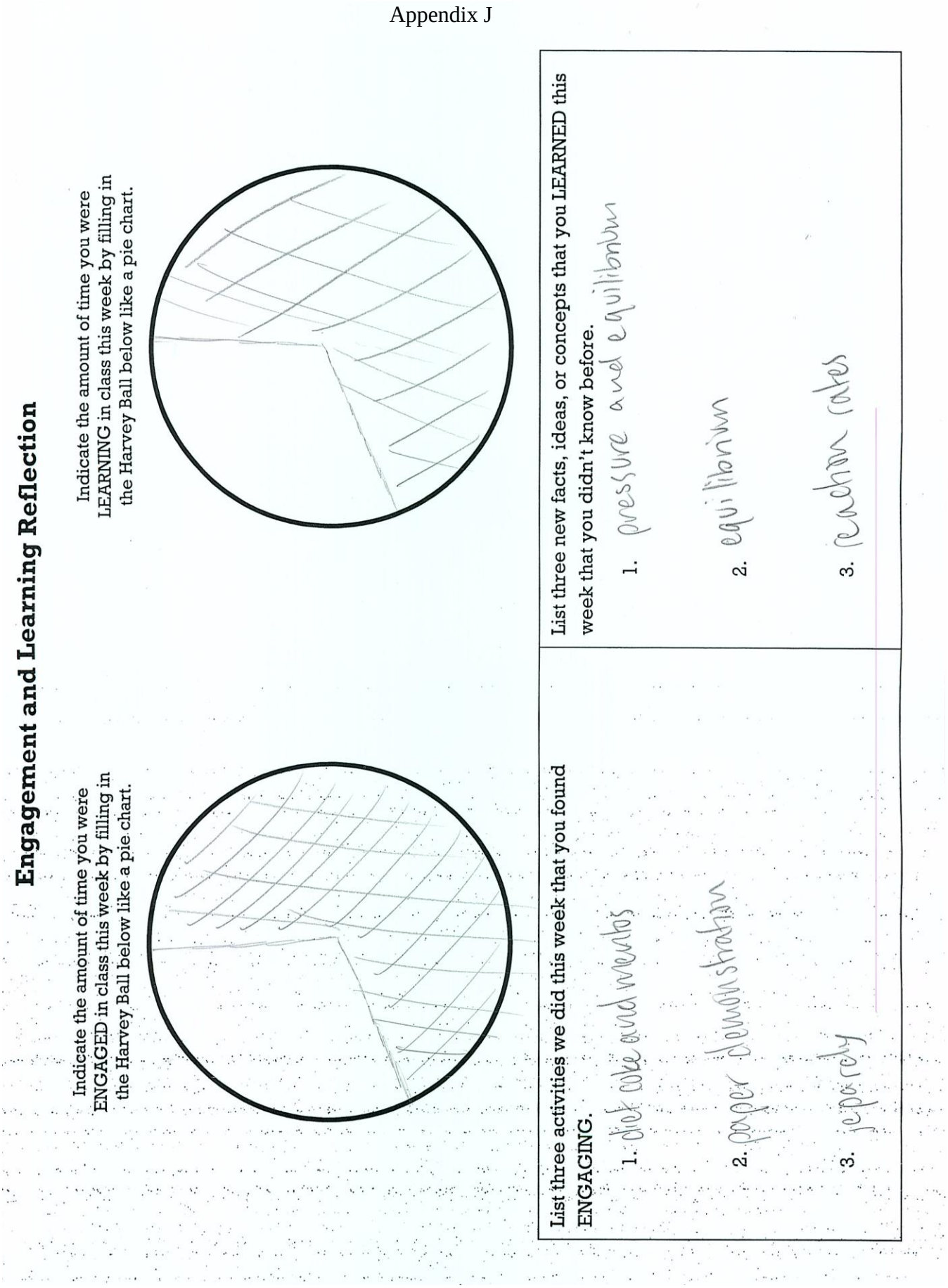
| **Trial** | **Reactants & Amount (g)** | **Observations** | **Drawing** (System, Surroundings, Heat Flow) |
|---|---|---|---|
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |

**Report to Health Company**

Choose the most effective exothermic and endothermic reactions you tested and create a 1-page persuasive advertising report that includes the following:

- The chemicals involved in your most effective exothermic and endothermic reactions
- Detailed pictures of the System, Surroundings and Heat Flow for your two chosen reactions
- Description of how the hot pack and cold pack will work on an injury using at least 4 thermochemical vocabulary words including (but not limited to): thermodynamics, heat, energy, endothermic, exothermic, conservation of energy
- Creativity in your report! All words and drawings should be in ink. Use of color is highly encouraged.

Appendix J



**Engagement and Learning Reflection**

Indicate the amount of time you were ENGAGED in class this week by filling in the Harvey Ball below like a pie chart.

Indicate the amount of time you were LEARNING in class this week by filling in the Harvey Ball below like a pie chart.

List three activities we did this week that you found ENGAGING.

1. diet coke and mentos
2. paper demonstration
3. jeopardy

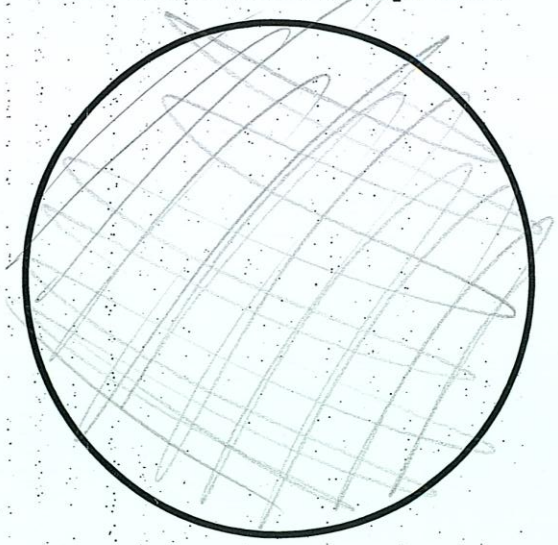
List three new facts, ideas, or concepts that you LEARNED this week that you didn't know before.

1. pressure and equilibrium
2. equilibrium
3. reaction rates

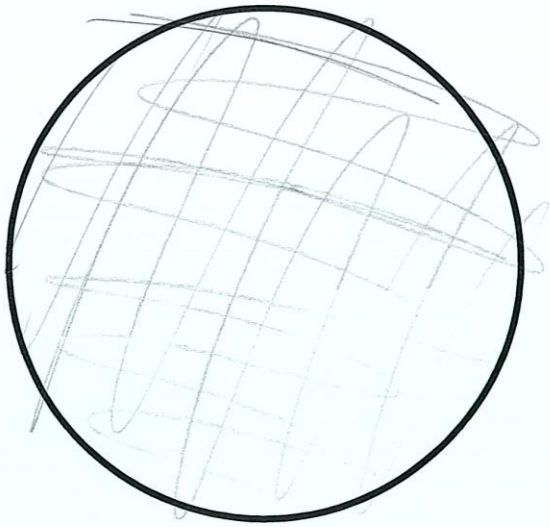
Appendix K

## Engagement and Learning Reflection

Indicate the amount of time you were ENGAGED in class this week by filling in the Harvey Ball below like a pie chart.



Indicate the amount of time you were LEARNING in class this week by filling in the Harvey Ball below like a pie chart.

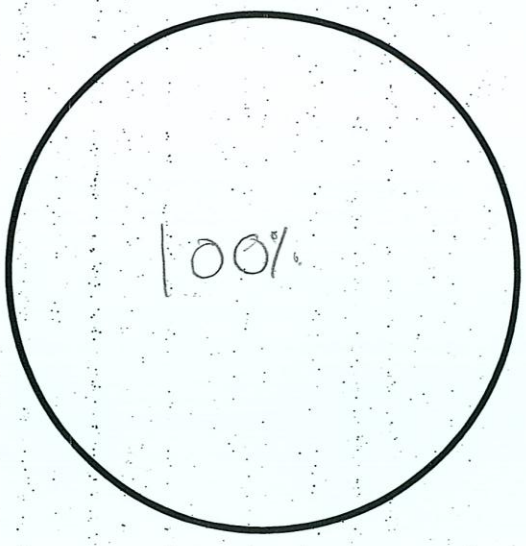


| List three activities we did this week that you found ENGAGING. | List three new facts, ideas, or concepts that you LEARNED this week that you didn't know before. |
|---|---|
| 1. equalibriam throwing | 1. learned how forward and reverse can still be equalibriam when less on one side |
| 2. Jeopardy | 2. things will be leaving at the same rate |
| 3. mentos | 3. ~~atomic~~ electronic config. |

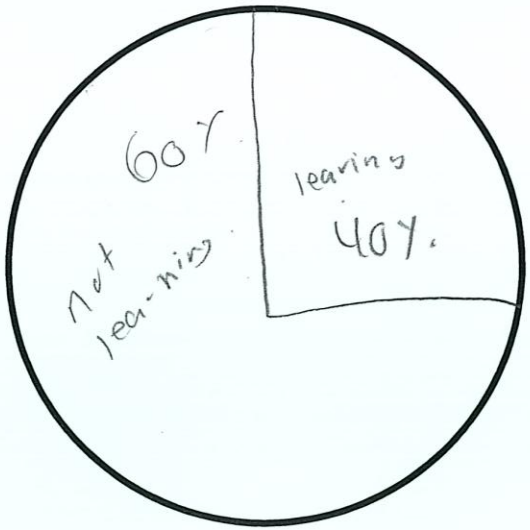
Appendix L

## Engagement and Learning Reflection

Indicate the amount of time you were ENGAGED in class this week by filling in the Harvey Ball below like a pie chart.




Indicate the amount of time you were LEARNING in class this week by filling in the Harvey Ball below like a pie chart.

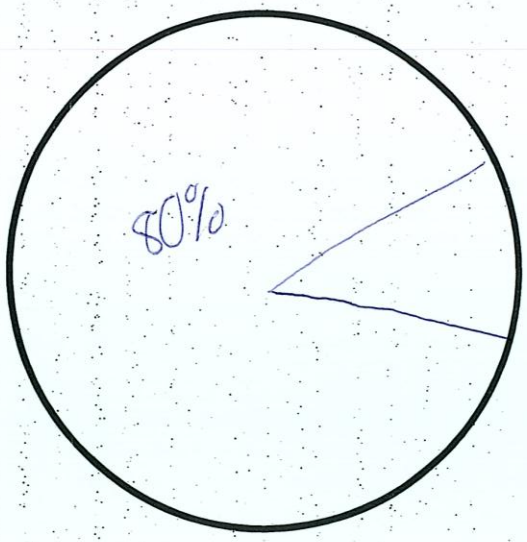



| List three activities we did this week that you found ENGAGING. | List three new facts, ideas, or concepts that you LEARNED this week that you didn't know before. |
|---|---|
| 1. Jeopardy | 1. about the Oklahoma bombing |
| 2. throwing balls | 2. that you came from Japan |
| 3. Soda | 3. and how mentos reacit to carbon dioxide |

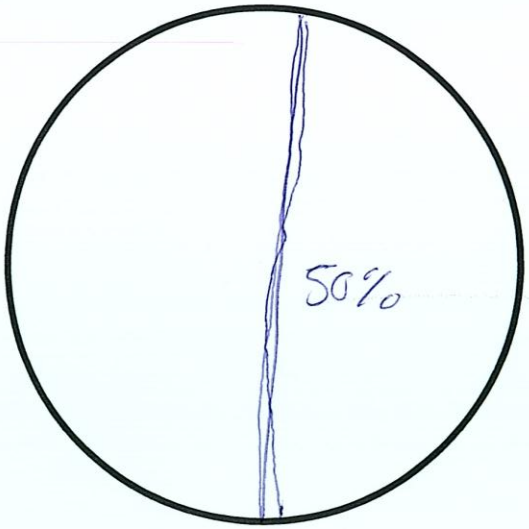
Appendix M

## Engagement and Learning Reflection

Indicate the amount of time you were ENGAGED in class this week by filling in the Harvey Ball below like a pie chart.




Indicate the amount of time you were LEARNING in class this week by filling in the Harvey Ball below like a pie chart.

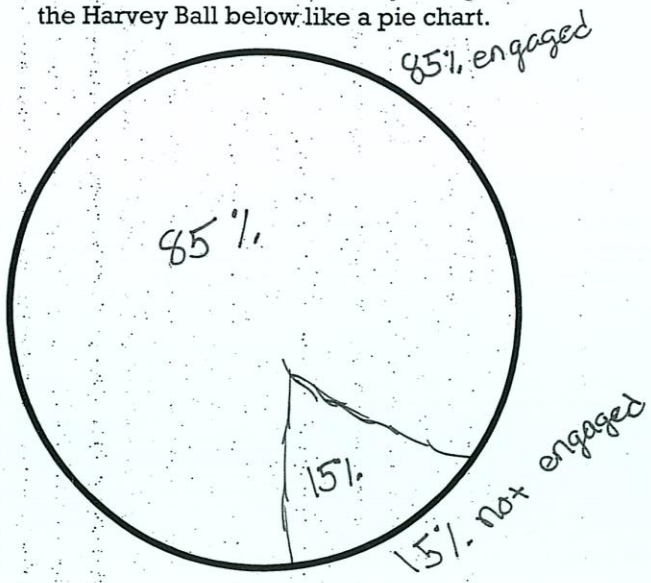



| List three activities we did this week that you found ENGAGING. | List three new facts, ideas, or concepts that you LEARNED this week that you didn't know before. |
|---|---|
| 1. Mentos w/ coke | 1. Nuclear processes |
| 2. Equillibrium game | 2. Understanding better equillibrium |
| 3. Jeopardy | 3. Radiation (alpha, gamma, Beta) |

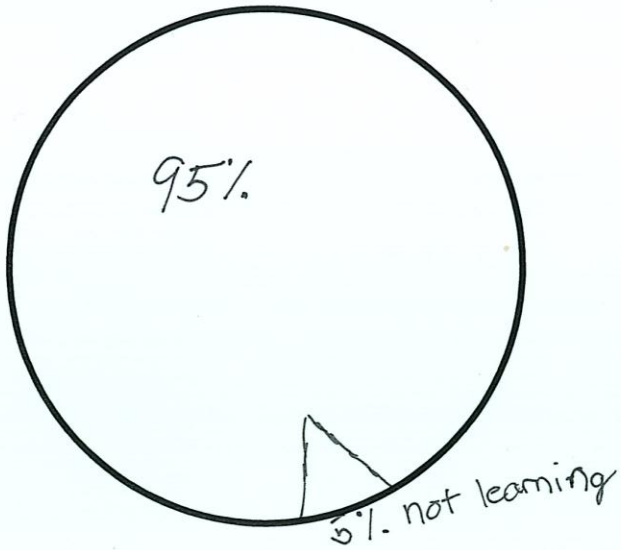
Appendix N

## Engagement and Learning Reflection

Indicate the amount of time you were ENGAGED in class this week by filling in the Harvey Ball below like a pie chart.




Indicate the amount of time you were LEARNING in class this week by filling in the Harvey Ball below like a pie chart.




| List three activities we did this week that you found ENGAGING. | List three new facts, ideas, or concepts that you LEARNED this week that you didn't know before. |
|---|---|
| 1. Mentos lab | 1. nuclear process |
| 2. equalibrium game | 2. equalibrium |
| 3. Jeperdy | 3. Atomic structure |

Appendix O

Phase IIB Rotating Dry Ice Experiments: “Dry Ice Magic”

1. **Dry Ice Fog**
   Students mixed dry ice with cold, room temperature, and hot water to observe the effect of temperature on sublimation. Sublimation occurs much more quickly in water. Due to the greater kinetic energy of hot water, the dry ice will sublime faster than in the cold or room temperature water and create a thicker fog more rapidly.

2. **Exploding Dry Ice**
   Students created dry ice bombs (water and dry ice in a water bottle) to observe changes in volume and pressure. As dry ice sublimes, the continual creation of carbon dioxide gas (more moles) increases the volume of the water bottle. The increased number of molecules leads to more collisions, resulting in an increase in pressure. Eventually, the water bottle will reach its volume capacity and the bottle explodes to allow the molecules of high-pressure gas to expand and return to equilibrium.

3. **Dry Ice Crystal Bubble**
   Students will draw a piece of cloth across a soap film on the rim of a bucket that is filled with dry ice and water. As the dry ice sublimes, the bucket appears to develop a crystal ball filled with a cloud-like mixture of water vapor and carbon dioxide. As the bubble expands with carbon dioxide gas, its walls will become thinner and leak more. The bubble will pop to reduce pressure in order to allow the carbon dioxide gas to escape.

4. **Screaming Dry Ice**
   Students will press different materials to the surface of dry ice to observe the production of vibration and noise against metal objects as a result of rapid sublimation. The “screaming” noise heard will only occur with metal objects, since metallic bonds have high thermal conductivity and heat is transferred from hands to dry ice. When a metal object is pressed against dry ice, production of $CO_2$ gas creates pressure and pushes “up” against the metal. Pressure exerted from the hand (pressing metal object to dry ice) and additional pressure from heat, which further drives sublimation, will push the metal object back onto the surface of dry ice. Gas will escape around the sides of the metal object, causing it to vibrate quickly and make a “screaming” sound.

5. **Dry Ice Rainbows**
   Students will add dry ice and universal indicator to a very dilute basic solution to observe the effect of a proceeding chemical reaction on pH. Because the sublimation of dry ice in water produces $H_2CO_3$, or carbonic acid, the increasing acidic character of the solution will cause the indicator to change colors as the solution proceeds from basic to acidic.