Critical Science Education in a Suburban High School Chemistry Class

Patrick Ashby

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ABSTRACT

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To improve students' scientific literacy and their general perceptions of chemistry, I enacted critical chemistry education (CCE) in two "regular level" chemistry classes with a group of 25 students in a suburban, private high school as part of this study. CCE combined the efforts of critical science educators (Fusco & Calabrese Barton, 2001; Gilbert 2013) with the performance expectations of the Next Generation Science Standards (NGSS) (NGSS Lead States, 2013a) to critically transform the traditional chemistry curriculum at this setting. Essentially, CCE engages students in the critical exploration of socially situated chemistry content knowledge and requires them to demonstrate this knowledge through the practices of science. The purpose of this study was to gauge these students development of chemistry content knowledge, chemistry interest, and critical scientific literacy (CSL) as they engaged in CCE. CSL was a construct developed for this study that necessarily combined the National Research Center's (2012) definition of scientific literacy with a critical component. As such, CSL entailed demonstrating content knowledge through the practices of science as well as the ability to critically analyze the intersections between science content and socially relevant issues.

A mixed methods, critical ethnographic approach framed the collection of data from open-ended questionnaires, focus group interviews, Likert surveys, pre- and post unit tests, and student artifacts. These data revealed three main findings: (1) students began to develop CSL in specific, significant ways working through the activities of CCE, (2) student participants of CCE developed a comparable level of chemistry content understanding to students who participated in

a traditional chemistry curriculum, and (3) CCE developed a group of students' perceptions of interest in chemistry. In addition to being able to teach students discipline specific content knowledge, the implications of this study are that CCE has the ability to affect students' critical science thinking in positive ways. However, to develop longer lasting, deeper critical insights that students use to participate in science-related issues outside of class, critical science education must be enacted longitudinally and across disciplines. Furthermore, it must be enacted in ways that either prompt or help students to transfer classroom learning outside of the classroom as they engage in critical issues in the classroom.

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Chapter 1

INTRODUCTION

Despite the valiant efforts of modern day critical pedagogues, the main function of American schools continues to be the molding of students into an endless supply of producers and consumers in our disengaged, capitalist society (Gilbert, 2013; Hinchey, 2004; Mayo, 2012). Positivist attitude, belief that there is an objective truth to knowledge (Giroux, 2009), still reigns supreme in education, resulting in the practice of stripping knowledge from its context and ignoring the complex ways knowledge is socially constructed and mediated by the power structure of society (Kincheloe, 2005). Guided by this mindset, traditional American schooling is largely conceptualized as a form of exchange of knowledge for control (Willis, 1977). As a result, American education is fundamentally absent of critical thought, supplying students with a series of agreed upon, decontextualized facts determined to be “right” for everyone to know that all students must memorize to be successful on large-scale standardized tests (Gilbert, 2013; Janesick, 2007; Kincheloe, 2005). This seems to be especially true in science classes, chemistry in particular (Gilbert, 2006), where a dominant positivist mindset rigidly maintains the myth of objective truth, leaving very little room for conversations about the social dynamics that underlie what happens in science and science classrooms, and how science connects to socially relevant topics at large (Calabrese Barton, 2001; Gilbert, 2013).

The effect of our modern education system on students’ perceptions and feelings about science class has been quite negative, especially for “young women and students marginalized on the basis of their culture” (Aikenhead, 2005, p. 2). More specifically, students’ generally negative perception of chemistry can be attributed to their belief that it has very little relevance in the real world (Gilbert, 2006). In the end, within this traditional science teaching framework where low-level fact memorization is the predominate instructional strategy, "most students tend not to learn science content meaningfully, that is, they do not integrate it into their everyday thinking" (Aikenhead, 2005, p. 3).

Meanwhile, for years the science community has been arguing for a level of scientific literacy for *all* students that far exceeds fact memorization so they can all equally participate in a democratic society where being knowledgeable about science becomes increasingly important (DeBoer, 2000; National Research Council [NRC], 1996, 2012). There is an obvious disconnect between what we hope to achieve for all students and how we are currently teaching science. New techniques and curricula must be enacted in science classrooms to reach all students (Gilbert, 2013). These techniques should work to improve students' perceptions of the relevance of science (Gilbert, 2006). Moreover, they should strengthen students' understanding of the nature, content, and practices of science as well as their critical understanding of how science connects to socially relevant issues that can have dramatic effects on the people and environments of the world (Calabrese Barton, 2001).

Purpose

In this study, I investigate the yearlong enactment *critical science education* in a high school chemistry class at a suburban New England private school. Fusco and Calabrese Barton (2001) write that critical science education (CSE) "questions… the nature of science and knowing science, the relationship between science and society, and the implications these belief structures have for how we view science as a school subject" (p. 338). The goal of CSE is the development of a *critical scientific literacy* (CSL) that, in addition to including an appropriate level of scientific content understanding, helps students to use the content and practices of science to more fully participate in our democratic society, making decisions that could improve the welfare of the world. To do this, CSE motivates students to critique their positions as producers and consumers within the global capitalist culture, helps them to recognize both the positive and oppressive nature of science's role in society, and opens their minds to different perspectives on the nature of science. Ultimately, CSE and resulting development of CSL empower students to not only use scientific knowledge, but to generate scientifically based knowledge as well. While a CSE approach was used throughout the year, four units, specifically created for this study, were enacted at various points throughout the year (See Appendix A for Study Timeline, and Appendices B through I for unit maps and materials.)

The purpose of this study is to expand the body of science education research conducted from a critical perspective. More often, CSE research has focused on environmental and biological sciences (Birmingham, & Calabrese Barton, 2014; Mallya, Mensah, Contento, Koch, & Calabrese Barton, 2012; Mensah, 2011), which already tend to be more relevant to students (Gilbert 2006), and has been conducted in urban settings, composed largely of students traditionally marginalized by science education (Brown, 2004; Emdin, 2010) with a particular focus on middle school level students (Basu, & Calabrese Barton, 2007; Calabrese Barton, Tan, & Rivet, 2008). This study focuses on high school chemistry in a suburban setting where despite increases in diversity, the majority of students still come from the dominant cultural background, i.e. White, middle to upper class, straight, Christian, first language English speaking students (Kincheloe, 2005; Ryan, 2010). Enacting critical education with these students is important because according to Trueba (1999), educators must "accelerat[e] the conscientization of the oppressed and the oppressors [and that] without this reflective awareness of the rights and obligations of humans, there is no way to conceptualize empowerment, equity, and a struggle for liberation" (p. 593). More specifically, student outcomes resulting from critical science education such as critical scientific literacy, chemistry content knowledge, and perceptions of interest in chemistry are examined.

Research Questions

The main question of the study is "What does the implementation of a critically transformed chemistry curriculum look like in a private, suburban, high school chemistry class?" This research question is elaborated upon by three sets of research sub-questions (See Appendix J for Research Design Matrix).

1. How and to what extent do students develop and demonstrate critical scientific literacy (CSL) within critical chemistry education (CCE)?
2. What level of chemistry content knowledge do students demonstrate within CCE and how do they demonstrate it?
3. What does student interest in CCE look like in the classroom and how do students describe their interest in CCE?

Overview of the Dissertation

In this section, I briefly outline and summarize the rest of the dissertation. First, this dissertation is structured in a way where the three findings chapters are presented as stand alone research papers, complete with their own introduction, theoretical framework, methods, findings, discussion, and conclusion sections. Therefore, chapters two through four discuss the study as a whole and ground the three findings papers. In chapter two, a literature review of the pertinent work in the fields of interest is presented. In addition, the three theoretical frameworks that grounded the overall study are briefly summarized. In chapter three, the methodological approach that guided the overall research project is described in detail along with a short summary of the specific data collection and analysis procedures. Chapter four provides a literature-grounded, detailed account of the critical chemistry education (CCE) curriculum created and enacted for the study.

Each of the three findings chapters, five through seven, addresses one of the research sub-questions. Chapter five discusses the development and demonstration of students' critical scientific literacy (CSL). In chapter six, the chemistry content knowledge students learned within the CCE curriculum is grounded in sociocultural learning theory. Chapter seven addresses students' perceptions of interest in chemistry after engaging in CCE.

Finally, chapter eight ties the three findings chapters together and concludes the dissertation as a whole. Within this chapter, implications for critical science education curriculum design and future research are discussed based on the overall findings of the dissertation.

Chapter 2

LITERATURE REVIEW

This chapter is composed of two sections. In the first section, a review of the literature is undertaken that highlights the goals of and issues with current science and more specifically chemistry education. Moreover, it outlines some nontraditional science and chemistry education innovations that hope to improve students' meaningful and empowering integration of science into their everyday thinking. First, the *Next Generation Science Standards* (NGSS) are examined and how they are still lacking in reaching the goal of significant scientific literacy for all. Next, I undertake a review of context-based chemistry education and Science-Technology-Society (STS) in particular. Then, I review science education grounded in critical perspectives. Finally, science education research grounded in an interest framework is reviewed. Considering these four topics was especially important to the creation of the four units that were enacted for this study.

In the second part of this chapter, a short summary of the theoretical lenses that framed the development and execution of the enacted curriculum and the concurrent study is undertaken. Each framework will be elaborated upon within the pertinent paper of the findings chapters. First, social constructivist learning theory is reviewed. Second, a conceptual framework for critical science education and critical scientific literacy is presented. Third, the construct of interest is defined.

Review of the Literature

The *Next Generation Science Standards* and Scientific Literacy for All

According to the NRC (2012), a scientifically literate citizen must understand core scientific ideas as they relate to the practices of science and engineering so that they can appreciate and knowledgeably participate in a democratic society that has to deal with climate change, health care issues, and other global science related issues. To achieve this lofty goal and to improve science education for the twenty-first century, the NRC partnered with the American Association for the Advancement of Science's (AAAS) and the National Science Teachers Association (NSTA) to create *A framework for K-12 Science Education* (NRC, 2012), which serves as the backbone of the *Next Generation Science Standards* (NGSS) created by Achieve and 26 lead states (NGSS, 2013a, 2013b).

Necessarily, as some researchers argue, the NGSS attempt to move science education away from the incentive-based, standardized test driven curricula brought on by the unsuccessful Title 1 and The No Child Left Behind Act (NCLB) (Perrillo, 2012; Ryan 2010). At their core, the NGSS;

> represent performance expectations (PEs) that require all students have a deep understanding of a smaller number of disciplinary core ideas (DCIs), are able to show evidence of that knowledge through scientific and engineering practices, and connect crosscutting concepts across disciplines. (Pruitt, 2014, p.145)

The NGSS are guided by learning progressions (LPs) (NGSS, 2013b), which are research-based tracks of students' longitudinal learning along a core concept grounded in learning theory (Corcoran, Mosher, & Rogat, 2009). LPs provide coherence to the progression of the concepts of a DCI by tracking the sophistication of students' developing ideas about these concepts through grade bands (NGSS, 2013b). In addition, LPs provide guidance for teachers to support students in accomplishing the PEs of the NGSS that require a much deeper understanding of phenomena than current state standardized tests require (Pruitt, 2014).

However, Birmingham and Calabrese Barton (2014) have some reservations about the NGSS. They claim, "[w]hile students may be encouraged to be active learners in the pursuit of scientific thinking and practice [within the NGSS], they are positioned as passive with respect to acting on that knowledge to engage with relevant real world problems" (p. 311). Furthermore, while the NGSS acknowledge the need for diverse, culturally relevant teaching to improve equitable science education for all students, they do not provide any tangible examples that demonstrate the integration of culturally relevant teaching with scientific and engineering practices and content (Rodriguez, 2015). Along with this shortcoming, the NRC and NGSS still only conceive of a scientific literacy defined from the subjective perspective of Western-dominated, modern science. According to Lee (1997) this is the very institution that has marginalized women and diverse ethnic and cultural groups. Therefore, it is paramount to deconstruct this traditional definition of scientific literacy and reconstruct it to include diverse perspectives on what it means to know and practice science to achieve scientific literacy for all. Overall then, as a set of standards, the NGSS do not provide teachers with specific ways or curricula on how to contextualize science education to ensure that all students develop an integrated and meaningful understanding of not only the content of science, but also how it connects to everyday, societal issues.

Context-based Chemistry Education and STS

Gilbert (2006) identified five challenges or problems in current chemistry education: (1) Students are overloaded with too many content topics due to the ever-accumulating body of chemistry knowledge. (2) Content is taught as isolated facts, which decreases students' ability to build mental schema that represent clear conceptual understanding. This also leads to low levels of student engagement in their learning and to their quickly forgetting the information. (3) Students lack the ability to transfer the skills they learned to solve certain problems and apply them to similar problems presented in novel ways. (4) Students do not perceive chemistry to be relevant, or if they do, they only perceive it as being useful to their reaching a science that is interesting, like medicine. (5) There is an overemphasis in high school chemistry on providing a solid foundation for future science endeavors. This is inadequate because most students do not head in this direction and it does not build scientific literacy for all.

Gilbert (2006) claimed that theoretically grounded, context-based learning in chemistry has the particular ability to limit content overload and isolated, fact-based teaching as well as the ability to improve students' perceived relevance of chemistry. He proposed a template for how to use context-based learning in chemistry that incorporated context-based learning theory (Duranti & Goodwin, 1992), constructivist learning theory (Ogborn, 1997), situated learning (Greeno, 1998), and interconnected human activity in learning (Vygotsky, 1978). The template consisted of four criteria: (i) A community of practice must be established and used to "provide a framework for the setting of focal events" (p. 965), events situated in chemistry content and sociocultural issues that typically come from major public policy issues like global warming. (ii) A clearly defined task must be outlined that identifies the specific behaviors and communication that will be used. (iii) The teacher should incorporate the background knowledge of students in enabling them to use the specific, socially constructed chemical language associated with the focal event. (iv) Students must be encouraged to connect their prior knowledge, partially composed of their content knowledge and their own ideas, to the focal events.

Gilbert (2006) identified the STS framework as one of the important working models for context-based learning that to a large extent adheres to his model for context-based learning. According to Solomon (1993) the roots of STS can actually be traced all the way back to the sixteenth century in Britain where people like Francis Bacon sought to politicize science. The argument for the modern conception of the STS movement, started in the 1970s, was generated from four points: (1) science has the ability to generate wealth and provide health for society, (2) craftsmen and the general public should understand science, (3) the use of science in warfare and science's potential to effect the environment reveals the need for values and responsibility in science, and (4) a reconsideration of the neutrality of science (Solomon, 1993). Essentially, STS brings together ideas surrounding the scientific community's interaction with external societal issues and ideas about the scientific community's internal epistemologies and values (Aikenhead, 2005). The general features of the modern STS framework include:

- An understanding of the environmental threats, including global ones, to the quality of life.
- The economic and industrial aspects of technology.
- Some understanding of the fallible nature of science.
- Discussion of personal opinion and values, as well as democratic action.
- A multi-cultural dimension. (Solomon, 1993, p. 18)

In a review of STS research, Aikenhead (2005) documented several trends in the findings of this body of work. First, students who participate in an STS curriculum do as well as and occasionally better than students who participate in a traditional science curriculum on science content assessments. Second, students of STS classes can have a better understanding of the interactions between science and society than students of traditional science classes, if the STS teacher emphasizes this point. Third, an STS approach can significantly improve students' attitudes towards science. Fourth, students of STS classes can have superior critical and creative thinking skills than students of traditional science classes, if the STS teacher emphasizes these skills. Fifth, some students of STS classes "can enhance their socially responsible actions when taught by certain teachers" (p. 9). In addition, the work of Bennett, Hogarth, and Lubben (2005) and Bennett, Lubben, and Hogarth (2007) has echoed Aikenhead's first and third findings providing addition support for an STS approach.

There have been studies that have specifically documented effects of an STS approach in high school chemistry. For example, in 1994, Winther and Volk conducted a study to test if a *ChemCom* curriculum ("Chemistry in the Community" – a version of STS curriculum developed specifically for chemistry and sponsored in part by the American Chemical Society) improved students' chemistry achievement to a greater extent than a traditional approach in an "inner-city" high school.   They found a statistically significant difference in the achievement levels of the two groups indicating that the *ChemCom* approach did enhance student achievement to a greater extent than a traditional chemistry course. The authors felt that this was particularly impressive considering the achievement test that all the students took in their study was designed to assess all the content contained in the traditional course, but not that of the ChemCom course.

Aikenhead (2005) documented another *ChemCom* study conducted by Mason (1996). In Mason's research it was found that students who had participated in a *ChemCom* curriculum in high school did as well as students who had completed traditional high school chemistry classes in a first-year college chemistry course for non-science majors. Finally, in a study of a non-*ChemCom* specific STS approach implemented in secondary chemistry and physics courses conducted by Solbes and Vilches (1997), it was found that students developed a more meaningful and complete picture of these sciences with an improved comprehension of the role of scientists. Furthermore, the STS approach enhanced students' interest in these two disciplines.

There is a variety of other context-based chemistry approaches cited in the literature. The Salters approach to context-based science learning has been implemented in Britain since the 1980s (Bennett & Lubben, 2006). In its most current formulation, Salters Advanced Chemistry intends:

- to show the ways chemistry is used in the world and in the work that chemists do;
- to broaden the appeal of chemistry by showing how it relates to people's lives;
- to broaden the range of teaching and learning activities used; and
- to provide a rigorous treatment of chemistry to stimulate and challenge a wider range of students, laying the foundations for future studies yet providing a satisfying course for those who will take the study of chemistry no further. (Bennett & Lubben, 2006, p. 1003)

Two themes have emerged in the research on the Salters approach to context-based chemistry education as indicated by Bennet and Lubben (2006). First, advanced chemistry courses based on the Salters approach seem to develop higher levels of interest in and appreciation for chemistry and perhaps produce more future chemistry majors in college than traditional courses. Evidence for this set of conclusions was documented in the research by Barber (2001) and Key (1998). Second, the level of chemical understanding achieved by students in Salters approach chemistry classes seems to approximate that of students in traditional courses. The work done by Barker and Millar (1996) found equivalent general chemical understanding in Salters class students and traditional class students when they used the same assessment for both groups. Furthermore, they found that students exposed to the Salters approach did slightly better in the specific areas of chemical bonding and thermodynamics. Moreover, Banks (1997) documented superior results for Salters course students within the topic of chemical equilibrium. On the other hand, Barber (2001) found that students in advanced chemistry courses designed around the Salters approach achieved lower results on the Royal Society of Chemistry annual survey than students from traditional courses. But, she also found that these same sets of students did equally well on their own chemistry course final exams (the different final exams were assessed to be approximately equivalent in conceptual difficulty).

Finally, *Chemistry in Context (CiC)* is a context-based chemistry curriculum used in undergraduate programs primarily for non-science majors (Schwartz, 2006). The creators of the curriculum claim two of the major goals of *CiC* are to improve the general population's chemistry literacy and to attract students from underrepresented populations in science such as women, and Latino/a, African American, and Native American students to chemistry and other science disciplines. A description of *CiC* consists of eight points:

- The curriculum is centered on real-world societal problems and issues with significant chemical content.
- Chemical phenomena, facts, and principles are introduced, as needed, to inform the study of the core issues that create the context.
- The curriculum makes important interdisciplinary connections, especially to the social sciences.
- In so far as possible, chemistry is taught as chemistry is practiced.
- The curriculum includes chemical phenomena, methodology, and theory.
- It integrates laboratory, library, and class work.

- A student-centered approach emphasizes discussion and group work.
- Considerable attention is devoted to problem-solving and critical thinking. (pp. 980-981)

The textbook that accompanies the *CiC* curriculum contains chapter headings such as "Protecting the Ozone Layer," "The Chemistry of Global Warming," and "Neutralizing the Threat of Acid Rain" (p. 985).

Initial pilot research into the effect of the *CiC* curriculum on students' attitudes towards chemistry has noted positive increases from the beginning of a semester long course to the end (Nakhleh, Bunce, & Schwartz, 1995). Although, the authors also found that traditional undergraduate courses developed similar increases in positive attitudes towards chemistry by the end of a semester. They suggest that a more fine-tuned research design is required for future work in this area to better identify differences between *CiC* courses and traditional courses and how these courses affect students' attitudes. In addition, while there has not been any research that formally compares the level of chemical understanding of students enrolled in a *CiC* course to a traditional course, Schwartz (2006) notes that professors of *CiC* courses have been pleased with student results on final exams developed specifically for *CiC* courses. He goes on to suggest several assessment points and strategies that are important to evaluating the level and type of chemistry literacy aimed for by *CiC*. His suggestions include using essay questions that require students to argue for or against policy issues, assessing if students can apply chemical knowledge in new contexts, and using newspaper articles that students have "to critically analyze…, commenting on the accuracy of the science and the plausibility of the conclusions and identif[y] any important unanswered questions" (p. 991).

The work noted above, especially that of Gilbert (2006), provides an excellent base for transforming a traditional chemistry curriculum to one that is context rich, student-centered, sensitive to diverse student backgrounds, and reflective of politicized chemistry related societal issues. However, it falls a little short of developing the level critical scientific literacy described in this study. The curriculum activities and units developed for this study seek to additionally address issues such as who decides what is important scientific information and how science is conducted and communicated, who does scientific information and scientific modes of communication benefit, who does it potentially harm or oppress, and in what ways (Calabrese Barton, 2001). In addition, while there is much work documenting the benefits of context-based approaches in chemistry class, Gilbert claims that there is a continued need for more research into the effect of context-based chemistry learning on students' scientific knowledge. This research aims to address this issue by evaluating students' development of critical scientific literacy and chemistry content knowledge as they progress through the school year.

Studies in Science Education Grounded in Critical Perspectives

This section of the literature review describes some of the research that has been conducted in science education from several different critical perspectives, including, but not limited to, multicultural science education (MSE) (Atwater, 1993, 1995), feminist pedagogy (Brickhouse, 2001), and critical science reading and writing (Oliveras, Marquez, & Sanmarti, 2013, 2014). Without disrespect for the many important nuances of these studies, this review is organized into four broad themes.

Students from diverse cultural backgrounds. First, there are studies that address science education from the perspective of students from diverse cultural backgrounds. Some of these studies focus on students from urban settings (Emdin, 2010, 2011; Kahl, Meece, &

Scantlebury, 2000), and others on students from rural settings (Yerrick, Schiller, & Reisfeld, 2011), or on occasion, both of these settings (Bang & Medin, 2010). The research of Bang and Medin (2010) provides an interesting example of this work. In part of a larger research project, they brought together members of the American Indian community living in Chicago (a very diverse community in itself, composed of people from over 100 Native American nations), and members of the rural Menominee tribe to develop a summer science program "designed to support students' navigation among multiple ways of knowing, including their community-based ways of knowing," science (p. 1019). The major goal of this effort was to honor "Indigenous epistemological practices… as relevant to science and science learning" (p. 1018). In their work to document students' perceptions of science before and after the summer program, they found that students began to realize science is something done by Native people, sources of scientific knowledge extend beyond traditional textbooks, science is a practice for creating knowledge that Western and Native people participate in, and that students began to have a more holistic interconnected view of humans' interaction with nature.

Other critical, multicultural studies have focused on after school or community science programs rather than classroom settings (Basu & Calabrese Barton, 2007; Birmingham & Calabrese Barton, 2014; Fusco & Calabrese Barton, 2001). Basu and Calabrese Barton conducted a critical ethnography on the science interest levels of ethnically diverse, middle school students living in a high poverty, urban setting working in an after school science projects program. Their work was grounded in the concept of *funds of knowledge*, which are the knowledge, skills, and practices of the community or cultural background the students come from and enter school with (Gonzalez & Moll, 2002). They found that a sustained interest in science could be achieved in students if their science instructional experiences connected to their funds of knowledge and desires for their futures, as well as supported social relationships and student agency.

Finally, some critical, multicultural studies have specifically addressed diverse students acquisition of the dominant language of science or their positions as defined by language norms (Brown, 2004; Brown & Spang, 2008; Kurth, Anderson, & Palincsar, 2002; Warren, Ballenger, Ogonowski, Rosebery, & Hudicourt-Barnes, 2001). In particular, Brown conducted an ethnographic study and used discourse analysis to gauge the different levels ethnic minority students in a high school, urban setting assimilated dominant science discourse into their discursive identities (identities based on chosen forms of discourse that signify types of cultural memberships) and how this affected their performance in class. He found that the level of assimilation of the culture of science into student identity generally corresponded to the level of achievement. He concluded with a description of an approach to teaching science that directly addresses the importance of acquiring science classroom discourse.

Girls and women in science. A second important area of critical science education research has focused on girls and women in science (Brandt, 2007; Brickhouse, 2001; Brotman & Moore, 2008; Buck, Plano Clark, Leslie-Pelecky, Lu, & Cerda-Lizarraga, 2008; Calabrese Barton, 1997; Calabrese Barton, Tan, & Rivet, 2008; Chinn, 2002; Parker & Rennie, 2002). Fundamentally, feminist science education calls for a more student-centered science classroom that ultimately improves education for all students (Brickhouse, 2001; Calabrese Barton, 1997; Parker & Rennie, 2002). Calabrese Barton notes that science class can be oppressive for girls and many other students because of the traditional mindset that science is a method for determining a body of facts. If students feel like that do not relate to the traditional method or feel like they do not make sense of the facts in the same way the dominant group does, then they are deficient in some way. She envisions science classrooms where girls and boys reflect upon how their past experiences shape the way they make sense of science. She suggests that this must be deliberately orchestrated by the teacher, but at the same time, not forced upon students through the single perspective of the teacher. Students must be free to explore their own questions and share their own standpoints about gender and other issues of inequality in science and science education.

One of Calabrese Barton's (1997) main focuses for creating a more student-centered classroom is on addressing the male biased language of science. She suggests that male biased metaphors and aggressive language in science should be explicitly discussed, and analyzed in the search of more gender inclusive language. For example, she notes the aggressive ways particles are described as interacting during chemical reactions such as positive ions attacking negative ions and considers ways students can come up with new ways to describe these interactions. All people are mixes of rational and emotional qualities that are expressed to different degrees in different contexts through language. Investigating the language of science in the science classroom makes this explicit and improves the scientific experience for all types of students, not just girls. Ultimately, not only does this address the male dominated language of science, it also helps students understand scientific content better because it allows them to discuss multiple perspectives on the same topic.

Brickhouse (2001) explores student-centered, feminist science education through the lens of learning theory. She claims that while constructivism has been utilized as a learning theory that has worked successfully to frame the work of some feminist science educators, it is largely individualistic in nature and does not address the social dynamics of the classroom where gender issues reside. She proposes that "situated cognition provides better resources for feminists than other accounts of learning" (p. 284) because of the important role identity formation plays within this learning framework and in understanding gender. Brickhouse's interpretation of situated cognition recognizes that rational science is a cultural practice situated in social norms. Not only is scientific knowledge a fundamental part of context, it is inseparable from context. Therefore, learning science and learning in general is a socially situated phenomenon as well. In fact, learning is always happening whenever people engage in the world and socially interact. Furthermore, learners become who they are – they form their identities by how they participate in knowledge sharing and creation within a community.

Brickhouse (2001) goes on to emphasize that students can go through identity transformations as they learn science, which then affects how they participate in science class. She believes that this is something that must be recognized by science teachers. Teachers should help students take on scientific identities like environmentalists and informed consumers as they participate in multiple communities of practice that reside outside and inside the classroom. Brickhouse believes that concentrating on identity transformations allows students to play with gender identities in fluid ways that do not pigeon hole girls or boys into specific gender roles. Ultimately, if students can take on an identity of participating in a scientific community of practice that allows them to do something practical with their scientific knowledge, then they will not be enculturated into the traditional male dominated practice of science, and they will learn to take on identities that shape scientific knowledge creation for the benefit of their communities.

Parker and Rennie (2002) note that student-centered, gender inclusive pedagogy welcomes all students' prior knowledge, experiences, and interests to the classroom. They also suggest teachers must consider students preferred learning and assessments styles. Furthermore, they believe teachers should use real-life scientific contexts to interest students and draw out multiple student perspectives. To challenge male bias in science, Parker and Rennie argue that the historical hegemonic, value-laden nature of science must be made explicit in the classroom. In addition, they argue that students and teachers should share and explore alternative ways of knowing and practicing science that include more domestic, nurture-based, and holistic views in the classroom.   Finally, they believe it is important to identify the lost women of science like Rosalind Franklin and identify modern day women scientists to act as role models for girls.

Critical reading and writing in science. Third, there has been research that documents approaches to critical reading and writing in science (Hildebrand, 1998, 2001; Oliveras et al., 2013, 2014). Hildebrand's (1998) work focused on critical science writing. Her work stemmed from the notion that positivistic, hegemonic, stereotypically masculine writing practices of traditional science gives students the false impression that science is the recall of facts rather than the construction of knowledge. She studied four Australian teachers use of *hybrid imaginative writing*, writing that combines formal science writing with things like first person narratives and poetry, for three years. She found that hybrid imaginative writing was an important tool for teachers to use to progress ideologically from disruption pedagogy, a pedagogy guided by the desire to disrupt or change traditional secondary science education, to an enabling pedagogy, one that "construct[s] an environment where play is supported, where ideas from students' social worlds connect with their learning, and where pleasure in the pursuit of learning is possible" (p. 358). More specifically, hybrid writing in science provided marginalized students different access points to the language of science and ownership of science, and catered to diverse ways of knowing and diverse levels of ability.

The research documented in this section provides an excellent framework for conducting the proposed study. First, the methods used to conduct these studies, especially the ethnographic approach, discussed in more detail in the next chapter, ground the proposed research design. Second, the instructional strategies and orientations discussed above provide guidance for the creation and implementation of the curricular changes to be studied in this research, especially in terms of welcoming and better engaging girls and the small number of students from diverse cultural backgrounds at the proposed school setting to the chemistry conversation. On the other hand, none of these studies address the affect of a critical science education approach on upper middle class, White students from dominant cultural backgrounds taking a rigorous high school course in a core scientific discipline like chemistry. In addition, while the work of Basu and Calabrese Barton (2007) addressed the affect of a critical approach on students' interest in science, it focused on an after school program, and it did not utilize an interest framework for grounding the results. This dissertation study aims to build on their work by addressing the effect of a critical approach on interest development in the core secondary science of chemistry. Furthermore, it hopes to add to the diverse body of critical pedagogy literature by implementing and studying the affects of this approach on chemistry students from dominant cultural backgrounds.

Studies of Student Interest in Science

Over the last twenty years there have been quite a few reports suggesting that in general student interest in science is low and has been trending downwards across the globe (Jack & Lin, 2014; Krapp & Prenzel, 2011; Martin et al. 2008). On the other hand, Krapp and Prenzel (2011) described a much more nuanced picture of student science interest research over the same time period than this simplistic claim would suggest. They found that different types of students had varying levels of interest in different areas of science under different circumstances. For example, Haussler and Hoffmann (2000) found that students were more interested in physics topics that have practical or social implications than the pure scientific principles. They also found students' low levels of interest in physics as a school subject had more to do with their self-efficacy in the subject than their general interest in the content of physics. Another study suggests student interest in science is complicated by different variables (Jones, Howe, & Rua, 2000). In their study of sixth grader's attitudes towards science they found gender differences in students' interest. For example, boys were more interested in topics related to the physical sciences like atoms and x-rays, while girls were more interested in biology related topics like healthy eating and AIDS.

According to Jack and Lin (2014), in the last ten years there has been a trend in science interest research that focuses on studying students' situational or short-term interest in specific science content and activities in the classroom. Some of these studies focus on factors that generate or improve students' situational interest. For example, a study by Palmer (2009) found that a ninth grade science lesson focused on inquiry skills generated substantial situational interest and that the main sources of the interest in the lesson were novelty, student choice, physical activity, and student collaboration. Dohn (2013a) conducted a study of sixth grade students' situational interest in an engineering design program. He found that designing inventions and student collaboration, among several other factors, were sources of interest in the program. Overall, the design tasks stimulated student interest, but only if students had autonomy in doing their work. In another study by Dohn (2013b), situational interest was generated by active involvement through hands-on activities, novelty, and opportunities for socialization during a 12th grade fieldtrip to a zoo.

Some of these studies about students' situational interest in science have also addressed its affect on other classroom variables. For example, Palmer (2004) found that primary teacher education students experienced situational interest in science through instructional strategies that included active involvement, novelty, meaningfulness, group work, and instructor's personal anecdotes. In addition, Palmer's study assessed and subsequently found a link between developing situational interest and improvements in students' general attitudes, including interest, in science. The work of Kang, Scharmann, Kang, and Noh (2010) serves as another example. They studied, among other variables, the influence of situational interest induced by a discrepant event on seventh graders understanding of the concept of density. The instructional methods of the density activity were developed to promote learning through conceptual change. They found that students' situational interest had a strong influence on their conceptual change and subsequent understanding of density. Finally the research of Lin, Hong, and Chen (2013) sought to document how situational interest can be sustained and how it might be developed into long-term interest in chemistry. First of all, they found that situational interest in chemistry was maintained by demonstrations and hands-on activities that incorporated novelty. Second, they found that attempts to consistently sustain students' situational interest in an experimental group led to higher perceived levels of interest and enjoyment in science class by students in the experimental group than the students in a control group.

While the studies listed above have begun to document trends such as novelty, and student collaboration that affect, generate, and/or improve students' situational interest, researchers such as Renninger and Hidi (2011) and Jack and Lin (2014) suggest that work needs to continue in identifying classroom activities and instructional methods that generate and sustain interest in science. Only the work of Palmer (2004) and Lin, Hong, and Chen (2013) touched on situational interest's effect on lasting interest. This study is partially aimed at building upon this work and hopes to add to the body of knowledge about factors that generate and sustain students' interest in the specific context of chemistry. Furthermore, the positive increases in interest generated by inquiry learning and student collaboration documented above provide an excellent guide for creating critical chemistry activities and units that stimulate interest as well as develop critical scientific literacy.

Theoretical Lenses

Sociocultural Learning Theory

Sociocultural learning theory was used to guide the classroom activities and instructional strategies of the critical science education enacted in the classroom as well as the methodologies used during this yearlong study. Sociocultural learning theory can be conceived of as a blanket term for learning theories such as sociohistorical constructivism noted by Eisenhart, Finkel, and Marion (1996), the situated cognition noted by Brickhouse (2001), or social constructivism described by Driver, Asoko, Leach, Mortimer, and Scott (1994). At their core, these learning theories all claim that knowledge is a socially constructed phenomenon. It is created and shared within a group through the shared tools and practices of the group such as language. According to Hickey and Zuiker (2003), sociocultural learning theory explains learning as "participation in the use and transformation of socially defined knowledge" (p. 539). They add that "knowledge neither resides in the mind of the knowledgeable individuals nor in the environment waiting to be learned" (p. 540), it exists in an abstract space spread across all the people interacting within a specific contextual environment.

Critical Science Education and Critical Scientific Literacy

Fundamentally, critical science education (CSE) is a very student-centered approach to science education. CSE necessitates the creation of activities, lessons, and units that not only prompt all students to share their diverse personal interests and backgrounds in the science classroom, but that also help them see how they can use these unique perspectives to understand scientific content and to do scientific work. This can open the doors of science to more students – students who may come from backgrounds that have been traditionally marginalized from science or simply any student who has just never considered themselves interested in or capable of doing science (Gilbert, 2013). In addition, CSE leads students to ask questions such as: What is important scientific knowledge? Who does it benefit? Who does it oppress, and for what purposes (Kincheloe, 2005; Calabrese Barton, 2001)?

The goal of CSE is the development of critical scientific literacy (CSL). I conceived of CSL for this study as a traditional definition of scientific literacy enhanced by a critical component defined by CSE. Therefore, CSL entails that students learn an appropriate level of socially relevant, scientific content and develop the ability to employ the practices of science, which would be the main components of a traditional definition of scientific literacy (NRC, 2012). However, CSL also demands that students have the ability to use scientific content knowledge as well as produce their own scientifically based knowledge with their ability to practice science to critically exam the intersections between society and science (Fusco & Calabrese Barton, 2001).

Interest

A conceptual understanding of interest was used to frame the development of the units and activities of the critical science education enacted in the classroom as well as to inform the methods for collecting and analyzing evidence of student interest. For the purposes of this research, interest is regarded as an intrinsic, multidimensional, "motivational variable that refers to the psychological state of engaging or the predisposition to reengage with particular classes of objects, events or ideas over time" (Hidi & Renninger, 2006, p. 112).

The *person object theory of interest* (POI) elaborates on this definition. Essentially, interest is a concept that describes the relationship between a person and a specific object. The term object can represent anything from a tangible physical object to an abstract concept or topic. POI distinguishes interest from other motivational variables by noting that interest is guided by the specific rather than general attributes of an object. In addition, POI explains that interest is affected by both cognitive and affective responses in the brain (Hidi & Renninger, 2006; Krapp, 2007).

In the next chapter, I explain the methodology I used to develop answers to the research question: "What does the implementation of a critically transformed chemistry curriculum look like in a private, suburban, high school chemistry class?" and to specifically track students' critical scientific literacy, chemistry content knowledge, and interest.

Chapter 3

METHODOLOGY

Research Design

Ethnography

A quantitative, positivistic research approach is not adequate to fully capture the picture of critical pedagogy in a classroom (Kincheloe, 2007). For this reason, an ethnographic study containing mixed methods for data collection and analysis was conducted to completely answer the research questions. Ethnography is a unique qualitative methodology in that it can contain quantitative data points as well (Creswell, 2013). Ethnographies have been used to document student interest (Renninger & Hidi, 2011), and have been utilized extensively within the realm of critical educational research (Basu & Calabrese Barton, 2007; Brown, 2004; Calabrese Barton, Tan, & Rivet, 2008; Trueba, 1999).

The choice for conducting an ethnographic study was partially motivated by the identification of a unique group identity at the proposed school setting. Appiah (2005) claims culture can be understood as a group of people's language, stories, songs, religion, rituals, beliefs, traditions, cuisine, modes of dress, and ideas about family life. However, Appiah favors a transition from the term culture to the term collective identity. He describes that collective identities provide people with "scripts: narratives that people use in shaping their pursuits and in telling their life stories" (p.108). Furthermore, Appiah writes that identification with available labels, in part defined by aspects of collective identities, partially determines how an individual plays out their life and constructs one's identity. While the students at this setting are predominately Protestants of Western European decent, there is still enough cultural and ethnic variation in their backgrounds that classifying them as a single culture in the traditional sense would be inappropriate. Instead, Appiah's understanding of a group or collective identity frames the ethnographic approach taken here. Of course, there are levels of variation in the students, but in general, they are high achieving, highly competitive, ambitious, and have similar motivations, and mindsets. In addition, they follow certain scripts that lead to similar life stories.

Creswell (2013) states that an ethnographic approach, historically rooted in the discipline of anthropology, is an excellent methodology to use to create a rich description of the traditions, interactions, mindsets, and overall shared experiences of a culture, or in this case, a group identity within a community. Moreover, he suggests that a specific purpose or issue generally frames ethnographies. In this case, student interest, critical scientific literacy and chemistry content knowledge framed the study. In addition, Creswell notes that while most ethnographies result from continued, extensive observations and data collection, they can also focus on a limited number of group activities. The proposed ethnography combined the use of a researcher journal that documented observations and researcher reflections on a full school year of students' developing interest, critical scientific literacy, and content knowledge with a more detailed sampling of student outcomes in four specific units that occurred spread out through the second, third, and fourth quarter of the school year.

More specifically, this study was framed as a critical ethnography. A critical ethnography is a research approach that includes an advocacy perspective that is responsive to current issues in society that are controlled or manipulated by groups in power to their benefit and to the detriment of other groups (Creswell, 2013). Critical ethnography hopes to "reach a higher level of understanding of the historical, political, sociological, and economic factors supporting the abuse of power and oppression" (Trueba, 1999, p. 593). The main goal is to critically empower the group being studied (Creswell, 2013). However, Trueba (1999) notes, “critical ethnography typically remains at the level of a detached discourse without telling us how to take the emancipation route and how to construct an effective pedagogy” (p. 594). He goes on to suggest that research must begin to find ways to reach emancipation. More recently, Basu and Calabrese Barton (2007) suggest that critical ethnography studies the transformation of educational practices that strive for empowerment. In this sense, critical ethnography can be described as applied research in that it seeks to change and improve education for all students (Boeije, 2010). The proposed applied, critical ethnography aimed to empower both the dominant and diverse cultural group student participants at one suburban, private school by studying the effects of critical science education on students’ development of interest, critical science literacy and chemistry content knowledge. Of course, it sounds a bit counterintuitive to want to empower students from the dominant cultural group, but I believe, as does Trueba (1999), that students from all cultural groups, oppressors and the oppressed, must be empowered with critical understandings of their positions in society and how their thoughts and actions affect others to improve society for everyone. In addition, all students, regardless of background, deserve efforts to improve their education.

Ultimately though, this applied, critical ethnography was purely analytical in that it aspired to explain the development of student interest, critical science literacy, and content knowledge in a secondary chemistry class that had been transformed by a critical science education approach. It did not make any claims that the adopted critical approach provided a comparatively better science or chemistry education than other progressive attempts for improvement. Finally, the use of qualitative and quantitative data points within the applied, critical ethnographic framework supported concurrent triangulation. Concurrent triangulation describes a framework for a mixed methods research approach where qualitative and quantitative data approximately share equal weight in triangulation, the attempt to support themes that answer research questions with multiple sources of evidence (Boeije, 2010).

Field Setting and Participants

This study was conducted over the course of a school year in two sophomore chemistry classes ($N = 25$) at an independent (private) school in a highly resourced, New England suburb, approximately 35 miles outside of New York City. The average age of sophomore students at this setting was about 15 years. The school runs pre-kindergarten through twelfth grade. This school was unique in that Pre-K through eighth grade was all girls while the upper school (high school) classes were composed of boys and girls. The classes were mixed between the girls from this school and the boys from the brother school that was located across the street. While the student body at the two schools was still quite homogeneous, mainly composed of the children from the highly resourced, White families that live in the town and surrounding area, they had both made concerted efforts to improve the diversity of the student populations. To do this, they had both reached out to diverse communities that were nearby and provided financial aid for approximately 22% of the students enrolled yearly. In 2012, 25% of the student body identified themselves as students of color.

Purposefully diversifying a student body is not inherently negative. Indeed, in this school's case it was done to broaden the educational experience of their predominantly White student body, as well as to provide diverse students with opportunities they may not realize in struggling public schools. But, a problem can arise in these situations when all the educational decisions made, from classroom practice to dress codes, privilege students from the dominant cultural background while marginalizing students from diverse cultural backgrounds (Kincheloe, 2005). This school did celebrate cultural diversity in many ways through festivities for Martin Luther King Day and Chinese New Years, but implicitly expected students to shed their cultural backgrounds and participate in science classes through dominant Western cultural norms such as abstractly discussing objects of study as if they have no connection to the environments they exist in; environments that are socially constructed by human perception [see for example Nisbett, Peng, Choi, and Norenzayan (2001) for a discussion of the differences between Western and Eastern thought]. In general, this can be a very difficult dynamic for diverse students and some can become disillusioned by the environment, causing them to feel like they must reject their backgrounds to be accepted (Banks, 2004; Kincheloe, 2005). The result is that many of these students become disinterested in what they are learning because it does not connect to them personally and makes them feel marginalized from the dominate discourse. This is especially true in science where there is rarely any consideration for cultural differences or mindsets (Calabrese Barton, 2001).

Role of the Researcher and Ethical Issues

Role of the researcher. Lichtman (2010) does not believe that researchers can totally eliminate bias from their work. As a result, she believes they should acknowledge their points of view from the outset. First and foremost, as a White, Christian, heterosexual male of Western European dissent I enjoy a position of privilege in our society, one that I had to be constantly aware of as I enacted critical science education in my classroom and interpreted the data from this study. Constant reflection in my researcher journal, and close collaboration with my colleagues and especially my students during the school year hopefully helped guard against my own biases.

Furthermore, I must acknowledge my critical, social constructivist lens that guided the study. Social constructivism takes into account the significant role of social interaction in knowledge production and learning. Social constructivism is predicated on the fact that all knowledge is constructed with socially mediated symbols and tools (i.e. spoken and written language). Therefore, no knowledge is really individual knowledge or individually developed, it is all socially constructed and understood through socially determined means, defined by the cultural and social norms of the participants (Driver et al. 1994). So from a social constructivist point of view, students are not “empty vessels” to fill with knowledge. Along with their teachers, they are co-creators of their own knowledge whose initial or prior knowledge must be considered before moving forward in the learning process (Taylor, 1998). Furthermore, a critical social constructivist lens requires the recognition that there is no such thing as an abstract, objective truth to knowledge separate from human creation, even scientific knowledge, that people can achieve, and that dominant cultures control knowledge validity, construction, and transmission through their social norms (Taylor, 1998).

Social constructivism provides an excellent lens through which to study a culture or group that has shared motivations and concerns like the student participants at my school (Creswell, 2013). I believe that multiple realities on the individual and group level exist that are co-constructed between the members of a group sharing and discussing their individually and collectively lived experiences. I also believe that an understanding or knowledge of these realities is co-constructed by researcher and participants.

I had taught honors and regular level chemistry at this school for five years. In addition, I had coached tennis, worked with the robotics team, and been an advisor and a participant in the community service group. These experiences allowed me to spend many hours in and out of school with these students. Therefore, I did not need a "gatekeeper," someone who would allow me access to this setting (Creswell, 2013), as I was already "embedded," and had already established comfort and trust with my participant students so that I could record a true emic, insider, perspective (Merriam, 2009). On the other hand, I did not personally identify with the group identity my students seemed to share because I had always been an outsider in terms of socioeconomic status and because of my critical perspective, which allowed me to interpret and conduct this study from an etic, outsider, point of view (Merriam, 2009).

In addition, authors (Aikenhead, 2005; Smith, 2013) have documented the difficulties of researchers navigating the politics of implementing critical or other progressive approaches in classrooms in traditionally minded school settings. The work of Carlone, Haun-Frank, and Kimmel (2010) provides a framework for describing my role as a progressive educator in my school setting for five years and my role as a teacher/researcher for the last of those five years. I worked as a "tempered radical," a person that delicately balances their inclusion and acceptance in the school community with their desire for reform. Tempered radicals use "improvisations" in their teaching that balance historic traditions with reformed science education (Carlone et al., 2010). For example, I had incorporated inquiry-style projects in my instructional practices by using lab time in the classroom to collect data and blogs to complete the work outside of the classroom. The blogs minimized the impact of these projects on class time, which made senior colleagues in the science department happy because they preferred that an extensive breadth of chemistry content be taught through lecture and traditional classroom lab methods. The procedure for the research continued this balancing act by only partially transforming the chemistry curriculum from a critical perspective so that students could still be prepared for the extensive breadth of information contained on large, traditional, multiple-choice final exam that the school preferred to use as a measurement of success.

The work of Carlone and Webb (2006) provided assistance in conducting research in the traditional school environment where this study took place. They recommend deconstructing the traditional roles within the hierarchy of schoolteachers, administrators, and researchers. To do this, they suggest that researchers establish an open dialogue with school administrators to develop a high degree of comfort between the two groups. In this way, the researcher can invite administrators to participate in the research by providing advice and feedback about the progress of the study. In this study, the researcher sought feedback from colleagues and administrators about ways to improve the critical activities and units that were implemented. Furthermore, the researcher kept in close communication with the administration about ways to maintain comfortable and open dialogues with student participant parents during the course of the research project. Moreover, Carlone and Webb as well as other authors (Boeije, 2010; Creswell, 2013) believe that is ethically imperative for researchers to maintain open relationships with school communities after the research is completed to make sure that the community feels respected and appreciated, which this researcher continues to do.

Ethical issues. The setting and critical approach of this study coupled with the fact that the researcher and teacher of the two classes were one in the same raised several other ethical considerations. To begin, there was the chance that students could have felt coerced to participate in the research or that they should respond in a certain way to the research. I believe both of these issued were minimized by the level of trust the teacher/researcher had established with this community over five years of highly involved work at the school. Furthermore, the teacher/researcher maintained a great degree of open and comfortable dialogue with his student/participants, their parents, his colleagues, and administrators at the school throughout the research process. This dialogue was enhanced by reminders on the Teachers College, IRB approved parent consent form and the student assent form that participation was completely voluntary and that they could back out of the research at any time during the school year without fear of retribution.

A second ethical issue related to this study arose for the teacher due to its critical nature. Freire (1998) states that it is paramount for the critical pedagogue to confront students' beliefs in a safe and delicate way that does not make the students feel like the teacher is imposing his or her own beliefs or critical consciousness on them. Students must feel free and comfortable developing and expressing their own critical consciousness without feeling oppressed or offending other students or the teacher. This is a complex task that requires a very student-centered approach run by a teacher that can both take a step back and can act as an authority figure in the classroom (Freire, 1998; Kincheloe 2005). This advice guided the creation of the critical transformations of the chemistry curriculum in the hopes of addressing this ethical issue. For example, the activities and units created for the study were structured in a way to allow students to consider multiple viewpoints of any one topic through question sets that required individual reflection and research, small group activities, discussion, inquiry-based lab work, and whole group discussions that intended to stimulate students to ask and answer their own questions.

Data Collection Methods and Analyses

The qualitative and quantitative data collection methods and analysis used in this mixed methods study were selected for their compatibility with critical ethnography, interest research, and methods used to investigate classroom activities created through the lens of sociocultural learning theory. First, Creswell (2013) notes the use of extensive field observations, artifact analysis, and focus group interviews within an ethnographic study. Brown (2004) video recorded the classroom in his ethnographic study because he was both the teacher and researcher and could not record field notes, as is the case in the proposed study. Oliveras et al. (2013) used an interval based grading rubric to analyze student artifacts for critical scientific literacy.

Interest researchers (Krapp & Prenzel, 2011; Renninger & Hidi, 2011) note the extensive use of quantitative surveys and open-ended questionnaires in interest research. They suggest that surveys and questionnaires work best in a pre/post procedure that occurs right before and right after the curricular transformation. Furthermore, they suggest that these measures are not sufficient to accurately gauge interest. They suggest that interviews and especially observations must be used to support students' self-reports of interest on surveys and questionnaires because students can have difficulties grasping their own levels of interest.

Finally, according to Barab and Kirschner (2001), from a sociocultural learning perspective, the knower cannot be separated from what is known and the context within which it is known. Furthermore, because learning environments are dynamic – always changing as students and the teacher interact affecting the direction of the learning – proper evaluation must take this into consideration. Therefore the unit of analysis cannot be what is happening in an individual's brain alone. Analysis must occur at the "intersection of the individual, context, and activity over time" (p. 6), and must recognize "cognition occurs and is given meaning through the dynamic relations among knower, the known, and the evolving context through which knowing occurs" (p. 9). Finally, Barab and Kirschner suggest that this level of analysis requires video recording classroom activities, and mapping, coding, and interpreting the transcripts.

Methods. The qualitative data collection methods employed in this study included video recordings of classroom activities, open-ended questionnaires, and audio-recorded focus group interviews (See Appendices K – Q). All 25 students participated in the classroom activities and questionnaires. However, only 18 students participated in the interviews. These 18 students were not specifically selected, nor were the seven that did not participate purposefully not selected. The 18 who did participate were essentially self-selected because they were better able to make time in their busy schedules to be a part of an interview that occurred outside of class. Finally, a researcher journal was kept for the entire school year. Each qualitative data collection method is described in full detail within the relevant papers of the findings chapters later in the dissertation.

Quantitative data collection methods included Likert-type, interest surveys, rubric-scored student artifacts, pre/post unit tests, and a cumulative final exam (See Appendices R – FF). All 25 students participated in the Likert surveys, activities that generated the student artifacts, and the tests. Each quantitative data collection method is also described in full detail within the relevant papers of the findings chapters.

Analysis. Qualitative analysis was performed using NVivo, a qualitative analysis software tool. I *open coded*, or created "nodes" in the vernacular of NVivo, the transcripts of the classroom video recordings, questionnaires, and interviews. This process entailed identifying and segmenting concise statements from the data and categorizing them by names or codes, ideas that reside in the data (Boeije, 2010). Next, a data analysis approach to ethnography suggested by Fetterman (2010) was implemented on the coded qualitative data. In this process, multiple data sources are compared or evaluated against each other to identify patterns or themes in participant behaviors and thoughts that focus on key instances in the activities of the group (as cited in Creswell, 2013). To accomplish this task, nodes were categorized, word frequency queries were run, and node matrices were created, all in NVivo, and used to identify broader patterns in the qualitative data sources. Qualitative data analysis is elaborated upon in the relevant findings chapters.

Quantitative analysis of the Likert surveys consisted of generating a point value from 0 to 5 for each student on each survey. Rubrics were used to score the student artifacts from 0 to 1.0. And scores from 0 to 1.0 were determined for each student on each pre- and post-test and the final exam. Histograms and Shapiro-Wilk's tests were then used to test the normal distribution of each data set and Bartlett's tests were used to confirm homogeneity of variances between compared sets of data.

Several inferential statistical tests were performed on each type of quantitative data as well. Likert surveys were examined with time series regression and analysis of variance (ANOVA). The rubric-scored student artifacts were examined with time series regression and *t*-tests. And the pre- and post-tests and final exam were examined with *t*-tests. The specific details of each of these tests are included in the papers of the findings chapters.

Finally, during the analysis of all quantitative data, whenever there was a statistically significant *t*-test result, an effect size (ES) was determined using Cohen's d (Cohen, 1988), which calculates ES by subtracting the means and then dividing by the standard deviation of either group (as long as variances are approximately homogeneous). But, because all the data from this study came from the same set of students, the effect size was calculated using the standard deviation of the pre-test in unit test comparisons, or the standard deviation of the group with the larger standard deviation in all other comparisons, rather than the mean standard deviation or the pooled standard deviation, which are usually used in practice, to protect against an overestimate of the ES (Dunlop, Cortina, Vaslow, & Burke, 1996).

Process and Procedures

The research was conducted over the course of an entire school year in two “regular level” high school chemistry classes. Before the school year began, I had formally created four critical curricular transformations or units grounded in the critical science education, sociocultural learning theory, and interest research outlined in the theoretical framework of Chapter 2. A full description of these four units is undertaken in Chapter 4.

All the parents of the students of the two classes and the students themselves agreed to participate in the study (N = 25). The research process began with all students informally participating in an open-ended questionnaire in which they described, in their own words, their conceptions of what interest is, some of their interests in and out of school, and their initial level of interest in chemistry (See Appendix K). The questionnaire results provided guidance for future teaching practices in terms of engaging students in their chemistry education by addressing their interests, provided guidance for the questions created on a small portion of the open-ended questionnaires, and provided a baseline for the rest of the formal interest research.

The first formally created critical unit of the research project was enacted and video recorded during the second quarter of the school year. Students participated in class in a pre Likert survey just before the critical unit was undertaken and an identical post Likert survey just after, which gauged students’ general interest in chemistry and the specific components of the critical unit. In addition, students participated in a post unit, open-ended questionnaire and a post unit test. Unfortunately, a pretest was not undertaken for this first unit as there was a time issue that occurred due to the proximity to winter break. Within a week of the unit’s completion, two focus group interviews were conducted for 30 minutes each outside of class. Finally, student artifacts were collected from the unit.

A very similar process was implemented for the next three critical units that occurred during the third and fourth quarters of the school year. In between each round of data collection, preliminary analysis was conducted to inform subsequent collection. In all, these data points were used to measure the extent to which and ways in which students' critical scientific literacy, chemistry content knowledge, and interest developed over the course of the school year (See Appendix A for Study Timeline and Appendix J for Research Design Matrix).

Safety procedures. First, none of the data was collected anonymously as it is impossible to guarantee anonymity. On the other hand, confidentiality was protected through several procedures. All the students were given pseudonyms. The pseudonym/student key was only known to the researcher, saved on his laptop computer, and backed up on his personal hard drive. The laptop computer is password protected, and the hard drive is locked up at the researcher's home. All the data collected from the surveys, the questionnaires, the student artifacts, the audio recordings from the focus group interviews, and the video recordings of the classroom activities during each of the units were only viewed by the researcher, saved on his computer, and backed up on his hard drive. All the surveys and questionnaires were conducted securely via email links to the Qualtrics system, a survey tool provided by Teachers College. Finally, when it was not in use, the researcher's journal was locked in his desk drawer at the school or at home.

Second, while there was a very minimal risk to participating in this research, several precautions were undertaken. There was the risk that students could have a small amount of psychological or emotional distress from participating in the proposed units and focus group interviews where different viewpoints were critiqued. This potential was minimized by the student centered nature of the activities, and was minimized further by the use of a researcher journal that helped the teacher/researcher be observant and reflective about maintaining a positive and comfortable atmosphere for all students.

Elements of Rigor

Due to the fact that the mixed methods, critical ethnographic research model was largely qualitative and guided by the researcher's critical, social constructivist lens, elements of rigor were largely conceived within the constructivist research terminology of Guba and Lincoln (1989). On the other hand, the researcher's use of quantitative measures to establish a deeper, more complete description of students' interest, critical scientific literacy, and content knowledge within the ethnography warranted the use of positivistic terms as well.

First of all, the methodology for the study supported credibility. Credibility is the constructivist conception of internal validity that emphasizes establishing a "match between the constructed realities of respondents (or stakeholders) and those realities as represented by the evaluator and attributed to various stakeholders" rather than a search for an objective reality (Guba & Lincoln, 1989, p. 237). According to qualitative researchers (Creswell, 2013; Guba & Lincoln, 1989), clarifying researcher bias and consistent researcher reflection, prolonged and persistent observations, and member checking are some of the important strategies for establishing credibility. This study outlined researcher bias and maintained researcher reflection through the use of a researcher journal. Prolonged and persistent observations were conducted in my five years of teaching and my school year long role as a formal researcher at this location.

The embedded nature of the researcher at the setting also facilitated member checking, sharing the data collection and analysis process with participants (Creswell, 2013). Using member checking allowed participants to more fully co-construct the study and added credibility because it increased the degree to which multiple points of view were present in the study and because it guarded against researcher bias (Guba & Lincoln, 1989). Member checking was carried out during the entire research process through informal conversations with student participants before and after class, formal conversations with administrators and parents, and especially through the sharing of documents that contained data points and preliminary analysis via focus group discussions and email exchanges with the student participants.

Finally, even though Guba and Lincoln (1989) do not favor triangulation because of its positivist connotations, Creswell (2013) still considers it an important part of establishing credibility or validity in qualitative research. In the proposed study, concurrent triangulation between qualitative and quantitative data points was used to credibly answer all three sets of research sub-questions. Answers to the first sub-question were triangulated between data from the video recordings, questionnaires, focus group interviews, and student artifact analysis. Answers to the second sub-question were triangulated between data from the video recordings, questionnaires, focus group interviews, student artifact analysis, pre and post unit tests, and the school wide, cumulative final chemistry exam. Answers to the third sub-question were triangulated between data from the video recordings, questionnaires, focus group interviews, and interest Likert surveys (See Appendix J for Research Design Matrix).

Transferability, the constructivist conception of generalizability, is very elusive according to Guba and Lincoln (1989). From a constructivist point of view, the context of any classroom setting is so complex that it is very difficult to suggest that what happens in one setting will transfer to another. A very extensive and rich description of the research setting and findings is required to support any attempt to identify similarities between settings and to attempt to transfer the findings from one setting to the other similar setting (Creswell, 2013; Guba & Lincolin, 1989). This research project provided a rich description of the setting and findings developed from many different data points, both qualitative and quantitative, within its ethnographic approach.

Dependability, parallel to reliability, describes the stability of the data or how easily it can be replicated. Confirmability, parallel to objectivity, is concerned with making sure that the data, analysis, and conclusions are rooted in the context of the setting and the participants' views rather than an invented portrayal by the researcher (Guba & Lincoln, 1989). Dependability and confirmability were simultaneously supported in this study through a very detailed explanation of the logic used to construct the overall methodology as well as the specific data collection methods and analyses. In addition, a very detailed presentation of the findings was undertaken. Through these measures, other researchers can trace all data and findings to their logical inception (Guba & Lincoln, 1989).

A more traditional conception of reliability was also supported in the study by several other factors and procedures. First, the reliability of the qualitative data was further enhanced by the transcription of the video recordings and audio recordings by the researcher himself (Creswell, 2013). Second, the reliability of the interest surveys was supported by the previously performed Rasch analysis conducted on the questionnaire by Schiefele et al. (1993) that served as the basis for the survey used in this study.

Third, the reliability of the rubric derived scores for the five student performance assessment artifacts (the three critical inquiry labs, the critical writing assignment, and the functional group model project) were supported by a procedure for determining inter-rater agreement or reliability by calculating Cohen's Kappa (Cohen, 1960). First, a peer collaborated with the researcher in establishing a coherent interpretation of the grading rubrics used to score each artifact (See Appendices V – X). Then, the researcher scored all the student artifacts and the peer scored at least 20% of each type of artifact: 20 of the 75 inquiry labs, 5 of the 25 writing assignments, and 10 of the 25 model projects. The separate scores of the researcher and the peer were then used to calculate a weighted Cohen's Kappa value for each type of artifact. Initially, the weighted Kappa value for the inquiry labs was only 0.518, which was determined to be unacceptable. Further collaboration between the researcher and peer and a rescoring of the inquiry labs resulted in a weighted Kappa of 0.809, which was determined to be an acceptable reliability for these rubric scores. Finally, the weighted Kappa for the writing assignments was 0.790, and the weighted Kappa for the model projects was 0.859, both of which were considered acceptable reliabilities.

Limitations

Even though this was not an experimental study, there were still several quantitative research limitations that could be described using Campbell and Stanley's (1963) explanations of issues in experimental educational research. The first issue concerned interaction of testing. The very act of surveying interest could have affected the interest levels of the participants. In a sense, it may have been interesting or annoying to be asked about one's interest, which could have increased or decreased students' perceptions of interest. Next, there was an issue of internal validity concerning a change in instrumentation. Even though the five critical performance assessments (CPAs) were all constructed to elicit student demonstration of critical scientific literacy (CSL), they were still five different assessments. This presented an issue in comparing the five CPAs for a statistically significant increase in CSL through the use of a time series regression. In addition, the lack of a fully constructed and reliably used rubric in the literature for assessing students' CSL within complex CPAs like the ones utilized in this study necessitated the creation of three different novel rubrics that had never been used before. The uses of these rubrics posed threats to the reliability and validity of the research, even though they were designed from and grounded in the literate, and were implemented through the use of a procedure for determining an adequate level of inter-rater reliability. Furthermore, while transferability is always an issue in social science research, the fact that the research occurred at a private school might complicate matters to a greater extent when making comparisons to public schools. On the other hand, there were many similarities between this private school setting and suburban public schools in terms of demographics and mindsets.

Another limitation of the study was the fact that even though I had been acting as a tempered radical for many years, taught inquiry labs for many years, and had conducted some pilot research into implementing a critical approach in my chemistry classes all prior to this study, I taught all four units for the first time during the study. This meant the units probably did not go as smoothly as they would have if they had been enacted several times before the time of the study. This could have had a detrimental effect on the development of student interest, CSL, and chemistry content knowledge. In addition, my own bias as a privileged, White male could have had a unfavorable effect on my enactment of diversity-sensitive, critical scientific education and my interpretations of multiple, diverse view points in the classroom. The hope is that my constant reflection through the use of a researcher journal and conversations with my colleagues and student participants minimized these limitations.

In many ways, the limitations of this study were inevitable and due to the novel, complex nature of the critical transformation of the chemistry curriculum at the setting, especially when the approach hoped to stimulate complex, critical though in students, and change student products from traditional multiple choice tests to critical performance assessments such as inquiry labs. Furthermore, some of these limitations were very minimal, like the issue of interaction of testing, while other limitations were minimized by procedures for determining inter-rater reliability, the thorough keeping of a researcher journal, the thorough and detailed description of procedures used in the study, and the grounding of the data collection methods in the literature.

In the next chapter, I introduce and ground the CCE curriculum developed and enacted for this study in the literature.

Chapter 4

DEVELOPING AND ENACTING CRITICAL CHEMISTRY CURRICULUM

As a “tempered radical” (Carlone et al., 2010), I balanced my desire to challenge my students to critically reflect upon their positions of privilege and my desire to develop in them the ability and aspiration to use their understanding of chemistry to make socially positive decisions outside the classroom with my school’s desire for me to largely follow a very traditional curriculum. Quite often this balancing act took the form of informal critical discussions of chemistry content and the nature of science as it relates to societal issues when the students asked questions in class that moved in these directions that were embedded in traditional lectures about chemistry content topics. However, for the purposes of this research, four critical transformations of the chemistry curriculum or units, containing a variety of activities and assignments, were formally created using context-based chemistry research, interest research in science, and critical science education research. These units were exemplars of *critical chemistry education* (CCE). They were integrated into the mainstream curriculum spread out over the school year. The first unit occurred in December, the second in March, the third in April, and the fourth in May. These four instances of CCE served as check in points where the continued development of students’ critical scientific literacy, chemistry content knowledge, and interest were gauged.

The four formal critical transformations were integrated into the mainstream curriculum to varying extents that can be described in relation to Banks’ (2010) typology of multicultural education integration, which serves as a great way to frame the integration of any critical approach. Banks’ typology consists of four levels. In the first level, the contributions approach, science teachers mention or include the contributions of scientists from diverse backgrounds to the fields of science. In the second level, the additive approach, science teachers include multiple perspectives in understanding the nature of science, diverse knowledge sources, and discuss how science and the power structure of society are connected, but do not fully integrate this into the mainstream, content-driven, science curricula by adapting these curricula. In the third level, the transformative approach, teachers fully integrate different perspectives on complex scientific issues by changing or transforming the mainstream curricula of the science disciplines. Finally, in the fourth level, the social action approach, teachers inspire students to use scientific content knowledge to improve their local communities and the world at large (as cited in Atwater, 2010).

The Curricular Transformations of CCE

Guided by the critical ethnographic approach to the research and a desire to enhance the transferability of the study, in this chapter, I describe each of the four CCE curricular transformations or units in great detail.

Critical Metal Unit

The first curricular transformation was a short unit that was built around an inquiry-based lab on metals and the activity series that took place over four one hour classroom periods on four days (See Appendices B and C for the unit map and materials). This short unit was integrated into a larger traditional unit on chemical reactions. This instance of CCE fell somewhere between Banks' (2010) additive and transformative approaches because cultural perspectives and critical discussions were fully integrated into the mainstream chemistry content of the embedded unit on the properties of metals, single replacement reactions, and the activity series, but did not fully transform the whole, traditional unit on chemical reactions.

Overall, this critical unit attempted to balance the micro and macro objectives of classroom critical pedagogy (McLaren, 2009). The micro critical objectives of this unit were for students to apply their knowledge of metals and single replacement reactions within the real life context of using metals for construction purposes to discover the activity series for metal reactivity in a student-created inquiry style investigation. This contextualization of science content is paramount to good critical pedagogy (Gilbert, 2013; Kincheloe, 2005). The macro critical objectives of the unit were the discussion of the historical context of metallurgy in ancient and modern cultures, a discussion of gender inequality within the context of science and being a scientist, and the analysis of steel manufacturing as it relates to the modern day economies of the U.S. and developing countries. Connecting science to global economic issues, gender issues in science, and cultural/historical contexts are important to creating a critically minded, student-centered classroom environment that respects and welcomes all students into the science conversation (Kincheloe, 2005).

Before the students began work on their inquiry labs, a class period and a homework assignment were used to ground the chemistry content of the lab in a historical/cultural context. A video on the metallurgy of the ancient Native American culture of the Mississippi Tribe was viewed and discussed in terms of chemistry content, diverse perspectives on the nature of science in relation to WMS and ancient scientific knowledge, and issues of gender equality in the field of science (https://www.youtube.com/watch?v=AVtuxtIP4g4). Students discussed answers to questions such as: "How did the lead scientist describe the knowledge of the Mississippian Indians?" "How were the young female scientist and older male scientist positioned in the video?" The homework assignment for that night asked students to learn more about the history of metallurgy and use of metals in the arts and other artifacts of an ancient or modern culture they belonged to or felt connected to. They interviewed family members or members of their community and/or used Wikipedia to learn this information.

The inquiry-style investigation the students conducted addressed connections between engineering and science content and inquiry as outlined by the Next Generation Science Standards (NGSS) (NGSS Lead States, 2013a). The investigation guidelines led students to predict which of a series of metals would make the best material for the construction of a bridge in a moist environment if corrosion were the only issue of concern for the construction. Students generated hypotheses, created their own procedures to test their hypotheses, and analyzed and interpreted data to support their conclusions. In this way, the students discovered a partial order of the metals on the activity series as they gathered evidence to suggest which metal is the least likely to corrode out of a sample of several different metals. The students produced a written lab report that connected their results to the activity series of metals. Their lab report guidelines asked them to discuss their conclusions in terms of a critical question set that prompted them to consider the importance of alloys in the history of civilization, and in particular, steel's importance to modern day construction and the global economy. Students answered questions such as: "Which country produces the most steel?" "Which country uses the most steel?" "Where is the U.S. on these lists?" "What are the implications of this for the global economy and the future of U.S. jobs?" "What are the implications of this for U.S. science education?"

On the final day of this unit, the students informally presented the conclusions from their lab reports and participated in scientific peer critique. To prepare for the presentations and peer critique, students were asked to use a guideline modified from the work of Herrenkohl and Guerra (1998, as cited in Duschl, 2008) to actively participate as a peer reviewing audience (See Appendix C). The students used the guideline to prepare questions to ask their classmates about their lab results. The guideline prompted students to think of questions they would use to ask their classmates for clarification and challenge their classmates' claims (Duschl, 2008). This experience helped establish a community of scientific practice in the classroom where knowledge was shared and co-constructed within the group through the scientific practices of argumentation and critique (Brickhouse, 2001).

In addition, during this final day of the unit, students discussed their answers to their lab report critical question sets in a two-part process. First, students worked in small groups of about three students to share and summarize their answers to just two or three of the questions in the set on a piece of poster paper. Next, the students shared their poster papers with the whole class, which prompted a deeper and more meaningful whole class discussion of all the questions as they related to the chemistry content of the lab. Again, this activity was orchestrated to establish a community of practice where students could share and co-construct their understanding.

The creative, critical analysis and meaning making skills developed by the process of this contextualized critical science lab are in line with what critical pedagogues and other progressive educators (Kincheloe, 2005; Wagner, 2010, 2012) claim students need to navigate the ever-evolving information age we live in. More specifically, the student-created, critical inquiry investigations were "authentic assessments" in that they were realistic to the practice of science, involved judgment and innovation, and asked students to "do" the discipline of science by requiring the use of a repertoire of complex skills (Wiggins, 1998, as cited in Janesick, 2007). Furthermore, this critical lab experience extended many of the goals outlined in the NGSS (NGSS Lead States, 2013a) and the *Framework for k-12 Science Education* (NRC, 2012) in that it focused on the application of content, developed inquiry-based problem solving skills, emphasized the depth of knowledge over breadth of factual knowledge, and allowed for student interest to initiate and/or guide the direction of inquiry as well as considered diverse sources of scientific knowledge.

Critical Kinetics Unit

Banks (2010) would describe this second critical unit as completely transformative. The entire six-day unit was created from a student-centered, CCE approach that integrated chemistry content with two critical assignments (See Appendices D and E for the unit map and materials). The micro objectives of the unit were for students to enrich their understanding of chemical kinetics and collision theory by developing student-created investigations of the factors that could potentially affect reaction rate. The critical macro objectives of the unit were for all students to take on the persona of scientific experts, opening the door for all students to comfortably develop a scientific identity (Brickhouse, 2001), the discussion of science's potential to benefit some people while marginalizing or oppressing others (Calabrese Barton, 2001; Gilbert, 2013), and the critical analysis of the chemistry content connected to new energy sources and the future of the environment discussed in newspaper articles (Oliveras et al., 2014).

On the first day of the unit, students were confronted with the phenomenon of rates of chemical reactions through a demonstration of a slow chemical reaction and a fast chemical reaction. They were encouraged to think about and discuss why there could be different speeds of reaction. After this engaging activity, students were exposed to some of the terminology related to the phenomenon through a brief lecture that explained kinetics and some of the finer points of collision theory.

At this point, an inquiry-based lab, very similar to the one enacted in the first curricular transformation, was undertaken. However, there were several key differences. In the first lab, students were essentially given both the independent and dependent variable they were to study.

In this Critical Kinetics lab, students were only given the dependent variable: reaction rate. With the help of the teacher, students brainstormed possible independent variables, such as temperature and reactant concentration, that could possibly affect reaction rate and then chose which one in particular they wanted to investigate with their lab partner. This process set the stage for students to become the classroom scientific expert for their particular variable.

After another teacher demonstration of some of the lab equipment students could use to develop their investigations, like temperature probes and barometric pressure probes, students proceeded through the process of the lab in a similar way to the one described for the metal activity series. In this case, though, students generated Power Point presentations for final products that grounded their results in collision theory. Also included in this process was another critical question set that asked students to consider questions such as: "Who decides or who gets to decide if what you produced was scientific knowledge?" "Who in particular could profit from your knowledge production?" "Does scientific knowledge always benefit people?" "Could the scientific process you used in this assignment exclude certain people?"

While the classroom discussion of the critical question sets on the last day of the lab experience proceeded in the same manner as the last critical transformation, the presentations for this lab were much more formal. The students presented the Power Point slides of their results and conclusions as the scientific experts of that knowledge base. So in this case, not only did the students in the audience ask them questions to help clarify the claims made by their peers, they also took notes on the presentations to help them prepare for the unit test. The teacher did not contribute to the discussion of these topics. So, for example, the students' meaningful understanding of how temperature affects reaction rate as well as how collision theory explains this phenomenon was constructed as a class with one lab group acting as the scientific experts.

While the students were given time to prepare their Power Point presentations with their lab partners over the course of several nights of homework before the last day of the unit, the students embarked on the second critical assignment of the unit in class. According to Freire (1998), literacy must exceed being able to read words on a page. In fact, he believes that students must be literate beyond being able to read for understanding in different disciplines. He believes that students must attain a level of literacy where they are capable of reading between the lines of any text, uncovering the hidden agendas of the authors. This level of critical literacy is a crucial component of scientific literacy (Oliveras et al., 2014). Students must be able to read, understand, evaluate, and form a critical stance on scientific content presented in the media like newspaper articles. For these reasons, a critical science reading activity was implemented during this unit. In the critical reading activity, students read two articles about hydrogen fuel cell cars (Chang, 2014; Soper, 2015).

This activity lasted two days and had one night of homework. Students critically reflected on the two articles using an adaptation of the *elements of science critical reading* posed by Oliveras et al. (2013). In their framework, students engage with science content newspaper articles by following six steps: (1) Identify the main ideas of the text, (2) Identify the writer's purpose, (3) Identify the writer's assumptions and viewpoints, (4) Formulate a scientific question which the writer answers in the article, (5) Identify data and evidence given in the text, and (6) Draw conclusions based on the evidence. The addition of two questions to step (3) and step (6) that critical pedagogues identify as important to a critical reading of the world (Calabrese Barton, 2001; Freire; 1998; Kincheloe, 2005) were added.

In step (3), these questions were added: "Whose interests do the writer's viewpoints serve?" "Whose interests do the writer's viewpoints possibly hurt or even oppress? How or in what ways?", and in step (6), "Whose interests do your conclusions support? In other words, who benefits from your conclusions?" and "Whose interests do your conclusions possibly hurt or even oppress? How or in what ways?" were added. Similarly to the design of the activities described by Oliveras et al. (2013), the students used the elements of science critical reading during three different stages of reading the two articles: *before reading, during reading,* and *after reading*.

On the first day, in the *before reading* segment of the activity, students were prompted to individually reflect on questions that asked them to predict answers to the first three elements for each article based on having read the title of the article and having looked at the graphics of the article. For example, students were asked, "Why are we reading this article in chemistry class?" "What do you think the article is about?" "What opinion do you think the author will have about the topic?" A full classroom discussion opened and students shared some of their predictions.

For the *during reading* phase, students read the articles in class in small groups while they collectively answered question sets related to elements 1 – 5 for each article. The question set contained questions like: "Who wrote this article?" "Why must he or she have written it?" "Who benefits from the viewpoints held in this article?" "What assumptions does the writer make in the text? Are they justifiable?" "Identify the evidence the author uses to support his or her claims."

On the second day, students worked in different small groups to generate summaries for a certain section of the question set on poster paper that they had worked on the day before. In this way, a student could share the thoughts of his or her previous group with the new group to enhance collaboration and deepen the level of discourse. When the poster papers were completed, there was a whole class share out and full discussion of all the questions in the set.

Finally, students started working individually in class and finished for homework their own written stance and conclusions on hydrogen fuel cell cars to complete the *after reading* phase. Students were provided with a guide that was derived from the rubric used in the paper by Oliveras et al. (2013) to gauge the level of critical thought. The guide contained statements such as: "Clearly identify in your own words the writer's viewpoint," "Clearly identify the evidence the writer uses to support his or her viewpoint," "Clearly distinguish between scientifically collected evidence and opinions in the articles in your arguments," "Support your claims with evidence from multiple credible sources," and "Clearly identify at least one group of people your conclusions benefit and one group of people your conclusions hurt." In addition, students were prompted to choose to adopt either stance in the articles as their own or develop and alternative view. Furthermore, they were prompted to defend their stance by arguing agreements or disagreements with the information or evidence in the articles by citing at least two other credible sources from the Internet (students were assisted in determining credible Internet sites). This writing assignment addressed the final, sixth element of science critical reading.

Critical Organic Unit

The third critical chemistry unit would also be described as transformative (Banks, 2010). It was developed from a feminist-guided, critical science education perspective. First of all, the unit was meant to introduce organic chemistry in a critically and socially relevant way. The three main goals of the unit were for students to: (1) develop an understanding of the socially created, value-laden, and male-biased nature of WMS, (2) use scientific modeling and participate in scientific argumentation and critique, and (3) classify, organize, and model simple organic compounds based on different functional groups (See Appendices F and G for the unit map and materials).

Traditionally, high school organic chemistry focuses on nomenclature, a rather dull aspect of the exciting world of organic chemistry. To frame the important content of organic chemistry and to discuss a historical issue in science that is explicitly full of gender tensions, the real-world context of the history of the creation of the birth control pill was used in this unit. Grounding scientific content and classroom activities in interest-stimulating, real-world scientific contexts has been noted to be an important aspect of feminist science pedagogy (Brickhouse, 2001; Parker & Rennie, 2002). To do this, the unit started with students reading a chapter called "The Pill" from the book *Napoleon's Buttons: 17 Molecules That Changed History* by Penny Le Couteur and Jay Burreson (2003) that documents the history and organic chemistry of the birth control pill.

Briefly, the chapter begins by framing the issue of birth control in the Western world from the turn of the 20th century to the present day and the specific social impact of the pill. Then it discusses some historical, mystical or superstitious oral contraceptives. Next, the chapter begins to tackle Western science's progression to the pill from steroids to male and female hormones. It shows visuals of the structures of these complex molecules and breaks down the organic functional groups that are so important to the identities of specific steroids. After some of the chemistry is outlined, the specific contributions of a man named Russell Marker are outlined and discussed in terms of the history and social dynamics of the 1940s and 50s. Marker's contribution sets the stage for the authors to examine gender tensions and how scientific work towards a fertility drug was turned into an oral contraceptive for women. At this point, the interactions of female activists such as Margaret Sanger and Katherine McCormick (also a scientist) with male scientists such as Gregory Pincus and John Rock are discussed. Finally, the chapter ends with a discussion of the difficulty of the science behind a male version of the pill (Le Couteur & Burreson, 2003).

A reading guideline was provided for the students to facilitate their reading of the chapter for homework. The reading guideline was modified from the one used in the critical kinetics unit that was guided by the work of Oliveras et al. (2013). The reading guideline asked students to note who the authors were, what the main purpose of the chapter was, and what the main purpose of each subsection of the chapter was. Furthermore, the guideline asked students to consider and note questions they had about the scientific content and the history presented in the chapter. It also asked them to consider if anything was missing from the chapter or glossed over in terms of the history. In other words, it asked students to consider if multiple perspectives were being represented in the chapter.

After the chapter was read for homework, in class the students discussed what they noted in their individual reading guidelines in small groups to help them remember what they read and focus their attention. After this focusing activity was completed, a small group exploration of a question set aimed at explicitly engaging students in a discussion of the value-laden, and male biased nature of science was undertaken. Explicitly addressing this issue in the science classroom is important according to Calabrese Barton (1997) who suggests that this must be done in a way where students can reflect on their past experiences and not feel like the teacher is forcing his or her perspective on the students.

Each small group explored the same initial set of questions that asked students to connect their past experiences to issues of gender equality using the book as a starting point. The initial question set contained the following questions: "Who determined or influenced the research agenda described in the chapter, men, women, or both to varying degrees?" "Who do you think should have influenced the research agenda described in the chapter?" "Who do you think usually determines the research agendas of science, men or women?" "Do you know of any other examples of research agendas?" "How are the women and men portrayed in the chapter?" "Do you think stories in science portray women and men differently? How so?" "Do you think gender defines these portrayals? How so?" "Have you ever felt like your gender defined you in science class? How so? Are you comfortable sharing a personal experience (without sharing specific names)?"

In addition, each small group received a second set of questions during this small group activity that was unique to each group. The second question set related to different aspects of the chapter: (1) the mystical oral contraceptives of the past presented in the chapter, (2) the motives of the scientists discussed in the chapter and the social relevance of the pill, and (3) the discussion of oral contraceptives for males.

As the small groups tackled their question sets, they summarized their discussions using poster paper. When this work was done, the small groups shared their poster papers with the whole class, which led to a full class discussion facilitated by the teacher that attempted to elicit additional student questions about gender and science in the hopes of creating an even more student-centered environment. Some the questions that prompted this portion of the activity were: "What are some of the positive and negative, perhaps oppressive results of the research presented in the chapter?" "Overall, was the work to produce a contraceptive pill for females positive or negative (oppressive)? Why or why not?" and "What are some other questions this chapter and discussion raise for you in terms of gender and science?"

The next three days of the unit tackled the organic chemistry content that was presented in the book chapter, “The Pill,” and focused on developing students’ scientific practice skill sets. First, the students identified the organic functional groups located on the molecules depicted in the chapter and read about the related chemistry in their textbooks. Students also participated in Q and A sessions with their teacher about the content they were reading and listened to the teacher lecture about the nature of organic chemistry functional groups and their structural formulas. These lectures also focused on the many real-world applications of organic chemistry. At the end of the third day of the unit, students were presented with the task of modeling a specific functional group with a partner that was important to one or more of the organic molecules discussed in the chapter on the pill.

The projects were intended to be creative outlets for the students where they could personalize a *signature artifact* they created by connecting their outside the classroom practices, knowledge bases, and interests with the scientific content and practices of the classroom (Calabrese Barton et al., 2008). Providing students with the opportunity to create a signature artifact is one of the ways Calabrese Barton and colleagues suggest teachers can open up a *hybrid space* for girls and other students who are potentially turned off by male-biased WMS to explore scientific content from diverse perspectives and practices. Furthermore, in presenting their functional group projects to the class, the students once again took on the identity of scientific expert, contributing to the shared knowledge of the classroom (Brickhouse, 2001).

In addition to modeling and presenting their understanding of their functional group, an important scientific practice for students to participate in (NRC, 2012), the students participated in an activity that required them to critique the work of their classmates and revise their own models according to peer feedback on the last day of the unit. Again, this established a community of scientific practice in the classroom where knowledge was shared and co-constructed within the group through scientific practices such as modeling, argumentation, and critique (Brickhouse, 2001). In preparation for the activity, students were asked to use another guideline, similar to the ones used for the first two curricular transformations, to actively participate as a peer reviewing audience.

Critical Acid/Base Unit

The fourth instance of CCE would fall between Banks' transformative approach and the social action approach because it completely adapted an entire mainstream chemistry unit on acids and bases to include fully integrated reflections on different cultural perspectives, debates about global environmental issues, and discussions on the moral responsibilities of the media and pharmaceutical companies as these issues relate to the content of acid/base chemistry that encouraged students to consider if not attempt some level of social action. The unit spanned thirteen one-hour class periods on thirteen days (See Appendices H and I for the unit map and materials). Due to the length of the unit, a more holistic summary is presented here, rather than a day-by-day account.

The micro critical objectives of this unit were for students to understand the theoretical foundations of acid/base chemistry, pH, neutralization, and reaction rates within the real life contexts of acid rain, environmental pollution, and heartburn remedies, and to be able to apply this content in a student-created inquiry style investigation as well. The macro critical objectives of this unit were the analysis of propaganda in advertisements (Kincheloe, 2005; Mutegi, 2011), the discussion of acid rain as it relates to industry and governmental policy, the discussion of the implications of pharmaceutical companies massive investment of capital in the production and advertisement of over-the-counter heartburn remedies on equitable, global healthcare, wellbeing, and food consumption (Calabrese Barton, 2001; Gilbert, 2013). Indeed, this unit added political consideration to the chemistry content, without replacing the importance of contextualized content, which is the important base for critical analysis to work from in the classroom (Kincheloe, 2005, 2007). In this way, rigorous academics were maintained, while students developed political insight and a critical consciousness that could potentially lead to positive social action (Kincheloe, 2005). In addition, the inclusion of local, cultural knowledge (Kincheloe, 2005; NRC, 2012) or "cultural funds of knowledge" (Fraser-Abder, Doria, Yang, & De Jesus, 2010) in the discussion of heartburn remedies and other forms of medicine was used to challenge the hegemony of WMS (Calabrese Barton, 2001), and drew students traditionally marginalized by WMS into the conversation. This empowered all the students of the classroom because it enlightened the dominant group students to new knowledge about the world, knowledge they had never considered before, and because it validated the knowledge diverse students had all along (Kincheloe, 2007).

The inquiry-style investigation the students conducted and then presented as part of this critical unit was similar to the two in the first two critical transformations. The investigation guideline prompted students to ask their own questions about over-the-counter and cultural home remedies for heartburn. It asked them to develop their own scientifically based definition of an effective heartburn remedy within the framework of the chemistry concepts of reaction rate, pH, and acid/base neutralization reactions and the biology of the human digestive system. In this way students determined their own independent variable and dependent variable to investigate, which was even more student-centered than the first two inquiry labs. The rest of the lab experience progressed much like the first two and on the final day the students discussed their results in term of critical questions such as: "Who benefits from your conclusions?" and "Who could possibly be hurt or oppressed by your conclusions?" Moreover, on the day of their presentations, the students discussed the implications of their results in terms of a broader societal context related to healthcare, nutrition, pharmaceutical companies, and the advertising industry.

The purpose of the inquiry lab was not necessarily for students to learn new chemistry content, nor was it for them to decide if a cultural, home remedy is better or worse than a WMS-produced over-the-counter remedy. The purpose was for them to have a real world context to apply their chemistry content knowledge and for them to develop scientific inquiry skills that they could use to generate scientifically based knowledge. In this way, the inquiry labs were very similar to what Fusco and Calabrese Barton (2001) would call a *critical performance assessment*. For instance, this assessment contained a representation of multiple worldviews by including cultural home remedies for heartburn and situated content in a real-life contextual problem. In addition, it asked students to interact with their world through rigorous scientific inquiry rather than passively absorb knowledge, and it was simultaneously the production of scientific knowledge that could be used to make critical decisions as a citizen of our global society and the production of an assessment.

In the next three chapters, the findings from the enactment of the CCE curriculum are presented as three separate research papers. In chapter five, students' development of CSL is investigated. In chapter six, chemistry content knowledge is examined. And in chapter seven, the potential for CCE to enhance students' perceptions of chemistry is studied.

Chapter 5

FINDINGS

CRITICAL SCIENTIFIC LITERACY IN A SUBURBAN CHEMISTRY CLASSROOM

Abstract

This study documents how a group of 25 students in a suburban, privileged, private school setting, the vast majority from dominant cultural backgrounds, engaged with critical chemistry education (CCE). CCE contextualizes chemistry education in socially relevant issues and engages students in a critical analysis of the intersections between chemistry and society. More specifically, students' demonstration and development of critical scientific literacy (CSL) is gauged. CSL elaborates on the recent definition of scientific literacy by the National Research Council (2012) by including an ability to use the content and practices of science to critically analyze the connections between Western modern science (WMS) and socially relevant issues, and ability to positively act upon these analyses. Qualitative data from classroom video transcripts, questionnaires, and focus group interviews document that students' developed and demonstrated CSL in three specific ways in the classroom: (1) the ability to critically analyze the products of WMS, (2) the integration of WMS with diverse knowledge bases in their thinking, and (3) a meaningful understanding of inequality in WMS. Quantitative data from five rubric-scored, critical performance assessments suggest students' overall CSL increased to some degree over the course of the year. However, data also reveal weaknesses in the level of CSL demonstrated by the students. Namely, students were not documented to have actually used what they learned in chemistry class through CCE to act outside of class.

Introduction

Interest groups such as the National Research Council (NRC), the American Association for the Advancement of Science (AAAS), and the National Science Teachers Association (NSTA) have been discussing the concept of scientific literacy for decades (DeBoer, 2000). The term scientific literacy has been around since Paul Hurd first defined it in 1958 as essentially being a person's understanding of science as a cultural force, its content, and its practical use to improve technology and society. Since then it has gone through many iterations (DeBoer, 1991, 2000). Most recently, the *Framework for K-12 Science Education* (NRC, 2012) and the *Next*

Generation Science Standards (NGSS Lead States, 2013a) have suggested that a scientifically literate citizen must understand core scientific ideas as they relate to the nature and practices of science and engineering so that they can appreciate and knowledgeably participate in a democratic society that has to cope with climate change, health care issues, and other global science related issues. They also make it clear that *all* students, from all types of backgrounds, have an equal ability and right to attain this level of scientific literacy.

At the same time, some researchers have been critical of how interest groups have defined scientific literacy and critical of the weakness in these groups' plans for reaching high levels of scientific literacy for all students. For example, Eisenhart, Finkel, and Marion (1996) noted that for people to be able to truly participate in our democratic society through meaningful understandings of scientifically based, socially relevant issues, they require more than scientific knowledge alone. They must "understand and apply knowledge about the nature and value of science," (p. 283). They elaborated:

> Minimally then, using science in socially responsible ways would seem to entail: (a) understanding how science-related actions impact the individuals who engage in them; (b) understanding the impact of decisions on others, the environment, and the future; (c) understanding the relevant science content and methods; and (d) understanding the advantages and the limitations of a scientific approach. (pp. 283-284)

More recently, Birmingham and Calabrese Barton (2014) have expressed some reservations about the scientific literacy explored in the NGSS. They claim, "[w]hile students may be encouraged to be active learners in the pursuit of scientific thinking and practice [within the NGSS], they are positioned as passive with respect to acting on that knowledge to engage with relevant real world problems," (p. 311). They note that "educated action" is missing from the NGSS. In other words, the ability to actually use scientific knowledge and practices to "inform democratically responsible actions" is absent from the NGSS, (p. 287).

Moreover, the NRC and NGSS still largely conceive of a scientific literacy defined from the subjective perspective of Western-dominated, modern science (Lee, 1997). According to Lee, this is the very institution that has marginalized women and diverse ethnic and cultural groups. Therefore, it is paramount to deconstruct this traditional definition of scientific literacy and reconstruct it to include diverse perspectives on what it means to know and practice science that may provide marginalized students with access points to learning science, achieving scientific literacy for *all*.

These critiques of scientific literacy led to my development and investigation of a yearlong enactment of *critical chemistry education* (CCE) in two high school chemistry classes. CCE is based in a more general critical science education (CSE). According to Fusco and Calabrese Barton (2001), CSE "questions… the nature of science and knowing science, the relationship between science and society, and the implications these belief structures have for how we view science as a school subject" (p. 338). Essentially, CSE can be conceived of as an umbrella term for unique constructs such as multicultural science education (MSE) (Atwater, 1993, 1995), feminist-framed science education (Brickhouse, 2001), and critical science reading and writing (Oliveras, Marquez, & Sanmarti, 2013, 2014).

The goal of CSE, as conceived of for this paper, is the development of a *critical scientific literacy* (CSL) that, in addition to including an appropriate level of scientific content understanding, helps students to use scientific knowledge and practices to more fully participate in our democratic society, making decisions that could improve the welfare of the world. Furthermore, CSL addresses the concerns of Lee (1997) in that it entails an understanding that Western modern science (WMS) is only one of many diverse ways of knowing and understanding the world. Finally, CSL potentially answers Banks' (2004) call for a critically engaged level of democratic citizenship in today's culturally interconnected globe;

> The world's greatest problems do not result from people being unable to read and write. They result from people in the world – from different cultures, races, religions, and nations – being unable to get along and to work together to solve the world's intractable problems such as global warming, the HIV/AIDS epidemic, poverty, racism, sexism, and war. (p. 298)

The setting of the two high school chemistry classes that participated in the enactment of CCE developed for this study was a New England private school, consisting of a student body largely composed of White students from highly resourced, dominant cultural backgrounds. I chose this setting because I had worked there for five years, and felt that while the traditional chemistry curriculum I had been teaching prepared students who were interested in science to move to the next level, it was not preparing all my students to capably use chemistry knowledge to critically examine relevant, "real world" issues. In other words, I was not developing all my students' CSL. In addition, I wanted to enhance the student-centered nature of the chemistry curriculum at this setting by better incorporating ways to include the perspectives and interests of girls and the small number of ethnically and culturally diverse students who attend this school. I knew these efforts would improve the inclusivity of my chemistry classroom for any student who may not have been previously interested in or comfortable with science class. Finally, I wanted to challenge and broaden the perspectives of the dominant cultural majority at this setting. The work of Trueba (1999) elaborates why this is also so important. He writes educators must "accelerat[e] the conscientization of the oppressed and the oppressors [and that] without this reflective awareness of the rights and obligations of humans, there is no way to conceptualize empowerment, equity, and a struggle for liberation" (p. 593). In other words, not only should students from diverse populations be aware of their oppression, students from the dominant cultural group must be aware that at any moment their actions and their thinking could be oppressing other groups. Furthermore, their awareness and acceptance of varying and diverse sources of knowledge might help them recognize and promote outside-the-box solutions to some of the world's scientifically grounded problems like energy usage (Kincheloe, 2005).

The purpose of this study is to provide insight into how students at this setting, working within the context of a rigorous high school chemistry class engaged with and reacted to CCE as well as to document the specific ways CSL was attained by these students. The research question that guided this study was: How and to what extent do students develop and demonstrate critical scientific literacy (CSL) within critical chemistry education (CCE)?

Theoretical Framework

Critical Theory and Critical Pedagogy

Critical pedagogy can be traced back to the development of critical theory in post World War I Germany in what is referred to as the Frankfurt School (Giroux, 2009; Kincheloe, 2005). While there is no single, accepted critical theory framework, this school established some general principles in the 1920's and 30's that permeate most conceptions of critical theory today (Giroux, 2009). In response to shifts in the practice of capitalism and its growing strength as the universal economic system, these philosophers explored and reinterpreted traditional Marxist sociological thought and the psychological theories of Freud, among other social science and philosophical frameworks, to analyze and critique the growing global "cultural superstructure" rife with power stratification, hegemony, and implicit control over knowledge production, transmission, and most importantly, validity (p. 29). Fundamentally, in their struggle for justice, critical theorists challenge the objective neutrality of a positivist conception of reality, exposing underlying social dynamics, and acknowledge the value-laden and historically routed interests of the power structures of society (Giroux, 2009). Indeed, Giroux claims, "critical thought becomes the precondition for human freedom" (p. 37).

A critical pedagogy, derived from critical theory, requires all participants in the education process, students, teachers, parents, administrators, and members of academia, to be more introspective of what seems commonplace in all facets of school to see how it could be further interpreted (Christensen & Aldridge, 2013; Kincheloe, 2005). This requires searching out the dialectics or contradictions of life that are manifested in the tension of opposites (Christensen & Aldridge, 2013, McLaren, 2009). For example, a dialectic can be found in the tension created by teaching the content curriculum of chemistry class while also unintentionally teaching the "hidden curriculum" of school (Kurth, Anderson, & Palincsar, 2002) through student/teacher and student/student interactions governed by social norms that maintain the existing power structure of society.

In general, critical pedagogy "cultivates a rigorous, intellectual ability to acquire, analyze and produce both self-knowledge and social knowledge, [and it results in] individuals [who are] equipped to participate in the democratic process as committed and informed citizens" (Kincheloe, 2007, p.24). Specifically outlined by Kincheloe (2005), critical pedagogy is grounded in justice and equality, which makes it inherently political and dedicated to the alleviation of human suffering. It teaches students to read for subtext (revealing dominate ideologies), challenges students to engage with their teachers in a critical exploration of the world, and cultivates intellect through analysis and the rejection of fact memorization. Finally, critical pedagogy accounts for making adjustments to the cognitive and affective needs of individual students based on their initial skill sets and their cultural and social backgrounds.

Teachers are empowered in a critical pedagogy framework. They are not "infantiliz[ed]" by standardized lessons, curricula, and tests, or by administrators (Kincheloe, 2005, p.19). They are acknowledged as the position of authority in the classroom, but at the same time are not authoritarian or believed to be the soul suppliers of knowledge. They use their position to support students by being in tune with their needs, and to challenge students to see multiple perspectives, uncovering hidden features of society (Freire, 1998; Kincheloe, 2005). Furthermore, teachers who believe in critical pedagogy do not impose their middleclass norms of communication and values on diverse students. They relinquish control of discussion and debate to their students, allowing for diverse modes of communication to breathe (hooks, 2009). Practices like these give students the freedom to develop their own *critical consciousness* (Kincheloe, 2005).

The ultimate goal of critical pedagogy is to support the development of a critical consciousness in all students. A critical consciousness requires the realization that there is a subtext to all human endeavors and interactions, and the uncovering of the contradictions buried within a reality constructed by the dominant culture. In other words, it is a metacognitive awareness of one's position in the power structure of society, which is situated in historical and cultural contexts and maintained by the psychosocial and economic forces of the dominant culture. It is also an awareness of the dominant culture's control over knowledge production and transmission. Moreover, a critical consciousness leads one to empathize with the struggles of oppressed others, resulting in social action and the eventual transformation of the world (Freire, 2000; Kincheloe, 2005).

Critical Science Education and Critical Chemistry Education

Prevailing positivist methods in the practice of Western Modern Science (WMS) (Quigley, 2009) isolate the objects of study, stripping them of their surrounding context in an attempt to reach some *object*ive truth, separate from human existence (Fusco & Calabrese Barton, 2001). This allows those with power and resources to use WMS to control the perceived validity of all knowledge (Gilbert, 2013; Giroux, 2009; Kincheloe, 2005). Furthermore, research in WMS is driven by capitalism. Corporation's hunger for profit "influences the direction and products of science" (Calabrese Barton, 2001, p.851). A WMS guided by capitalism and the bottom line does not necessarily advance the overall wellbeing of society. It only benefits the people who can afford to reap the rewards of what advances are made (Calabrese Barton, 2001). Therefore, WMS oppresses diverse groups who do not have access to the controlled practice of WMS or access to the benefits of WMS advancements (Calabrese Barton, 2001).

A highly competitive globalized capitalist system ensures that nations use scientific knowledge to accumulate capital at all cost. This results in the commodification of science teaching and learning and the commodification of the students the system hopes will produce future scientific gains for profit (Gilbert, 2013). In other words, national interests to improve science education are for maintaining the dominant group's control, rather than for improving the lives of the students in the classrooms or the overall environment of the world. Consequently, this actually leads to the stratification of society to an even greater extent (Gilbert, 2013).

Rarely are the social dynamics of WMS mentioned, analyzed, or discussed in science class because the curriculum is driven by the memorization of the "objective" facts produced by WMS. Fundamentally, a critical science education brings these factors to the forefront (Calabrese Barton, 2001; Dalke & Franklin n.d.; Gilbert; 2013; Ramesh & Patel, 2013).

Students must learn to ask questions like: What is important scientific knowledge? Who does it benefit? Who does it oppress, and for what purposes (Kincheloe, 2005; Calabrese Barton, 2001)? Finally, Fusco and Calabrese Barton (2001) write that a critical science education "questions… the nature of science and knowing science, the relationship between science and society, and the implications these belief structures have for how we view science as a school subject" (p. 338).

Some researchers (Dalke & Franklin, n.d.; Harding, 1986; Ramesh & Patel, 2013) suggest that a critical analysis of WMS can and should be carried out in the classroom by the very skills scientists use to analyze the natural world and that science teachers hope to develop in their students. They claim that not only should students learn to generate and test hypotheses about variables that affect natural phenomena through the rigorous collection, analysis, and interpretation of evidence, students should follow this same process to critique the underlying social mechanisms of WMS. According to Ramesh and Patel, this is the best way for students to understand their lives in ways related to WMS and for them to develop a critical consciousness. Moreover, critical pedagogues and progressive educators alike (Kincheloe, 2005; Wagner, 2010, 2012) claim students need the creativity and problem solving skills that can be developed by learning science through the process of inquiry to navigate the ever-evolving information age we live in.

Ultimately, this study is framed by an *inquiry-guided critical chemistry education* (CCE). Within an inquiry-guided CCE framework, inquiry-based lab work and other activities are used to critically examine the intersections between chemistry content and the global capitalist super culture. Inquiry-guided, CCE motivates students to critique their positions as producers and consumers within the global capitalist culture, helps them to recognize both the positive and oppressive nature of science's role in society, and opens their minds to different perspectives on the nature of science and diverse cultural ways of knowing and communicating. The *critical performance assessments* (Fusco & Calabrese Barton, 2001) used within an inquiry-guided, CCE require students to analyze multiple worldviews, to interact with their world through rigorous scientific inquiry rather than passively absorb knowledge, and to produce their own chemistry knowledge based on local needs. This, in effect, takes the performance expectations of the NGSS and adds a critical component.

The goal of an inquiry-guided, CCE is the development of *critical scientific literacy* (CSL). For this research, I defined CSL as an elaboration on the NRC's definition of scientific literacy consisting of three parts. Necessarily, CSL demands: (1) understanding core scientific ideas and (2) the ability to participate in the practices of science and engineering (NRC, 2012). However, CSL also entails: (3) the use of the content and practices of science to ultimately produce scientifically based knowledge that can be used to more meaningfully understand real-world, socially relevant issues as they relate to science. Examples of socially relevant issues include, but are not limited to, appreciating multiple perspectives on scientific knowledge, understanding White, Western, male bias in science, and considering how our choices as consumers affect the environment and people of the world. In addition, this third component of CSL entails students' ability to critique the nature and products of WMS through their understanding of scientific content and scientific practices.

In this study, I used the construct of CCE to develop the curricular transformations of the traditional chemistry curriculum at the research setting, which consisted of four integrated units. In addition, the conception of CSL was used to measure student development during CCE.

Methodology

Critical Ethnography

Critical ethnography hopes to "reach a higher level of understanding of the historical, political, sociological, and economic factors supporting the abuse of power and oppression" (Trueba, 1999, p. 593). The CCE curricular transformations enacted at the research setting during this study constituted an applied, critical aspect of this study that hoped to empower all students (Basu & Calabrese Barton, 2007). Fundamentally, all students, regardless of cultural, ethnic, or socioeconomic background, must be empowered with critical understandings of their positions in society and how their thoughts and actions affect others so that society can be improved for everyone (Trueba, 1999).

Field Setting and Participants

The setting for this school year-long study was unique in terms of critical pedagogy research: an independent (private) all girls school in a suburb of New York City. However, the two sophomore chemistry classes ($N = 25$, mean age 15 years) where I enacted CCE also contained boys from the nearby all boys school. Until recently, the student body at this setting was quite homogeneous, mainly composed of the children from the highly resourced, White families that live in the town and surrounding area. However, around the time of this study, the school had been making a concerted effort to enhance the cultural, ethnic, and socioeconomic diversity of the student population. In part, this work resulted in 25% of the student body identifying themselves as students of color in 2012.

Role of Researcher

I had taught honors and regular level chemistry at this school for five years. In addition, I had coached tennis, worked with the robotics team, been an advisor, and was an active participant in the community service group. These experiences allowed me to spend many hours in and out of school with these students. Therefore, I did not need a "gatekeeper," someone who would allow me access to this setting (Creswell, 2013), as I was already "embedded," and had established comfort and trust with my participant students so that I could record a true emic, insider, perspective (Merriam, 2009). However, a critical lens also guided my efforts in this study, which I made clear to my student participants. They understood as we participated in CCE together that I was invested in challenging them and opening their minds to ideas they had never considered in science class before. Moreover, this critical lens helped me to interpret data from an etic, outsider, point of view (Merriam, 2009).

The Critical Curricular Transformations of CCE

I balanced mixing critical approaches into my mainstream curriculum throughout the year. Quite often this took the form of informal critical discussions of chemistry content and the nature of science as it relates to societal issues when the students asked questions in class that moved in these directions. For the purposes of this research, four critical transformations of the chemistry curriculum or units, containing a variety of activities and assignments, were formally created using critical science education research. The main goal of these curricular transformations was to empower students by improving their critical scientific literacy (CSL).

Overall, the activities and assignments of the four curricular transformations were framed by inquiry-style investigations that addressed connections between engineering, scientific content, and scientific practices such as inquiry and modeling as outlined by the NGSS (NGSS Lead States, 2013a). Assignment guidelines generally required students to make predictions, generate hypotheses, create procedures or models to test their hypotheses, and analyze and interpret data to support their own conclusions. In addition, the activities and assignments asked students to critically analyze how the content knowledge they produced for themselves related to socially relevant issues.

As a result, these assignments extended the performance expectations outlined in the NGSS (NGSS Lead States, 2013a) and the *Framework for k-12 Science Education* (NRC, 2012). Not only did they focus on the application of content, the development inquiry-based problem solving skills, emphasize the depth of knowledge over breadth of factual knowledge, and allow for student interest to initiate and/or guide the direction of inquiry, they also considered diverse sources of scientific knowledge, considered gender equality in the field of science, and asked students to use chemistry content knowledge to critically analyze their positions as producers and consumers in our free market, global economic system. In this way, the assignments were very similar to what Fusco and Calabrese Barton (2001) would call *critical performance assessments* (CPAs). A total of five CPAs were enacted within the four units of CCE. Essentially, the CPAs assessed all three aspects of CSL.

The units were exemplars of CCE. They were integrated into the mainstream curriculum spread out over the year. The first unit occurred in December, the second in March, the third in April, and the fourth in May. The four formal critical transformations were integrated into the mainstream curriculum to varying extents that can be described in relation to Banks' (2010) typology of multicultural education integration, which serves as a great way to frame the integration of any critical approach.

Critical metal unit. The first curricular transformation was a short unit on metals and the activity series (See Appendices B and C for the unit map and materials). This unit was integrated into a larger traditional unit on chemical reactions. This instance of CCE fell somewhere between Banks' (2010) additive and transformative approaches because diverse cultural perspectives and critical discussions were fully integrated into the mainstream chemistry content of the unit on the properties of metals, single replacement reactions, and the activity series, but did not fully transform the whole traditional unit on chemical reactions. The content objectives of this unit were for students to apply their knowledge of metals and single replacement reactions within the real life context of using metals for construction purposes to discover the activity series for metal reactivity in a student-created inquiry style investigation. The critical objectives of the unit were the discussion of the historical context of metallurgy in ancient and modern cultures, a discussion of gender equality within the context of science and being a scientist, and the analysis of steel manufacturing as it relates to the modern day economies of the U.S. and other countries.

Critical kinetics unit. Banks (2010) would describe this second critical unit as completely transformative. The entire unit was created from a student-centered, CCE approach that integrated chemistry content with two critical assignments (See Appendices D and E for the unit map and materials). The content objectives of the unit were for students to enrich their understanding of chemical kinetics and collision theory by developing student-created investigations of the factors that could potentially affect reaction rate. The critical objectives of the unit were for all students to take on the persona of scientific expert, opening the door for all students to comfortably develop a scientific identity (Brickhouse, 2001), the discussion of science's potential to benefit some people while marginalizing or oppressing others (Calabrese Barton, 2001; Gilbert, 2013), and the critical analysis of the chemistry content connected to new energy sources and the future of the environment discussed in newspaper articles (Oliveras et al., 2014).

Critical organic unit. The third critical unit would also be described as transformative (Banks, 2010). It was developed from a feminist-guided, critical science education (Brickhouse, 2001). First of all, the unit was meant to introduce organic chemistry in a critically and socially relevant way through the context of the history of the development of the female oral contraceptive. The three main goals of the unit were for students to: (1) develop an understanding of the socially created, value-laden, and male-biased nature of WMS, (2) use scientific modeling and participate in scientific argumentation and critique, and (3) classify, organize, and model simple organic compounds based on different functional groups (See Appendices F and G for the unit map and materials).

Critical acid/base unit. The fourth instance of CCE would fall between Banks' (2010) transformative approach and the social action approach. It completely adapted an entire mainstream chemistry unit on acids and bases to include fully integrated reflections on different cultural perspectives, debates about global environmental issues, and discussions on the moral responsibilities of the media and pharmaceutical companies as these issues relate to the content of acid/base chemistry. Furthermore, the unit was designed to encourage students to consider if not attempt some level of social action (See Appendices H and I for the unit map and materials).

Data Sources

Audio/video classroom recording. A multimode method was used to document the classroom activities of CCE from multiple perspectives (See Appendix A for Study Timeline). First, two video cameras were used to ensure the complete collection of all visual data in the classroom. Second, students' laptop computers were used to record audio data from three to eight different positions around the room depending on the activity to guarantee clear audio data when multiple students were talking at the same time in small group work. These audio recordings were then matched with the video recordings. I personally transcribed the recordings and combined them for each day to document complete classroom events from multiple angles.

Questionnaire. An open-ended questionnaire was administered using Qualtrics at the end of each of the critical transformations. While the initial intent of the questionnaire was to gauge student interest in CCE, it additionally provided insights into students' CSL and became an important data source for this study as well (See Appendix L).

Focus group interview. Loosely framed, focus group interviews that lasted approximately 30 minutes were conducted and digitally audio recorded within a week of each unit with several randomly selected student participants. On average, there were about six students per interview. Again, while the initial protocol of the interviews was developed to document student interest, students moved the conversations in directions that provided insights into their developing CSL (See Appendices M – Q).

Researcher journal. I kept a journal from the very beginning of the school year, well before I started collecting data. In this way, the journal helped me to reflect upon how I would enact the CCE curriculum with the students who were to become my student participants for the study. In addition, I used the journal as a valuable tool to help me identify ways I could improve data collection procedures after the research process had already begun, balance my roles as a teacher and researcher, to reflect upon my own biases, and to effectively communicate with the administration at the school setting.

Student artifacts. The five critical performance assessments (CPAs) enacted in the four CCE units were collected as student artifacts in this study (See Appendices B through I). Three of the CPAs were framed as inquiry-based labs. The first inquiry lab required students to determine which of a group of metals was the least reactive and then use this knowledge to critically analyze the importance of alloys to the history of different cultures and of steel to the modern global economy. The second inquiry lab required students to determine what factors affect reaction rate and then discuss how the results of scientific inquiry, even the results from their kinetics labs, can result in both positive and negative outcomes for different people. In the third inquiry lab, students used acid/base content knowledge to investigate diverse, cultural home remedies and WMS, over-the-counter remedies for heartburn and then discuss the implications of their results for healthy eating and pharmaceutical companies advertisement budgets. The fourth CPA was called the critical science reading/writing assignment. In this assignment, students used chemistry knowledge to analyze the content presented in two newspaper articles about hydrogen fuel cell cars (Chang, 2014; Soper, 2015). In addition, students had to critically examine the possible motivations of the two authors of these articles and then write a personal stance on these analyses. Finally, the fifth CPA was a project that required students to build and then peer critique models of organic functional groups presented in a book chapter about the social and chemistry history of the female oral contraceptive (Le Couteur & Burreson, 2003). The projects were meant to be creative outlets for students to use their personal interests in chemistry class. In addition, building the models was meant to help students understand the organic chemistry presented in the book chapter, which aided a critical examination of Western male bias in the development of "the pill" as well as other WMS research agendas. Overall, each of the five CPAs was collected to assess the complete, integrated development of CSL, composed of three parts: (1) content knowledge, (2) the practices of science, and (3) the critical analysis of socially relevant scientific issues.

Qualitative Analysis

Qualitative data analysis started with the audio/video event transcripts of the classroom activities. While I transcribed the video and audio files for each classroom event, I constructed dialogue maps and noted some of my initial interpretations of students' conversations within the dialogue. After the dialogue maps were constructed from the first critical unit, I used NVivo, a qualitative analysis software tool, to do the rest of the analysis of the unit. I *open coded*, or created "nodes" in the vernacular of NVivo. This process entailed identifying and segmenting concise statements from the data and categorizing them by names or codes, ideas that reside in the data (Boeije, 2010). Coding was, in part, deductive and applied in nature (Boeije, 2010) because I was guided by my understanding of CCE and CSL. However, I was also careful to let codes emerge from the data that I had not considered before to more deeply and in a more nuanced way answer the research question. In this sense, the analysis was also inductive and interpretive (Boeije, 2010).

After nodes were created in NVivo for the dialogue maps of the first unit, they were used to open code the questionnaires and focus group interview transcripts of this first unit. During this process, quite a few more CSL-related nodes had to be created in NVivo to account for all the ideas emerging from the data.

Next, a data analysis approach to ethnography suggested by Fetterman (2010) was implemented on data from the first unit. In this process, multiple data sources are compared or evaluated against each other to identify patterns or themes in participant behaviors and thoughts that focus on key instances in the activities of the group (as cited in Creswell, 2013). To accomplish this task, nodes were categorized, word frequency queries were run, and node matrices were created, all in NVivo, and used to identify broader patterns in students' CSL across the dialogue maps, questionnaires, and interviews.

Through careful reflection using the researcher journal, the process of analyzing the first unit helped inform future data collection and was used to guide the analysis of the subsequent units. After each unit, fewer and fewer new nodes and node categories were created. Furthermore, while node matrices and word frequency queries created in subsequent units revealed some new patterns, several larger themes began to appear in the data as a whole from these analyses. Finally, the themes were interpreted in terms of the CCE framework guiding this study to help determine how and to what extent students developed and demonstrated CSL.

Quantitative Analysis

The five CPAs collected as student artifacts were scored using three different rubrics. The three inquiry labs were scored by a rubric modified from the work of Oliveras et al. (2013) that sought to gauge students' CSL by measuring their content knowledge and inquiry skills based on four separate rubric categories each scored 0 to 4, and by measuring their ability to critically analyze how their scientific work interconnected with socially relevant, real world issues based on a single category scored 0 to 4 (See Appendix V). A second, distinct rubric was used to score students' overall CSL based on six rubric categories, each scored 0 to 4, for the critical science reading/writing assignment (See Appendix W). It was a slightly modified version of the rubric used in the work of Oliveras et al. (2013). A third, distinct rubric was used to score students overall CSL on the organic model project with four categories each scored 0 to 4 (See Appendix X).

After students' scores were determined for each CPA, the average CSL level was determined from the categories of the grading rubrics and turned into a decimal score for each student for each artifact ($N = 25$). Histograms and Shapiro-Wilk's tests were used to determine that the data were *not* normally distributed for any of the CPAs, and a Bartlett's test confirmed homogeneity of variances. Finally, even though there were only five CPAs for the year, a time series regression was used to evaluate how much students' CSL, as measured by the rubrics, varied in relationship to the days of the school year numbered 1 through 160. However, because the data were not normally distributed, Spearman's Rho was used.

Elements of Rigor

Due to the fact that the mixed methods, critical ethnographic research model was largely qualitative and guided by the researcher's critical, social constructivist lens, elements of rigor were largely conceived within the constructivist research terminology of Guba and Lincoln (1989). First of all, the methodology for the study supported *credibility* by outlining my biases at the outset and maintaining researcher reflection through the use of a research journal. In addition, my embedded nature at this school setting allowed for prolonged and persistent observations and facilitated *member checking* with my student participants during data analysis through informal conversations in the classroom and formal focus group interviews (Creswell, 2013). Furthermore, data from three qualitative sources and one quantitative source were concurrently triangulated (Boeije, 2010) to develop the answers to the research questions.

Transferability was supported by the rich description of the setting and findings developed from many different data points, both qualitative and quantitative, within this ethnographic approach. *Dependability* and *confirmability* were simultaneously supported in this study through a very detailed explanation of the logic used to construct the overall methodology as well as the specific data collection methods and analyses. Through these measures, other researchers can trace all the data and findings to their logical inceptions (Guba & Lincoln, 1989).

In addition, dependability was further enhanced by the transcription of the video recordings and audio recordings by the researcher himself (Creswell, 2013).

In addition, a traditional, quantitative conception of reliability was maintained in the rubric-derived scores for the five critical performance assessments (CPAs). A procedure for determining inter-rater reliability by calculating Cohen's Kappa (Cohen, 1960) was employed on the rubric scores. First, a peer collaborated with the researcher in establishing a coherent interpretation of the grading rubrics used to score each CPA (See Appendices V – X). Then the researcher scored all the CPAs and the peer scored at least 20% of each type of CPA: 20 of the 75 inquiry labs, 5 of the 25 critical writing assignments, and 10 of the 25 organic functional group model presentations. The separate scores of the researcher and the peer were then used to calculate a weighted Cohen's Kappa value for each type of CPA. Initially, the weighted Kappa value for the inquiry labs was only 0.518, which was determined to be unacceptable. Further collaboration between the researcher and peer and a rescoring of the inquiry labs resulted in a weighted Kappa of 0.809, which was determined to be an acceptable reliability for these rubric scores. Finally, the weighted Kappa for the critical writing assignments was 0.790, and for the organic functional group models it was 0.859.

Findings and Discussion

As a reminder, critical scientific literacy (CSL) is essentially composed of three key elements or facets: (1) a meaningful understanding of content knowledge, (2) the ability to employ scientific practices, and (3) an ability to use the content knowledge and practices of science to more meaningfully understanding the nature of Western modern science (WMS) and its connections to socially relevant issues as well as the ability to analyze and act on these connections through a critical lens. For ease of reading, the third facet of CSL is referred to simply as the "critical component" of CSL in the findings and discussion.

To answer how and to what extent students developed and demonstrated CSL working within critical chemistry education (CCE) the findings and discussion of this paper are combined and presented in two sections. The first section presents qualitative data from the video transcripts, questionnaires, and focus group interviews to specifically address students' demonstration and development of the critical component of CSL. The second section presents quantitative data from the rubric-graded critical performance assessments (CPAs) to address students' overall integrated development of the three facets of CSL.

The Demonstration and Development of the Critical Component of CSL

The third component of CSL was a complex skill to develop, composed of many interconnected critical concepts. While the four units of CCE were designed to address and develop as many aspects of this critical component of CSL as possible, analysis of the three qualitative data sources identified three CCE activities that began to develop three specific, important aspects of the critical component of CSL in the students at this setting. These three CCE activities and three aspects of the critical component of CSL are presented and discussed as three themes in the data: (1) *developing the ability to critically analyze the products of WMS*, (2) *developing the integration of WMS with diverse knowledge bases*, and (3) *developing an understanding of inequality in WMS*.

Developing the ability to critically analyze the products of WMS. During the critical science reading/writing assignment of the kinetics unit, students had the opportunity to develop their ability to critically analyze the products of WMS presented in two newspaper articles in conjunction with the critical analysis of the motivations of the authors of these two articles. The two articles (Chang, 2014; Soper, 2015) discussed some of the chemistry content that explains how new hydrogen fuel cell cars work. In addition, they discussed some of the potential positives of hydrogen cars for the future of our environment as well as some of the issues with infrastructure and extracting the required hydrogen that need to be worked out first before these cars can be a success. After an in depth discussion of the chemistry content that related to the articles, such as the difference between synthesis and decomposition reactions, and thermochemistry, the activity turned to an analysis of the assumptions and viewpoints of the authors of these two articles. In particular, how the introduction of these cars could benefit people and the environment, but at the same time hurt other groups of people was discussed in small groups and then in the class as a whole. After these discussions, students had to construct and write a personal stance on the content presented in the articles.

Initially during this activity, in their small group, Shane, Brooke, and Bill (all names are pseudonyms) discussed who could benefit and who could be hurt from the introduction of the hydrogen car:

> Shane: Whose interests do the writers' viewpoints serve? I think everybody because they want to save the earth.
>
> Bill: Yea, all environmental junkies.
>
> Shane: Yea… Whose interests do the writers' viewpoints possibly hurt? We could say gas companies.
>
> Brooke: Yea.
>
> Bill: I mean all electric ones.

During the whole group discussion, different ideas were shared by their classmates, which prompted, with the help of the teacher, Shane, Brooke, and Bill's ideas to evolve and become more in depth:

Teacher: Ok, so we were talking about whose interests do the writers' viewpoints serve and you guys (gesturing to Annabel's group) pretty much said just the hydrogen car companies or any company that does something with hydrogen.

Several students: Yes.

Teacher: Does it serve anyone else?

Thom: Or anybody that actually cares about the environment. Environmentalists.

Teacher: Ok, so environmentalists are happy about it. Anybody else? Whose interests do the writers' viewpoints possible hurt or even oppress? How or in what ways? So you guys haven't started a question yet. What did you guys say about that (gesturing to Kent's group)?

Kent: We said the rival companies that produce the gas guzzling cars that use oil and the electric cars because it is going to take business away from them.

Teacher: Ok, and so who does that specifically oppress? We saw that over here also (gesturing to Shane's group). I mean it takes money away from… the fossil fuel industry. It takes money away from them. But, who does that actually effect?

Several students: The owners.

Shane: The workers.

Bill: It takes money away from everyone.

Brooke: If a company starts losing money, it is going to affect everyone.

Teacher: Everyone in the company?

Brooke: Yea, because some people are going to lose their jobs. Other people will make less.

These two conversations were exemplars of how students used this classroom activity to develop their examination of the possible positives and negatives of hydrogen cars experienced by different people. Initially, the small group ideas expressed by Shane, Brooke, and Bill were tentative and not very complete. In a sense, they used the small group to bounce their initial ideas off their classmates in the safety of a smaller group. Then, with the teacher's help, Shane, Brooke, and Bill elaborated on their initial, small group ideas and improved the level of their critical analysis during the whole group discussions. Brooke in particular was able to identify more specifically how a new WMS product like the hydrogen car, while potentially great for the environment, could still hurt specific people in specific ways.

Overall, between the two class sections, there were 22 instances of individual students contributing more elaborate, critical insights to the whole class discussions of the two newspaper articles about hydrogen cars after their small group work. These insights reflected that students were analyzing the pros and cons of the hydrogen fuel car from multiple angles in a similar way to Shane, Brooke, and Bill. For example, Emma, Ashley, and Sam developed an analysis of the pros and cons of the hydrogen fuel car during the whole group discussion from the perspective of America's dependence on foreign oil:

Sam: Because then the U.S. would not need to rely on oil from foreign countries.

Emma: Oh yea. So then countries with a lot of oil and gas would lose their money from trade.

Ashley: So the U.S. would benefit from that, but the other countries would not.

Emma: Because [the U.S.] would not have to pay to import it.

Again, while hydrogen fuel cars may potentially be good for the environment, Emma, Ashley, and Sam also developed an understanding that they may really benefit countries with people that can afford to buy them like the U.S., but that they could also possibly hurt countries that have economies highly dependent on exporting oil. In a similar vein, Kent and Amanda discussed how the high price of these cars limited the potential positive environmental impact to places where people could afford them as well, leaving air pollution caused by combustion engines high in developing countries where people may not be able to afford the car. In all, these 22 instances indicated that students were developing the ability to critically analyze the products of WMS during this critical science reading/writing activity that focused on the two hydrogen car articles during the critical kinetics unit.

In addition, evidence from the questionnaire and focus group interview conducted at the end of the kinetics unit suggested that the development of this ability to critique the products of WMS from multiple perspectives resonated with some students. Eight different students identified looking at the products of WMS from different perspectives, considering the potential positives and negatives, as something they felt was important about the critical reading/writing activity. For example, Thom, Emma, and Flinn discussed how they felt about the activity in the focus group interview:

Thom: …I want to know what I'm reading, how does it affect people, is it true?

Emma: … And also with the newspaper articles, it shows you like if you are not in a scientific field, like selling cars or something, you still need to know some of the stuff that we are learning.

Flinn: And also just buying cars as a person.

First, Thom commented that the activity spurred in him the desire to know more about the scientific products we were reading about and how they could affect people. Emma built off of Thom's remark and noted that even if a person is not a scientist, he or she still needs to know about this "stuff" – the positives and negatives of the products of WMS – to work in different careers. Finally, Flinn added to Emma's thought by saying people need to be able to consider the positives and negatives of the products of WMS to be an informed consumer as well, especially when purchasing a car. The comments made by the five other students were similar to these. Together, these students' remarks indicated how their views to critically analyze the products of WMS may have lasted throughout the school year, potentially allowing them to use science understandings in their lives outside the classroom.

The ability to critically analyze the products of WMS, identifying the positives and negatives or the ways they can benefit some while oppressing others, is an important part of critical conceptions of education in general and science education in specific (Kincheloe, 2005; Calabrese Barton, 2001). As such, this ability was included as an important part of the critical component of CSL as framed by this study. The hope is that students can use this ability to make socially positive and morally responsible consumer and democratic decisions in life outside of the classroom (Kincheloe, 2005, 2007). More specifically, Birmingham and Calabrese Barton (2014) speak of using the content and practices of science for *educated action* in the moment. This entails students using critical abilities, such as the ability to analyze the products of science, to effect positive change in their local settings in the present rather than assuming that one day students will make socially positive decisions down the road because of their education.

While the data suggested that students were making progress in their ability to critically analyze the products of WMS and that some of them also considered the application of this ability in real world situations outside the classroom, there was no evidence to suggest students were actually making any consumer or democratic decisions based on this ability. Essentially, they did not participate in educated action. They did not take what they had learned or what we had discussed in the classroom and actually acted upon it in their communities during the school year.

Part of the reason for this was certainly that the activity was not framed to truly promote educated action. In addition, the methods of this study were not constructed to collect data on what students actually did outside the classroom during the school year. However, despite these shortcomings, the findings demonstrated that the critical science reading/writing activity started to make progress in developing this important part of the critical component of CSL. The activity is a first step that can be built upon or enhanced to help students use the ability to critically analyze the products of WMS from multiple perspectives to participate in educated action.

Developing the integration of WMS with diverse knowledge bases. As part of the critical acid/base unit, students participated in an inquiry-style lab on heartburn remedies that prompted them to integrate the content knowledge and practices of WMS with diverse knowledge about heartburn relief. Before conducting the lab, students had to research diverse, cultural home remedies for heartburn by either using the Internet or by interviewing family or local community members that may practice a non-WMS, over-the-counter (OTC) heartburn remedy. As a result of this research, students discovered and shared with the class diverse heartburn remedies such as slippery elm tea, licorice, honey, and aloe juice. After this research was conducted and shared, students worked in pairs to follow the inquiry-lab guidelines, which started by prompting students to develop their own definition of "effective" for heartburn relief. The definitions could have been personally significant and had to be based in a scientific concept such as reaction rate, pH, acid/base neutralization reactions, or the biology of the human digestive system. For example, if a student's father said he preferred heartburn relief to be fast acting, then a student could use the concept of reaction rate to develop a personally relevant definition of heartburn relief. Furthermore, the lab guidelines prompted students to choose their own set of OTC remedies and cultural, home remedies to investigate. In this way, students determined their own independent variable and dependent variable to examine.

The rest of the lab experience progressed with students forming their own hypotheses, developing their own procedures, collecting and analyzing data in the classroom using basic chemistry glassware and technology such as temperature probes, pressure probes, and Vernier's Lab Quests and Logger Pro software. Finally, students wrote conclusions connecting their data to chemistry content knowledge about acids and bases and kinetics and to a critical question set. The question set asked students to consider: "Who benefits from your conclusions?" and "Who could possibly be hurt or oppressed by your conclusions?" Moreover, the question set asked students to be prepared to discuss the implications of their results in terms of a broader societal context related to healthcare, nutrition, pharmaceutical companies, and the advertising industry.

Ultimately, working through this inquiry lab integrated the content knowledge and practices of WMS with diverse knowledge about heartburn relief, which was documented in students' work and thinking. Evidence for this integration was documented in the classroom on the final day of the lab when student lab groups presented and critically analyzed lab data with Power Point. All 12 lab groups were coded to have made this integration in their presentations. For example, Steven and Jake chose to investigate speed of relief:

Steven: Our research question was which remedies between Alka-Seltzer, Milk of Magnesia, mineral oil, and coconut milk would cause the fastest change in pH per time?

Jake: We used the pH probe to measure it. We put it in a solution that we added these bases to. These are the results. We predicted that Milk of Magnesia and coconut milk would change it the fastest, be more effective. Milk of Magnesia was faster relief and coconut milk was as well for home remedies. Mineral oil actually had a negative slope. It actually got more acidic. That negative number actually threw off the graph because it is below. Besides that, you can see a big difference between the home remedies and the pharmaceuticals as far as speed goes because these are much bigger slopes than these two.

Teacher: I have a question. If mineral oil actually makes the pH go down, then why would, how could it be considered effective? What's another way mineral oil could be effective for heartburn?

Jake: Yea, because that is not the only way – lowering pH. It could help coat the esophagus or something like that to help relieve the pain. But, it might not lower the pH as much.

Teacher: Cool. Other questions? Cooper.

Cooper: How did you come up with using mineral oil if it doesn't even raise the pH?

Jake: Honestly, it was just one of the liquids from the list on the board.

Steven: And we wanted to do all liquids to keep that constant.

The lab was framed in a way where students would not make value judgments about which heartburn remedies would be better between cultural, home remedies and OTC remedies. Students only discussed the effectiveness of remedies based on their own construct or definition of effective. Steven and Jake chose to define effective in terms of speed of relief, and only discussed how the two OTC remedies, Alka-Seltzer and Milk of Magnesia, and the two home remedies, mineral oil and coconut milk, measured up in terms of change in pH per time. While they found that the OTC remedies were faster at increasing the pH per time, an indication that they would provide faster relief based on their definition, they did not make judgments about better or worse in general terms. In addition, Jake demonstrated that he was aware that even though mineral oil was not effective according to their definition, it could be considered effective based on a different construct. He noted that it might be considered effective according to someone else's desire for a substance that could coat the esophagus, which might provide relief or comfort. Finally, when Cooper challenged their decision to investigate mineral oil, Steven explained their decision in terms of the scientific practice of holding untested variables constant during an experiment. Overall, the heartburn inquiry lab and presentation provided Jake and

Steven the opportunity to develop the integration of WMS and diverse knowledge in their thinking.

Emily and Emma's lab presentation provided the class with inquiry work done from a perspective similar to the one Jake mentioned about mineral oil:

Emily: So we tested the effectiveness of heartburn remedies in terms of viscosity. This would tell us how well they would coat the esophagus.

Emma: Our research question was based on the speed of flow of Pepto-Bismol, Milk of Magnesia, honey, and coconut milk. Which of these substances would be the most effective heartburn remedy based on coating the esophagus, measured in terms of viscosity.

Emily: So this is our data table. We timed how long it would take for 40 ml of each substance to go from one container to another. So the honey took the longest time, and then the Pepto-Bismol, and then the milk of magnesia and then the coconut milk. So we concluded that honey would be the best to coat your esophagus.

Emma: And then in the graph, you can also see that honey took the longest in both trials.

Teacher: Do you have a reason for why there was such a discrepancy between the two trials for honey?

Emma: Because when we poured it, the angle of our arm was different between the two trials. Also how long we waited, like if we just waited for the bulk of it to go in or if we waited for every last drop.

Ashley: How does the viscosity test how well it will coat it? Like, is it just by the thickness of the substances?

Emily: Yea, so we kind of assumed that if it took longer to flow, so like we know honey is thick, then it would coat the esophagus better.

Some of the diverse knowledge about heartburn remedies that students researched suggested that some of these remedies were based in a soothing factor that may come from coating the esophagus and/or stomach. With this in mind, Emily and Emma developed an investigation that tested the effectiveness of two OTC remedies and two cultural, home remedies based on this concept. They adeptly came up with a way to determine a remedy's coating ability through a simple way to measure the viscosity of a liquid in the chemistry classroom lab. Furthermore, they were able to critically reflect upon some of the weaknesses in the way they carried out the experiment. In doing all of this, they integrated a diverse knowledge base with WMS in their lab work and their thinking.

Five students claimed in interviews and questionnaires that learning about the cultural, home remedies during the heartburn inquiry lab resonated with them. For example, in response to a question that asked students to discuss what they would elect to study further from the lab, Cassandra wrote in the questionnaire, "I would explore more [cultural], home remedies instead of having to take a medicine." Amanda noted in the same questionnaire to a question that asked students to discuss what stayed with them about the lab, "It really surprised me that the home remedies worked so well. My family is very doctor/medicine/pharmacy oriented and so I had honestly never heard of these home remedies before." Finally, Annabel said in the interview that it was very interesting "when we found out that baking soda was more effective than any of the [WMS] medicines that are being used." Baking soda was one of the home remedies students researched and then investigated in the inquiry lab.

The comments noted by Cassandra, Amanda, and Annabel all suggested that outside of the classroom activity, they were still reflecting upon the diverse, heartburn remedy knowledge they had learned about in the lab and had integrated into their WMS thinking. This suggested that they, along with the other two students who made similar comments outside of class, may potentially respect, consider, and even seek out diverse knowledge about scientifically based topics in their futures.

Fundamentally, helping students integrate diverse knowledge bases with WMS may provide girls and other students traditionally marginalized by WMS student-centered access points to learn science (Lee, 1997). Indeed, in a similar vein, Hildebrand (1998) found that providing students with diverse ways to write about WMS did help traditionally marginalized students acquire the language of science and develop an ownership of science. For this reason, even in a classroom that has very little diversity like the setting in this study, it was important to include the integration of diverse knowledge bases with WMS in the CCE curriculum and the heartburn inquiry lab specifically discussed in this section to help *all* students develop scientific literacy.

In addition, critical pedagogues believe that helping all students, privileged and marginalized, to integrate diverse knowledge bases into their thinking is important because not only does it help them see the world from different perspectives, minimizing bias and oppressing disregard for non-Western ideas (Glibert, 2013), it may also provide all students with another knowledge base to draw on when faced with novel problem-solving tasks. In other words, it may improve their ability to problem solve in complex, socially situated contexts that likely require input from various sources to tackle (Kincheloe, 2005). Furthermore, it may help them to recognize and support "outside the box," which in this case really means outside WMS, ideas to globally interconnected science based issues such as global warming that will require different peoples from all over the world to solve together (Banks, 2004). For these reasons, the ability to integrate diverse knowledge bases with WMS was considered a crucial aspect of the critical component of CSL.

This study was not designed to gauge whether or not integrating WMS and diverse knowledge bases into student thinking minimized their biases or helped them to participate in dealing with issues such as of global warming. The CCE curriculum and specifically the heartburn inquiry lab were designed to take initial steps in opening these students' minds to different ways of thinking. The findings presented in this section indicate that students seemed to be making progress in the area of recognizing the potential of non-Western ideas. In other words, they began to develop this aspect of their CSL.

Finally, at least one student made additional progress with this aspect of the critical component of CSL. In the focus group interview that occurred after this activity, Bill said, "I did a home remedy tea [for my heartburn]." Bill was referring to drinking slippery elm tea for his heartburn, which was one of the cultural, home remedies he had learned about during the inquiry lab. This statement provided evidence that he drew upon the diverse, heartburn knowledge he had integrated into his thinking, albeit in a small way, to problem solve outside of the classroom.

Developing an understanding of inequality in WMS. During the critical organic unit, students had to read and analyze a book chapter called "The Pill" (Le Couteur & Burreson, 2003). The chapter detailed the organic chemistry and social history of the development of the female oral contraceptive. "The Pill" served as a socially situated way to introduce the content of organic chemistry. One of the activities associated with reading the chapter was for students to participate in small and whole class discussions that, in part, entailed discussing the potential existence of White, male bias in the research for the female oral contraceptive and in WMS in general. Through the context or lens of this activity, students critically reflected upon these issues and began to develop an understanding of the inequalities inherent in WMS. Evidence for this came from 38 instances spread across 20 different students coded in the classroom transcripts that identified moments when students articulated a critical reflection on bias in WMS. Several examples from these coded instances are presented in the following paragraphs.

Initially, students' thoughts about bias or inequality were highly framed by the specifics of the story told in the book chapter. For example, Ashley, Megan, and Mike concluded in their typed responses to the small group discussion part of the activity that the "women were more talked about as test subjects," and the "men were looked at predominantly as the researchers, testing these drugs on these women." Their perception was that in the story of the female oral contraceptive, women were the "test subjects" that had to take different iterations of "the pill" to see if they would work, while men were in charge of the scientific work and free from the burden of having to be tested on. The students clearly articulated the imbalance of power and gender inequality they saw in the story of the pill.

During the same activity, but in a different small group, Chelsea stated to her partners:

> Women are sort of looked down upon almost. And like men are over powering them like when they were saying that no, this should not be legalized. But the women were saying that it should be. Like when they were saying that the government was against legalizing birth control, and the government was mostly male.

Chelsea's statement added another insightful element to the conversation. She pointed out that while the research for the pill was being conducted, women activists were arguing for the legalization of birth control, and a male dominated legislative body argued against it, which added another important layer to the gender inequality of the story that was intimately tied to the science.

In addition, during the whole group discussions of the two class sections constructed from the small group discussions, some students started to expand upon their conceptions of bias in WMS. For example, as the whole group discussed their perceptions of the interests of the White, male scientists, Chelsea and Emily contributed:

> Chelsea: And they were only interested on researching for their own good. Right?

Emily: Yea. That was probably like for colonial diseases. Like they didn't care if like the people they were colonizing got the diseases, but if they got them then they would find a cure.

Chelsea: They didn't care about what others wanted such as women, if it didn't benefit them.

Together, Chelsea and Emily elaborated that not only did bias in the research agendas of WMS likely predominately benefit Western, White men while oppressing women, it also likely oppressed people native to colonized areas of the world as well. These statements indicated that some students were developing a more complex and complete understanding of the bias or inequality inherent to WMS through this book chapter activity. This understanding went beyond the fact that women and culturally and ethnically diverse peoples have been and continue to be marginalized from the field of science to what this exclusion means in terms of oppressive research agendas.

Moreover, evidence from the questionnaires and focus group interviews indicated that outside of the classroom book chapter discussion activity, six students continued to reflect upon and develop their thoughts on bias in WMS and the potential implications of this phenomenon. Thom's interview comment was the most in depth statement made among the six students:

> I think that people would just look at it and say wow why can't someone like me be in there? What am I missing out on? Or why can't I be as intellectually... or been fed the silver spoon? Some people may feel jealous and some people may just feel left out, like they were never given those opportunities. Or some people may have never applied themselves in the right areas and now they are just complaining or like they just don't understand what is going on and why they don't see people like them in that field, or have what it requires to be in that field.

Thom's remark indicated that he continued to think outside of the classroom about how bias and exclusion from WMS could induce in women and people from diverse backgrounds complex, painful affective responses. However, it is important to acknowledge in this case that

Thom is African American and was one of the most intellectually engaged students I had for the year. Both of these attributes certainly affected the level of critical insight he revealed, which was not the norm for my students. Despite the fact that it was unique and not exemplar of the students as a whole, it demonstrated the complex ideas and feelings that the activity could potentially prompt in individuals. Overall, while the comments of the other five students were not as deep as Thom's, together these six students provided evidence that suggested some students' developing understanding of bias in WMS seen in the classroom activity was potentially continued outside the classroom.

Developing students' ability to understand the value-laden, Western male-biased nature of science in the classroom is an essential part of critical conceptions of science education developed from a feminist perspective (Calabrese Barton, 1997; Parker & Rennie, 2002), and for this study, an important part of the critical component of CSL. Overall, this critical approach helps students see the insidious ways bias can oppress girls and students of diverse cultural and ethnic backgrounds, which is important because as Calabrese Barton (1997) asks, "What is the purpose of teaching science to students, if the result is that they understand it, but remain oppressed by it?" (p. 145). Understanding the complexity of bias and oppression can then help them to more critically and meaningfully evaluate the content and products of WMS (Calabrese Barton, 1997), potentially making future consumer and democratic decisions that can help minimize oppression, which is all part of the critical component of CSL.

However, the data did not suggest that all students were developing a complex, meaningful understanding of inequality in WMS. Only 20 of the 25 students demonstrated critical reflection about the bias in WMS, and only six of the 20 showed evidence that they continued this line of thought outside the classroom. In addition, there was evidence from the focus group interview that at least one student did not believe gender bias existed in the story of the pill. Anthony stated in the interview, "…But for the pill, I was like there is zero bias. The researchers were guys, and the funders, the entrepreneurs were like the girls, and they both worked together." He believed that because women such as Margaret Sanger influenced the development and production of the female oral contraceptive that this balanced out the bias that could potentially arise from a male-dominated practice of science.

In addition, careful inspection of the reflective comments students did make about bias in WMS suggested that all of these students but Thom, both boys and girls, framed their comments from a historical perspective. For example, Emily referenced past colonial times in her remarks. In addition, during the book chapter classroom discussion, Megan commented, "I feel like in history it kind of did, but in the present now, it is like different." In this statement, it was evident that she perceived gender inequality to exist in the past and therefore only affected WMS research agendas in the past. She believed things were "different" now.

These data suggested that students did not reach an understanding that because modern Western male bias still defines most legitimate problems in science (Harding, 1986), the research agendas of WMS and the resulting products can still marginalize women and other diverse groups of people (Keller, 1996). Students did not seem to recognize that even though the story of the pill was situated in the past, the bias evident in the story still had implications for the modern day use of female oral contraceptives. The students were either too young to handle this complexity or were more comfortable situating Western, male bias in the past to avoid difficult, deeper, critical reflection and the implications this has for efforts to diversify WMS.

The latter interpretation is supported by similar findings from Haviland (2008). She found that student teachers avoided critical reflection on white privilege by telling stories “located safely in the past” (p. 45). She suggested that teachers use a “let’s work together” approach to help students comfortably “unpack” stories that exemplified white privilege to avoid putting people on the defensive and improve the level of critical dialogue. In a similar way, teachers of high school science could use this approach to help younger students better understand the ramifications of Western male bias in science and the importance/urgency of diversifying WMS.

However, Picower (2009) cautions that developing a person’s understanding of their own biases cannot really be accomplished in a single unit, or even in a semester-long class. In her work with White, preservice teachers, she found that their biases towards ethnically and culturally diverse students were entrenched in a set of emotional defense mechanisms, ideologies, and *hegemonic* practices or stories, practices used by or stories told by the dominant culture that maintain the power structure of society in its favor through social or psychological tactics rather than overt force. The biases were so entrenched that a single diversity course did not and was not going to affect any real change in the thoughts and practices of the preservice teachers. In a similar way, while there was some evidence of progress, a single unit in high school chemistry class was not likely to truly develop students’ understanding of the complex nature of bias in WMS.

In addition, Thom’s critical insight about bias was unique. No other student was able to articulate how positions of privilege and oppression are so intimately connected to the practice and teaching of science. His response was likely to be at least partially influenced by the fact that he is African American, a very small minority group at the school setting. Furthermore, Thom was new to the school as a sophomore, which likely gave him additional etic, or outside perspective on privilege at this setting. These attributes qualified him as a “marginalized cultural other," someone whose personal attributes are different from the cultural majority or who feels like he or she lives a life that is in opposition to the majority in some way (Suriel, & Atwater, 2012, p. 1288).

Thom's ability to reach that level of critical insight runs parallel to findings documented by Suriel and Atwater (2012). They found that young teachers were more capable of successfully implementing multicultural science education framed curricular pieces if they at one time or another felt like a marginalized cultural other to some extent. Thom's unique contribution and their findings call into question whether the majority of students at this setting that do come from the privileged, dominant cultural background, "upper middle class, white, heterosexual, first language English, and Christian" (Kincheloe, 2005, p. 8), would ever be able to reach deep understandings of bias after an activity, unit, or even full year of CCE, if they had never felt like a marginalized cultural other to some degree in their lives.

Although, this does not mean that the endeavor is futile. As Picower (2009) explains, it means that educating preservice teachers, or in this case high school students about their own biases or the bias in WMS requires longitudinal work across years of schooling and work that is integrated across the curriculum. Essentially, this requires science teachers to work with humanities teachers to develop curriculum and pedagogy that dissects issues of bias across contexts. The book chapter discussion activity and critical organic unit developed for this study provide an example of how to integrate bias education into high school science classrooms. However, it is only one example that must be built from or elaborated upon across science disciplines and other classroom subjects as well as through years of schooling to really help students understand their own biases and the inequality in WMS. Furthermore, the findings for this study and the work of Suriel and Atwater (2012) suggest that students might need to in some way experience first hand what it feels like to be a marginalized other to be able to better develop the overall critical component of their CSL. But, this would probably be a very difficult task to safely undertake in an open and positive way in the classroom.

The Integrated Development of Students' Overall CSL

The critical performance assessments (CPAs) were designed to measure students' overall ability to integrate and demonstrate the three facets of critical scientific literacy (CSL): (1) content knowledge, (2) practice of science, (3) critical analysis of socially situated, scientific issues (the critical component). While each of the CPAs was unique, covering different chemistry content, scientific practices, and aspects of the critical component, and was scored using a different rubric, they all generally measured individual students' demonstration of CSL. Furthermore, because this study was not designed as an experimental study where consistency in instrumentation would be important to maintain internal validity (Campbell & Stanley, 1963), the decimal CSL scores from the CPAs were quantitatively analyzed together to look for trends in students complete CSL. This analysis suggested one small, overall trend.

A time series regression was used to evaluate how much students' CSL scores on the CPAs varied in relationship to the days of the school year. As a reminder, the decimal scores on the CPAs were not normally distributed, so Spearman's Rho was used. The scores ranged from 0.50 to 1.00. Analysis revealed $r = 0.38$, $r^2 = 0.14$, and $p < 0.0001$. Figure 5.1 provides a graph of the regression line. With such a low *p*-value, the results suggest a statically significant increase in students CSL scores over the course of the school year. However, the low correlation value (0.38) and the weak effect size (0.14) indicate that there was only a small variation in students' CSL scores that trended upwards as the year progressed. Table 5.1 provides the mean CSL decimal score for each CPA. From these data, it can be concluded that there was a statistically significant, albeit small development in students' integrated, complete CSL that occurred as they worked through the units of CCE.

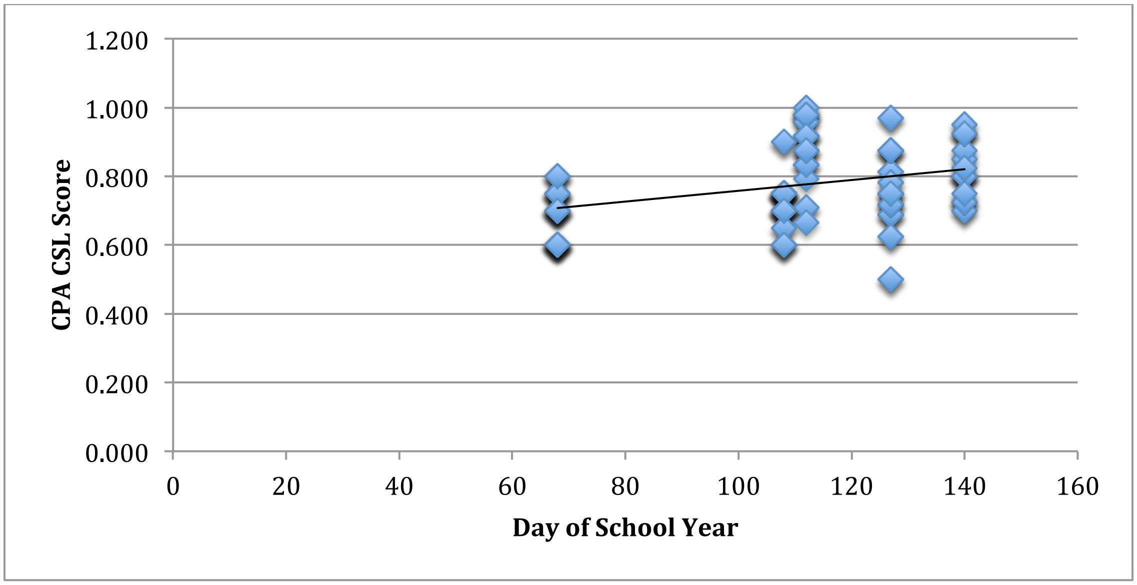

Figure 5.1. Critical scientific literacy (CSL) scores on critical performance assessments (CPAs). This figure illustrates how students' CSL decimal scores on the CPAs varied by the day of the school year.

Table 5.1
Mean CSL decimal scores for each CPA

	Metal Inquiry Lab	Kinetics Inquiry Lab	Critical Scientific Reading/ Writing Assignment	Organic Functional Group Model	Acid/Base, Heartburn Inquiry Lab
Mean (SD)	.67 (.07)	.72 (.08)	.89 (.09)	.75 (.12)	.82 (.08)

Implications and Conclusion

This study documents how a group of 25 students in a suburban, private school setting, the vast majority from dominant cultural backgrounds, engaged with critical chemistry education (CCE). The purpose of this study was to document how these students developed and demonstrated critical scientific literacy (CSL) while they worked through the four critical units created for CCE. CSL is a measureable construct that entails three facets: (1) understanding core scientific ideas, (2) the ability to participate in the practices of science and engineering, and (3) the use of the content and practices of science to critically examine science-based, real-world, socially relevant issues. Findings from the qualitative data sources suggest that the third, critical facet of students' CSL developed in three specific ways during three specific CCE activities created for the study. Students demonstrated that they were beginning to develop: (1) the ability to critically analyze the products of Western modern science (WMS), (2) the integration of WMS with diverse knowledge bases in their thinking, and (3) a meaningful understanding of inequality in WMS. Findings from the quantitative data suggest students made some progress in developing the integration of all three facets of CSL as the year progressed. Together, the qualitative and quantitative data indicate that students were able to develop their overall CSL in significant ways as they participated in the four critical units of CCE.

These findings add to the growing body of literature that describes critical approaches to science education and the resulting student outcomes. In particular, this study fills a gap in this literature by documenting the complexity of enacting a critical approach in a traditional, privileged, private school setting in a rigorous, content rich chemistry course and documenting that progress can be made with these students in terms of broadening their critical perspective and developing their CSL. In addition, this study is unique in its attempt to quantitatively measure a complex construct such as CSL through the use of scoring rubrics.

However, evidence suggests weaknesses in the level of CSL demonstrated by the students as well. Namely, while chemistry is likely to be a more difficult scientific field to spur students on to *educated action* (Birmingham, & Calabrese Barton, 2014) than perhaps the environmental or biological sciences, students were still not documented to have actually used what they learned in chemistry class to act outside of class, which is an important component of CSL and goal of CCE. Furthermore, students' understanding of bias in WMS was lacking in that they safely located bias in the past (Haviland, 2008).

My hands off approach and desire to maintain a student-centered classroom during complex critical conversations about the intersections of WMS and society likely played a part in some of the weaknesses documented in the levels of CSL achieved by students. In other words, I did not want to influence them in any one direction based on my own biases, so quite often I would let conversations tapper off on their own volition rather than push them in ways I would want the students to go. In addition, while the units I created for CCE seemed to develop students' CSL in specific, measureable ways, it did not provide them with opportunities or examples of ways to extend what they had learned into specific actions outside the classroom. Moreover, weaknesses in students' CSL were also likely caused in part by the sheltered and privileged positions many of these students held.

The weaknesses documented in students' CSL imply the need for further development of the activities and units of CCE that allow students to extend CSL outside of the classroom in ways that minimize a need for the teacher to push or direct students in specific directions, maintaining a student-centered environment. For example, drawing from Haviland's (2008) suggestion for "unpacking" these difficult topics with students, the teacher could provide students with more opportunities to develop their own questions to difficult critical topics rather than having them respond to challenging questions developed prior to an activity. The teacher could also motivate students to use their chemistry knowledge to develop socially relevant questions about their own neighborhoods, which might spark students to take classroom understandings outside of the classroom in the participation of educated action. For example, an investigation of the ions present in drinking water sources for different neighborhoods might instigate interesting critical analyses. In addition, the CSL weaknesses evident at this privileged setting imply the need for longitudinal and cross discipline critical education (Picower, 2009) that extends the four units these students experienced in a single chemistry course into all grade levels and all subject areas.

Finally, as I stated above, very little work was done during the course of this research to document what students did with the knowledge they gained from CCE outside the classroom. It would be very interesting to follow these 25 students longitudinally to see what impact, if any, CCE had on their future chemistry-related, socially relevant decisions and actions.

Chapter 6

FINDINGS

SOCIOCULTURAL LEARNING THEORY-ALIGNED TO THE DEVELOPMENT OF CRITICAL CHEMISTRY EDUCATION

Abstract

In an attempt to more fully engage students in an active, critically reflective, contextualized, real world chemistry education, I enacted critical chemistry education (CCE) in two "regular level" chemistry classes at a suburban New England private high school. CCE was the culmination of combining the concepts of critical pedagogy (Freire, 1998) and critical science education (Gilbert, 2013) with sociocultural learning theory (Zuicker & Hickey, 2003) to extend the performance expectations of the *Next Generation Science Standards* to include a socially situated, critical component. This paper specifically documents how and to what extent students demonstrate chemistry content knowledge working within CCE using a mixed methods approach that grounds quantitative, individual student scores on traditional multiple-choice tests (empiricist) and on performance assessments (rationalist) in event-based, qualitative data collected from video transcripts and focus group interviews (Zuicker & Hickey, 2003). Analyses of these data reveal that (1) CCE fostered a classroom community of practice where students shared and developed a meaningful understanding chemistry content knowledge and its intersections with socially relevant issues, (2) the performance assessments of CCE seemed to have a particularly positive effect on "lower achieving" students' demonstration of content knowledge, and (3) overall, students of CCE achieved the same level of chemistry understanding as students from the same setting that participated in a traditional chemistry curriculum. These results imply the power of sociocultural learning theory-aligned critical pedagogy to enhance students' meaningful, socially relevant science learning experiences while maintaining the development of domain-specific content knowledge in a rigorous secondary science course such as chemistry.

Introduction

The main function of American schools continues to be the molding of students into an endless supply of producers and consumers in our disengaged, capitalist society (Gilbert, 2013; Hinchey, 2004; Mayo, 2012). Positivist attitude, belief that there is an objective truth to knowledge (Giroux, 2009), still reigns supreme in education, resulting in the practice of stripping knowledge from its context and ignoring the complex ways knowledge is socially constructed and mediated by the power structure of society (Kincheloe, 2005). As a result, American education is fundamentally absent of critical thought, supplying students with a series of agreed upon, decontextualized facts determined to be “right” for everyone to know that all students must memorize to be successful on large-scale standardized tests (Janesick, 2007; Kincheloe, 2005). This seems to be especially true in science classes (Gilbert, 2013), chemistry in particular (Gilbert, 2006), where a dominant positivist mindset rigidly maintains the myth of objective truth, leaving very little room for conversations about the social dynamics that underlie what happens in science and science classrooms, and how science connects to socially relevant topics at large (Calabrese Barton, 2001; Gilbert, 2013).

To a certain extent, the *Next Generation Science Standards* (NGSS) address these concerns (NGSS Lead States, 2013a, 2013b). The main purpose of the NGSS are to integrate the learning of scientific content with the practices of science and engineering, which is a change from current state standards that treat content and practice as separate entities. Furthermore, the NGSS emphasize that scientific content and practices should “be taught in context – not in a vacuum” (NGSS Lead States, 2013a, p. 1). This stems from the authors’ belief that “in the real world science and engineering is always a combination of content and practice” (p. 2).

At their core, the NGSS;

> represent performance expectations (PEs) that require all students have a deep understanding of a smaller number of disciplinary core ideas (DCIs), are able to show evidence of that knowledge through scientific and engineering practices, and connect crosscutting concepts across disciplines. (Pruitt, 2014, p. 145)

The PEs of the NGSS are guided by learning progressions (LPs) (NGSS Lead States, 2013b), which are research-based tracks of students’ longitudinal learning along a core concept (Corcoran, Mosher, & Rogat, 2009) grounded in constructivist learning theory (Wiser, Smith, & Doubler, 2012). LPs provide coherence to the progression of the concepts of a DCI by tracking the sophistication of students' developing ideas about these concepts through grade bands (NGSS Lead States, 2013b).

However, as a set of standards, the NGSS do not provide a specific curriculum to contextualize science education (NGSS Lead States, 2013a) that ensures all students develop an integrated and meaningful understanding of not only the content and practices of science, but also how it connects to everyday, societal issues. In addition, while the NGSS provide examples of how to integrate the practices of science and engineering with DCIs and crosscutting concepts, they do not provide examples of the integration of culturally relevant teaching in science education in the same way, leaving teachers in the dark about how to improve equity in science education (Rodriguez, 2015).

In addition, according to Eisenhart, Finkel, and Marion (1996) it is important to embark on a critical investigation of learning theory before innovative science classroom curricula and instruction can be created to achieve meaningful science education that reaches all students. They claim that narrowly interpreted, individualistic constructivist learning theory, which continues to be the backbone of the NGSS, can "divert attention away from socially responsible science use and wider access" (p. 275). Eisenhart and colleagues advocate for what they call *sociohistorical constructivism* to guide instruction. For them, sociohistorical constructivism addresses the social structure of school and instruction, the use of socially mediated tools such as language, and the identities students construct in and during knowledge construction.

With these concerns in mind, to more fully engage students in an active, critically reflective, contextualized, real world science education, I combined the PEs of the NGSS with what Fusco and Calabrese Barton (2001) and Gilbert (2013) call *critical science education* (CSE) to critically transform the chemistry curriculum at the suburban New England private school where I had taught for five years. At its core, CSE "questions… the nature of science and knowing science, the relationship between science and society, and the implications these belief structures have for how we view science as a school subject" (Fusco & Calabrese Barton, p. 338).

To ensure a successful transformation of the chemistry curriculum that combined the ideas of the NGSS and CSE, I closely adhered to the principles of sociocultural learning theory while developing the activities and assignments of the new curriculum. Sociocultural learning theory can be conceived of as a blanket term for learning theories such as the sociohistorical constructivism noted by Eisenhart et al. (1996), situated cognition noted by Brickhouse (2001), or social constructivism described by Driver, Asoko, Leach, Mortimer, and Scott (1994). At their core, these learning theories all claim that knowledge is a socially constructed phenomenon. It is created and shared within a group through the shared tools and practices of the group.

The result of these efforts was the yearlong enactment of *critical chemistry education* (CCE) in the two "regular level" high school chemistry classes. As part of this work, I investigated the units I created from several different perspectives or angles. The overall purpose of this research is to expand the body of science education research conducted from a critical perspective into settings where the majority of students come from the dominant cultural background, i.e. White, middle to upper class, straight, Christian, first language English speaking students (Kincheloe, 2005). More often than not, CSE-framed research has traditionally focused on urban settings largely composed of students from diverse cultural and ethnic backgrounds (i.e. Birmingham, & Calabrese Barton, 2014; Brown, 2004; Emdin, 2010; Mallya, Mensah, Contento, Koch, & Calabrese Barton, 2012).

The specific purpose of this particular study is to investigate how and to what extent the students at this setting demonstrated chemistry content knowledge working through a critical approach to science education. The research question that guides the work is: "What level of chemistry content knowledge do students demonstrate within CCE and how do they demonstrate it?"

Theoretical Framework

The theoretical framework that grounded this study is composed of two conceptual constructs. The first is a critical lens, which framed my desire to curtail students' passive, decontextualized, fact-based science education and guided my conception of critical chemistry education. The second is sociocultural learning theory, which guided the specific construction of the activities and assignments of CCE. Furthermore, methods for assessing student learning framed by sociocultural learning theory are presented.

Critical Chemistry Education

Critical chemistry education (CCE) as conceived of for this paper is the synthesis of work from multicultural science education (MSE) (Atwater, 1993, 1995), feminist science pedagogy (Brickhouse, 2001; Calabrese Barton, 1997), critical science reading and writing (Hildebrand, 1998; Oliveras, Marquez, & Sanmarti, 2013, 2014), and critical science education (CSE) (Fusco & Calabrese Barton, 2001; Gilbert, 2013). MSE and feminist science pedagogy provide the groundwork for creating the fundamentally student-centered classroom that CCE has the potential to develop. Both of these frameworks explain that curriculum and pedagogy must be developed in ways that attempt to contextually situate science education in not all only the interests and backgrounds of girls and ethnically and culturally diverse students, but of all students. Furthermore, they promote the idea that all students should be provided opportunities to see themselves as scientists and participate in the practices of science (Atwater, 1993; Brickhouse, 2001). The adoption of these processes within the CCE framework necessarily provides all students with the chance to experience science in positive ways that potentially improve their understanding of scientific content and their perceptions of the relevance of science.

Freire (1998) explains that students must learn to read beyond the content of the writing and develop the ability to understand the hidden agenda of authors. According to Oliveras et al. (2014), part of being truly scientifically literate includes Freire's claim. In other words, students must be able to read, understand, evaluate, and form a critical stance on scientific content presented by authors in media sources, such as newspapers. Furthermore, Hildebrand (1998) suggests that combining formal scientific writing with more personal writing styles like first person narratives or poetry in the classroom provides more students access points to the language of science and ownership of science. CCE combines these efforts as part of a process where students critique the socially situated scientific content discussed in the media and construct written personal stances on these pieces grounded in scientific content.

Finally, CCE draws heavily from conceptions of critical science education (CSE). CSE requires that students develop a meaningful understanding of scientific content grounded in globally relevant social issues, such as environmental protection, as well as locally or personally relevant issues, such as developing a healthy diet. As part of this process, CCE also engages students in the exploration of diverse science-related knowledge bases (Gilbert, 2013). In addition, CCE prompts students to actively use scientific content knowledge and the practices of science to support socially responsible actions (Birmingham & Calabrese Barton, 2014). Furthermore, students develop a meaningful understanding of the biases inherent in Western modern science (WMS) working within CCE. Finally, CCE enhances students' ability to evaluate the potential positives and negatives of the products of WMS for different peoples and places (Calabrese Barton, 2001).

Critical performance assessments (Fusco & Calabrese Barton, 2001) provide the foundation and/or template for the activities enacted in the CCE framework of this study. Critical performance assessments (CPAs) are assessments co-created by students and teachers situated in real life contextual problems. These assessments require students to analyze multiple worldviews, to interact with their world through rigorous scientific inquiry rather than passively absorb knowledge, and to produce their own chemistry-based knowledge that can be used to better understand or even improve globally or locally relevant issues or problems. These CPAs, in effect, take the performance expectations of the NGSS and add a critical component.

Sociocultural Learning Theory

According to Hickey and Zuiker (2003), sociocultural learning theory explains learning as "participation in the use and transformation of socially defined knowledge" (p. 539). They add that "knowledge neither resides in the mind of the knowledgeable individuals nor in the environment waiting to be learned" (p. 540), it exists in an abstract space spread across all the people interacting within a specific contextual environment. Furthermore, Hickey and Zuicker identify two major lines of work that have contributed to sociocultural learning theory: social constructivism and situated cognition.

The work of Vygotsky had a major impact on the transformation of early, individually based, constructivist learning theory to social constructivist learning theory (Driver et al., 1994). Social constructivism describes knowledge as socially constructed through accepted and shared practices, of which language is likely the most important, within a culture or community of practice (Blumenfeld, Marx, Patrick, Krajcik, and Soloway, 1997; Driver et al., 1994). According to Wenger (1998, as cited in Barab & Duffy, 2000), “a community of practice involves a collection of individuals sharing mutually defined practices, beliefs, and understandings over an extended time frame in the pursuit of a shared enterprise” (p. 36). A major line of thought that appears within social constructivism is Vygotsky’s zone of proximal development (ZPD). He defined it as the distance a learner is from the successful use of the knowledge practices of a community (Hickey & Zuiker, 2003). Within the space of the ZPD, learners move from assisted to unassisted performance through the scaffolding the community practices provide (Blumenfeld et al., 1997).

The work of Brown, Collins and Duguid (1989) outlines the framework of situated cognition. For them, knowledge is not only easier to understand in context, it is inherently only truly understandable within the context of activity because of the way knowledge indexes context, evolves with use, and is socially constructed through accepted cultural or community practices. All cognition encompasses the contextual situation it applies to and arises in and can therefore not be separated from context. In other words, cognition and learning are always situated. Lave and Wenger (1991) elaborate that situated learning requires what they call legitimate peripheral participation. Individuals learn through active participation within a community that allows them to move from peripheral members to full members of the community. This process is interconnected with individual identity formation because “identity, knowing, and social membership entail one another” (p. 53). Finally, individual identity development causes the simultaneous evolution of the community of practice.

According to Hickey and Zuicker (2003), from the perspective of sociocultural learning theory as it applies to learning science, doing science in the classroom is the learning goal, not the abstract learning of scientific content or skills. Signs of students doing science in the classroom include students' participation in genuine social scientific practices like inquiry, modeling, peer critique, and argumentation. These activities help students form positive scientific identities.

Sociocultural Learning Assessment Methods

To effectively assess student learning in curricula designed from sociocultural learning theory, it is paramount that the assessment techniques align with the learning theory that guided the design (Barab & Kirschner, 2001; Hall, 2001; Hickey & Zuiker 2003; Kisidou & Roseman, 2002). Sociocultural learning theory guided the creation of the units of CCE to support and enhance student to student and student to teacher interaction as knowledge is co-constructed and shared within the classroom community of practice. According to Barab and Kirschner, from this perspective, the knower cannot be separated from what is known and the context within which it is known. Furthermore, because learning environments are dynamic – always changing as students and the teacher interact effecting the direction of the learning – proper evaluation must take this into consideration. Therefore the unit of analysis cannot be what is happening in an individual's brain alone. Analysis must occur at the "intersection of the individual, context, and activity over time" (p. 6), and must recognize "cognition occurs and is given meaning through the dynamic relations among knower, the known, and the evolving context through which knowing occurs" (p. 9).

In 2001, *The Journal of Learning Sciences* released an issue dedicated to methodology for evaluating learning from a sociocultural learning perspective. Three studies from the issue provided a basis for the methodology of this study. First, Roth (2001) discussed a method for studying individual and distributed cognition in terms of different time scale setting processes.

The study looked closely at the level of scientific language appropriation of participants to see how they developed individually within a community of practice and how the knowledge was distributed between participants. He "zoomed" in on video recordings of individual gestures and talk to answer questions about individual growth. He zoomed out on the same recordings to whole classroom discussions and the language norms and practices of the community to answer questions about community growth.

Second, Cobb, Stephan, McClain, and Gravemeijer (2001) described the collective practices and individual reasoning of students in an elementary mathematics classroom. They collected student interviews, video recordings, field notes, and student artifacts. These data sources allowed them to trace the development of individual student practices along dimensions such as individual reasoning skills and the particular behaviors of the individual based on his/her beliefs about his/her personal role in the classroom and the role of mathematics. In addition, they traced the development of shared practices along dimensions such as the normed ways of acting, reasoning, and arguing that occurred during the classroom activities.

Third, Barab, Hay, and Yamagata-Lynch (2001) advanced a methodology they used to describe the diffusion of students' practices and conceptual understanding across a classroom community of practice. Initially, they used video recording data and student interviews to create an observation protocol for further data collection. This protocol helped them to document and link the issues the students discussed with the students who initiated the issues, the students who participated in response within the discussions, and what resources and practices the students used to participate in the discussions of the issues. Grounded theory framed further data analysis and helped them turn these links into graphical maps through the use of computer software that displayed how the knowledge of the classroom was distributed across participants and that documented individual growth from peripheral to full participation in the community of practice of the classroom.

However, Hickey and Zuiker (2003) point out a crucial dilemma. Since the No Child Left Behind Act (NCLB), there is a growing movement to evaluate experimental curriculum using traditional, empiricist methods, such as standardized tests, to justify their validity and further implementation across varied settings. Similarly, administrators at the school where I teach are hesitant to support new curricular pieces if students do not do well on traditional, multiple-choice tests at the end of the year. The problem is that it is difficult for students to perform well on standardized tests that have been created from the perspective that knowledge resides in the individual and can be transmitted from teacher to student when the innovative curriculum they have learned within was developed from the perspective of sociocultural learning theory.

In an attempt to alleviate the tension of evaluating innovative curriculum within a traditionally minded system, Hickey and Zuiker (2003) propose what they call *dialectical reconciliation*. This reconciliation process includes the strengths of traditional, empiricist evaluation measures with the strengths of rationalist evaluation measures and situates data from these types of evaluations in "event-based evidence of participation in domain knowledge practices" (pp. 554-555). In this way, traditional, individual multiple-choice test scores (empiricist) and individual performance assessment scores from things like inquiry-based lab work (rationalist) are not considered at odds with each other or with interpretive data derived from observations of classroom activities. In other words, the three perspectives are used to completely evaluate an innovative curriculum's ability to reach its sociocultural learning theory-based goals from multiple angles.

Methodology

Mixed Methods Research

Fundamentally, a quantitative, positivistic research approach is not adequate to fully evaluate innovative classroom programs that are developed from the framework of sociocultural learning theory (Hickey & Zuiker, 2003). However, according to Hickey and Zuiker, traditional, quantitative analysis of individual students' artifacts is also important for two reasons. First, it can be used to appeal to policy makers that require positivistic methods for the valid evaluation of a classroom program or curriculum. Second, properly connected to or situated in the classroom context, quantitative data of students' individual cognitive development can support or enhance qualitative, interpretive data used to describe the social nature of learning in a classroom. For this reason, Hickey and Zuicker's (2003) dialectical approach to program evaluation was used to guide a mixed methods study.

Mixed methods research, the combination of qualitative and quantitative methods, is a powerful approach that can develop more detailed or complete answers to research questions than either approach on its own (Boeije, 2010). More specifically, this study was framed by a concurrent triangulation approach where qualitative and quantitative data were essentially collected at the same time and shared approximately equal weight (Boeiji, 2010) to fully describe the level of chemistry content knowledge students demonstrated within critical chemistry education (CCE) and how they demonstrated it.

Research Context and Participants

The independent (private) high school where I enacted CCE in two "regular level" chemistry classes was located in a highly resourced, affluent New England suburb of New York City. The majority of the students who attend this school is White and come from upper, middle class backgrounds. Annually, approximately 25% of the study body self identifies as a person of color. In addition, the socioeconomic diversity of the school is somewhat enhanced through financial aid, which is provided for approximately 20% of the student body annually.

The two regular level chemistry classes were selected because administrators at the school were hesitant to alter the honors level chemistry curriculum. All 25 students in the two classes agreed to participate in this study. There were nine students in one class, three girls and six boys, and 16 in the other class, six girls and ten boys. Furthermore, the ethnic makeup of the two classes approximated the level of diversity of the school as a whole. Finally, the average age was 15 years.

The Critical Performance Assessments of CCE

For the purposes of this paper, a description of each of the five critical performance assessments (CPAs) enacted during the four critical units I created as part of CCE provides a foundation for understanding what students did in my classroom during this study (See Appendices B through I for complete unit maps and materials). Fundamentally, the CPAs were guided by the concept of performance expectations described in the NGSS. Therefore, CPAs required students to demonstrate their chemistry content knowledge through the practices of science and engineering (Pruitt, 2014). The practices of science and engineering the students participated in during the CPAs consisted of: (a) asking questions and defining problems, (b) developing and using models, (c) planning and carrying out investigations, (d) analyzing and interpreting data, (e) using mathematics and computational thinking, (f) constructing explanations and designing solutions, (g) engaging in argument from evidence, and (h) obtaining, evaluating, and communicating information (NGSS, 2013a). In addition, the critical component of the CPAs asked students to thoughtfully analyze how the content knowledge they produced for themselves related to socially relevant issues or to ways they could better their communities or society as a whole.

Three of the CPAs were framed as inquiry labs. Essentially, each of these inquiry labs required that students ask a question, plan and carry out an investigation, analyze and interpret data, use mathematical thinking, construct explanations, and communicate information in written conclusions. In addition, student presentations of their inquiry lab work and subsequent peer critique activities in the classroom required students to engage in argumentation, and the communication and evaluation of information.

The metal inquiry lab of the critical metal unit was guided by the problem of determining a pure metal to use to construct a bridge in a moist environment that would best resist corrosion. This added an engineering component to this particular inquiry lab. The content knowledge students demonstrated through the practices of science incorporated in this inquiry lab included oxidation and reduction, single replacement reactions, the properties of pure metals and alloys, and the metal activity series. The critical component of this lab consisted of grounding students demonstration of metal-related content knowledge in the context of diverse metallurgy practices in ancient and modern cultures and the analysis of steel manufacturing as it relates to the modern day economies of the U.S. and developing countries.

The kinetics inquiry lab of the critical kinetics unit was guided by the question of what factors affect reaction rate. The content knowledge students demonstrated in this CPA included collision theory, reaction rate, and factors that affect reaction rate. One of the critical components of this lab included developing students' ability to take on the persona of scientific expert. This was accomplished by prompting each lab group to investigate their own, unique factor that may affect reaction rate. As a result, when students presented their findings to their classmates, they were the experts of that particular area of kinetics knowledge; experts that their classmates worked with to perform well on future assessments. Another critical component of this lab was the comparison of the empiricist practices of Western modern science (WMS) to other ways of thinking and developing knowledge such as intuition and the biases inherent in WMS.

The heartburn inquiry lab of the critical acid/base unit started by requiring students to define what an effective heartburn remedy would do from their own perspective and in their own words. In addition, it required students to then ask their own question about the ability of different cultural home remedies and over-the-counter remedies for heartburn to perform according to their own definition of relief. Students demonstrated their understanding of acids and bases, pH, neutralization, and reaction rate within this CPA. Moreover, students used chemistry content knowledge and the knowledge they developed about heartburn remedies through their own investigations to critically analyze scientific information presented in advertisements and to examine issues of healthy living, global healthcare, and the pharmaceutical industry.

The other two CPAs were unique. In the critical scientific reading/writing CPA of the critical kinetics unit, students read two newspaper articles about hydrogen fuel cell cars (Chang, 2014; Soper, 2015), and then constructed a critical, written stance on the information presented in the articles. Students used the practices of asking questions, analyzing and interpreting data, constructing explanations, and evaluating and communicating information to demonstrate their understanding of oxidation and reduction, electrolysis, synthesis and decomposition reactions, thermodynamics, and kinetics. This CPA was grounded in the critical concepts of investigating writers' hidden agendas, using personal writing styles to write about science, and examining the potential for the products of WMS to have both positive and negative outcomes.

Finally, in the critical organic unit, students created, presented, and then defended models of organic functional groups in a small group, peer critique activity. Through the scientific practices of modeling and argumentation, students creatively tied their personal interests to chemistry to demonstrate their understanding of simple organic molecules, organic functional groups, covalent bonding, and valence shell electron pair repulsion theory within this CPA. Students created these models to better understand the organic chemistry presented in a book chapter that discussed the history of the creation of the female oral contraceptive (Le Couteur & Burreson, 2003). This book chapter framed critical conversations about Western, white male bias in the research agendas of science.

Data Collection Methods and Analysis

To fully realize Hickey and Zuicker's (2003) dialectical approach, qualitative and quantitative data collection and analysis was framed by the four-level system of Barab, Sadler, Heiselt, Hickey, and Zuicker (2007) to develop a complete picture of how and to what extent students demonstrated chemistry content knowledge working within CCE.

Level 1 – Immediate-level qualitative data. At the immediate-level, interpretive, event-based, qualitative methods were used to document and analyze students' content knowledge through their participation in classroom activities (Barab et al., 2007). Three immediate-level qualitative data sources were collected for this purpose.

Video recordings. Video recordings of the classroom activities were collected from each critical unit of CCE (See Appendix A for Study Timeline). Table 6.1 details the number of the classes video recorded per unit. In addition, when students were working in small groups around the room, they made their own audio recordings of their work using their laptop computers. These audio recordings were then matched with the video recordings. I personally transcribed the recordings for each day to document complete classroom events from multiple angles.

Table 6.1
Video recorded data

	Metal	Kinetics	Organic	Acid/Base
Class meetings	8	7	4	10

Note. Class meetings refer to the number of hour-long class periods that were video recorded and audio recorded from multiple angles.

Focus group interview. Loosely framed, focus group interviews were conducted and digitally audio recorded within a week of each unit. For this paper, the purpose of the interviews was to prompt students to clarify and elaborate upon some of the content knowledge and behaviors I noted in the moment in the classroom (See Appendices M – Q). From a critical, social constructivist, research point of view, the interviews facilitated *member checking* in that they helped me to co-construct interpretations with my student participants in an open, reflective way (Creswell, 2013). Member checking helped to guard against my own biases and ensure a true emic, insider, understanding was developed, which supports the *credibility* of the study (Guba & Lincoln, 1989).

Researcher journal. The researcher journal also enhanced the *credibility* of the study by helping me to keep track of my thoughts during data collection and analysis. In addition the journal helped me to balance my roles as a teacher and researcher, to reflect upon my biases, and to communicate with the administration at the school setting. It also especially helped me to evaluate the comfort level of my student participants as they worked through a very rigorous critical chemistry education (Creswell, 2013).

Immediate-level analysis. Immediate-level analysis was used to situate an understanding of students' chemistry knowledge in the shared knowledge and practices of the classroom community of practice. This level of analysis began by mapping the transcripts from the classroom recordings of the first curricular transformation into action relevant episodes (AREs) (Barab et al., 2001). For the purposes of this study, AREs were segmented portions of the complete transcripts when there was a high level of interaction between students and between students and the teacher that followed a continuous thread of an idea, concept, or topic. At times AREs could be lengthy, at others, very short, consisting of only two participant contributions.

After the transcripts for the first unit were segmented into AREs, I used NVivo, a qualitative analysis software tool, to *open code*, or create "nodes" in the vernacular of NVivo, the dialogue from the AREs. This process entailed identifying and segmenting concise statements from the data and categorizing them by names or codes, ideas that reside in the data (Boeije, 2010). Coding was, in part, deductive and applied in nature (Boeije, 2010) because I was guided by the work acknowledged in the theoretical framework. However, I was also careful to let codes emerge from the data that I had not considered before to more deeply and in a more nuanced way answer the research question. In this sense, the analysis was also inductive and interpretive (Boeije, 2010).

Coding the first unit established a general mapping format and set of guidelines that were then used to code the AREs from the subsequent units. Table 6.2 provides an example of the mapping format. Each student's contribution was coded for the content topic discussed, classroom practice participated in, and the tool or resource used to share the content knowledge (Barab et al., 2001). In the example presented in Table 6.2, Brooke (all names are pseudonyms) shared content knowledge about single replacement reactions and metal reactivity with the class. Because the statement supported a claim with reasoning it was coded to be an example of argumentation. Evidence and/or theoretical reasoning-supported claims became the benchmark of argumentative practice used for this study (Berland & McNeill, 2010). Finally, Brooke used her group's lab data and information they had researched from the textbook as resources to share this content knowledge.

Table 6.2
ARE Map Example

Student	Dialogue	Content Topics	Classroom Practices	Tools/ Resources
Brooke	The magnesium replaced the copper in the nitrate compound because magnesium is more reactive than copper metal	Single replacement reactions Metal reactivity	Argumentation	Lab data Textbook

After all the AREs were coded, a "zoomed" in look at individual student contributions (Roth, 2001) was undertaken to log and map with NVivo node matrices all the classroom practices students participated in and tools they used to share content knowledge across all four curricular transformations. In addition, a "zoomed" out look at student-student interactions and student-teacher interactions (Roth, 2001) was undertaken in a similar way with NVivo to note trends in students' adoption of the classroom community of practices. In particular, it was noted when students were the initiators of either AREs or shared practices and when they were simply participants to document potential student movement from peripheral participation to full participation (Barab et al., 2001).

Level 2 – Close-level quantitative and qualitative data. At the close-level, rationalist-based (Hickey & Zuicker, 2003), quantitative and qualitative methods were used to document and analyze how individual students extended the practices of the classroom community to their work on five critical performance assessments (CPAs) from the four critical units of CCE (Barab et al., 2007).

Student artifacts. The five CPAs were collected from the four critical units of CCE. A Power Point presentation and Word document were collected for the metal, kinetics, and acid/base inquiry lab CPAs. A Word document was collected for the critical scientific reading/writing CPA. And the model and related Power Point presentation were collected for the organic functional group model project CPA.

Close-level quantitative analysis. The three inquiry labs were scored by a distinct interval-scale, scoring rubric with five separate categories each scored 0 to 4 (See Appendix V). A second, distinct rubric was used to score the critical reading/writing assignment of the kinetics unit with six categories each scored 0 to 4 (See Appendix W). A third, distinct rubric was used to score the organic functional group models the students created during the organic unit with four categories each scored 0 to 4 (See Appendix X). Students' total rubric scores on the five CPAs were determined and expressed as a decimal.

The reliability of the rubric-derived scores for the five CPAs was supported by a procedure for determining inter-rater reliability by calculating Cohen's Kappa (Cohen, 1960). First, a peer collaborated with the researcher in establishing a coherent interpretation of the grading rubrics used to score each artifact (See Appendices V – X). Then the researcher scored all the student artifacts and the peer scored at least 20% of each type of artifact: 20 of the 75 inquiry labs, 5 of the 25 writing assignments, and 10 of the 25 organic functional group model presentations. The separate scores of the researcher and the peer were then used to calculate a weighted Cohen's Kappa value for each type of artifact. The weighted Kappa value for the three inquiry labs that used the same rubric was 0.809. The weighted Kappa for the critical scientific reading/writing assignments was 0.790 and for the organic functional group models it was 0.859.

Then, histograms and Shapiro-Wilk's tests were used to determine if the data were normally distributed. However, in fact, the data were not normally distributed for any of the artifacts, thus indicating use of nonparametric statistics. However, a Bartlett's test confirmed homogeneity of variances. Next, Wilcoxon, nonparametric *t*-tests were used to compare students' scores on performance assessments to students' scores on unit posttests. All of this was done to quantitatively describe the extent of students' chemistry content knowledge demonstrated in the CPAs at the close-level.

Close-level qualitative analysis. The rubrics used to score the five CPAs did not measure content knowledge only. The rubrics assessed students overall critical scientific literacy for which content was only a part. Therefore, NVivo was also used to code the content knowledge exhibited in these performance assessments. An instance was coded as a demonstration of content knowledge if it explained a chemistry fact or concept and was used correctly to complete the CPA.

Level 3 – Proximal-level quantitative data. At the proximal-level, empiricist-based (Hickey & Zuicker, 2003), quantitative methods were used to document and analyze how individual students applied the chemistry knowledge they developed through participation in the classroom community of practice in the new context of a traditional, multiple-choice content knowledge-based post unit test (Barab et al., 2007). To complete, proximal-level analysis, students participated in pre- and post-unit tests for each of the four curricular transformations, except for the unit containing the critical metal activity series lab where there was only enough time before a school break to schedule the posttest. The pre- and post-tests of the kinetics, organic, and acid/base units were the same in structure and very similar in difficulty and content topics, but contained different questions to prevent students from doing better on the posttest because they remembered the questions on the pretest (See Appendices Y – EE).

Proximal-level quantitative analysis. Proximal-level quantitative analysis began by determining students' decimal scores on each of the pre and post unit tests. Next, histograms and Shapiro-Wilk's tests of normality were used and showed that the data for the organic and acid/base pre and post unit tests were normally distributed, but not for the kinetics unit. Bartlett's tests confirmed homogeneity of variances for all tests. Finally, parametric, paired *t*-tests were run on the pre and post unit tests of the organic and acid/base units, and a nonparametric, Wilcoxon, paired *t*-test was run on the pre and post kinetics unit tests. The tests sought to determine if there was a statistically significant increase in students chemistry content knowledge pre to post unit.

Level 4 – Distal-level quantitative data. At the distal-level, empiricist-based (Hickey & Zuicker, 2003), quantitative methods were used to document and analyze how individual students applied the chemistry knowledge they developed through participation in a full year of CCE on a large-scale, traditional, multiple-choice, standardized test designed to cover a range of topics (Barab et al, 2007). At this school setting, all "regular level" chemistry students took the same traditional, cumulative, final chemistry exam at the end of the year (See Appendix FF). This included the 25 students who participated in CCE in the two regular level chemistry classes that took part in this study. My chemistry department colleagues taught the other 80 students who took this final chemistry exam based upon a more traditional chemistry curriculum. The chemistry content covered by the CCE curriculum and traditional curriculum that appeared on the exam was the same.

Distal-level quantitative analysis. Distal-level quantitative analysis began by determining the mean decimal score of the two CCE classes and the mean decimal score of the 80 students from the traditional classes on the final exam. Next, histograms and Shapiro-Wilk's tests were used to determine that the data were normally distributed and Bartlett's tests confirmed homogeneity of variances. Finally, an unpaired *t*-test was run on the decimal scores from each of these two groups of students. This test sought to determine if there was a statistically significant difference between the two groups' overall chemistry content knowledge.

Findings

The findings are presented in four sections corresponding to the four levels of Barab and colleagues' (2007) work to develop a complete picture of how and to what extent students demonstrated content knowledge working within critical chemistry education (CCE). (1) At the immediate-level, "zoomed in" and "zoomed out" looks at the classroom transcripts are presented from the four curricular transformations to describe students' demonstration of content knowledge in a classroom community of practice. (2) At the close-level, findings from the five critical performance assessments of the four curricular transformations are presented. (3) At the proximal-level, results from the four pre/post unit tests are presented. (4) At the distal-level, results from the cumulative, final chemistry exam are presented.

Immediate-level "Zoomed In"

A zoomed in look at individual student contributions to classroom activities documented in the action relevant episodes (AREs) revealed students participated in six different classroom practices across the four critical curricular transformations: (a) argumentation, (b) modeling, (c) inquiry, (d) peer critique, (e) revision, and (f) presentation. The inquiry category (c) included the practices of asking questions, planning and carrying out investigations, analyzing and interpreting data, using mathematics and computational thinking, and constructing explanations. A category of (g) other was also used for practices that did not truly fit into any of these other categories.

In addition, this zoomed in look revealed students used seven different tools or resources to share content knowledge with the class: textbook, Internet, outside prior knowledge, shared classroom knowledge, student created model, student determined lab data, and newspaper article. When students were coded to have used the *textbook or Internet*, it was not that they read from these resources in the classroom, it was that they had read about something from these resources in previous work outside of class that they then shared with the class. *Outside prior knowledge* was defined as anything that had not been discussed during the school year in chemistry class. Most outside prior knowledge likely came from previous science courses or information shared in family or community settings. *Shared classroom knowledge* was defined as anything that had been brought up before in the class in any way: lecture, student contribution, lab work, etc.

The zoomed in look at students' individual, chemistry content knowledge contributions to the variety of classroom activities documented in the AREs revealed there were 274 coded instances when students shared content knowledge with the class during the four curricular transformations. Table 6.3 shows the number of times individual students contributed content knowledge to the classroom activities by major content area of the four units. Table 6.4 provides a detailed account of the types of classroom practices the students participated in when they shared content knowledge. Finally, Table 6.5 shows the tools or resources they used to share the content knowledge. For each of these tables, the number of instances of each type of contribution is separated into range categories of 0, 1-2, 3-4, and ≥ 5, which are tallied further for the number of students within each range ($N = 25$).

Table 6.3
Content knowledge contributions

	Metal Reactivity	Kinetics	Organic	Acid/Base	Other
≥ 5	2	0	6	0	6
3-4	6	5	8	6	5
1-2	13	18	8	11	13
0	4	2	3	8	1

Note. Content knowledge contributions per content area tallied by number of categories (rows) and number of students who contributed to each range of categories (columns).

Table 6.4
Classroom practices demonstrated

	Argument	Modeling	Inquiry	Peer Critique	Revision	Presenting	Other
≥ 5	7	1	4	0	0	1	1
3-4	10	8	6	2	0	11	4
1-2	5	12	11	12	7	12	16
0	3	4	4	11	18	1	4

Note. Classroom practices demonstrated in conjunction with shared content knowledge per type of practice tallied by number of categories (rows) and number of students who contributed to each range of categories (columns).

Table 6.5
Tools or resources used to share content knowledge

	Textbook	Internet	Outside Prior Knowledge	Shared Classroom Knowledge	Student-Created Model	Student-Determined Lab Data	Newspaper Article
≥ 5	0	0	0	9	5	1	0
3-4	4	2	2	10	7	3	3
1-2	12	13	11	6	10	18	6
0	9	10	12	0	3	3	16

Note. Tools or resources used to share content knowledge per tool tallied by number of categories (rows) and number of students who contributed to each range of categories (columns).

It is important to note that a single instance of shared content knowledge could have consisted of more than one content knowledge area, more than one practice, and more than one tool or resource; therefore, multiple coding was used to reflect these multiple instances. For example, while she worked with her partner to construct a hypothesis during the metal reactivity inquiry lab, Annabel stated, "Because of the closeness to the noble gases, the alkali and alkaline Earth metals are very reactive." This one sentence was coded as content knowledge related to metal reactivity and content knowledge of element's positions on the Periodic Table. Annabel demonstrated this knowledge during the practice of inquiry, and was also coded to have made an argument because she supported her claim with evidence in the form of theory in the sense that she understood that reactivity is connected to stability, which is exemplified by the noble gases. Finally, she used the tool of shared classroom knowledge to contribute this content knowledge.

In addition, most of the time the category of "other" practices was used for when students shared a chemistry fact or made a chemistry-based claim without supporting the fact of claim with evidence or reasoning. However, other times, the category of "other" was used when students asked pertinent, thoughtful, content-based questions that indicated they already had some content knowledge that they were trying to elaborate upon or hone in on to help the group with the classroom activities. For example, when Amanda and her lab partner were developing a procedure for the metal activity series lab, she asked her partner, “Is lead one of the ones that has two different charges?” This indicated that even if she could not precisely remember if lead did have two possible oxidation states, she was aware that it was a possibility for a metal located in the p block on the Periodic Table. In this sense, her question initiated the sharing of content knowledge as she and her partner looked up the answer to her question in their class notes.

Immediate-level “Zoomed Out”

A zoomed out look at these immediate-level data revealed that CCE fostered a student-centered, community of practice where students shared and developed chemistry content understanding with their classmates and the teacher, grounded in real world, socially situated contexts. Evidence for this came from 40 student-initiated AREs documented within the small and whole group discussions/activities of all four critical units. These AREs demonstrated students adopted the practices of the classroom to share and develop chemistry content knowledge. Here, I distinguish student-initiated AREs from other instances when the teacher prompted discussions of content knowledge to emphasize that students were adopting the community’s practices as their own practices. Within these 40 AREs, there were 73 instances of students sharing knowledge about one of the five categories of chemistry content noted above in Table 6.3 in the zoomed in findings. Table 6.6 provides the number of student-initiated, content relevant AREs documented for each critical unit and the total number of whole class video transcripts and individual small group transcripts recorded for each unit to provide a context for comparison.

Table 6.6
Student initiated AREs and the number of small and whole group transcripts per unit.

	Metal	Kinetics	Organic	Acid/Base
Transcripts	18	20	17	16
AREs	8	9	19	4

Note. The differences in the numbers of student-initiated, content rich AREs documented for each unit are the result of the nature of the activities of the units rather than an indication of students' relative content knowledge.

CCE seemed to foster the development of the community of practice by providing students with socially relevant contexts and activities. This afforded them opportunities to hone their understanding of chemistry while at the same time use content knowledge to better understand and analyze the socially relevant issues. An example excerpt from a student initiated ARE from each CCE unit along with a description of the context of the ARE fully describe the socially situated, content knowledge shared within the community of practice.

Metal unit. The metal inquiry lab was grounded in the socially relevant importance of metals and metallurgy throughout the history of civilization. Different cultural practices of metallurgy were discussed before the lab was conducted. Within this context, students performed an inquiry-based lab that aimed to enhance their understanding of single replacement reactions, metal reactivity and the activity series, and the durability of alloys. The driving question for the lab was, "Which pure metal would you use to build an ornamental bridge in a garden if corrosion is your only concern?" Of the pure metals provided for them, most students learned that copper would be the best metal for this job because it is the least reactive. On the last day of the lab activity, after students presented the results from their labs with Power Point, the developed, shared understanding of metal reactivity helped students to better analyze and understand the class's discussions about the importance of alloys such as bronze and steel in the history of civilization and modern day industry.

Table 6.7 documents Thom's critique of the lab work presented by Flinn and his partner on the last day of the metal activity series lab. This example demonstrates these students' use of peer critique and argumentation to participate in the classroom community of practice. Thom noticed the inconsistency that Flinn's lab results suggested that copper and iron were equally reactive, yet Flinn had chosen copper to build the bridge. Flinn defended his choice of copper based on what he and his partner wrote in the conclusion of their lab report. They wrote that even though their results did not parse out the difference in reactivity between iron and copper, the activity series did, which then served as the basis for their choice. In this example, it is evident that Thom's peer critique initiated the discussion of content knowledge that had not been made explicit by Flinn's initial presentation that potentially improved the class's overall understanding of metal reactivity.

Table 6.7
ARE map excerpt – Metal unit example

Student	Dialogue	Content Topics	Classroom Practices	Tools/ Resources
Thom	If iron and um copper are the same supposedly on your graph, then why did you choose um copper instead of iron [to build a bridge]…	Metal reactivity	Peer critique	Lab data
Flinn	Well, if I'm not mistaken, iron, um copper, is lower than iron and lead on the activity series so that led us to… It's less reactive so that is why we chose it.		Argument	Shared classroom knowledge

Kinetics unit. During the kinetics unit, students participated in a critical performance assessment that prompted them to critically analyze the validity and or strength of the information and viewpoints contained in two newspaper articles about hydrogen fuel cell cars (Chang, 2014; Soper, 2015). For example, students were asked to consider who potentially benefitted from the publication of these articles and who potentially did not. To do this, students had to know about synthesis and decomposition reactions, thermochemistry, kinetics, and catalysts; i.e. content knowledge was used to analyze the socially relevant topic. At the same time, the activity afforded students with opportunities to share and develop their understanding of these chemistry content topics.

Table 6.8
ARE map excerpt – Kinetics unit example

Student	Dialogue	Content Topics	Classroom Practices	Tools/ Resources
Peter	So wait, is it splitting or synthesis?	Chemical reactions	Question	Newspaper
Cooper	It is synthesis… because you are adding hydrogen and oxygen together.		Argument	Shared classroom knowledge, Newspaper
Emily	Yea, but why are they talking about splitting them apart first?		Resource analysis	Newspaper
Cooper	So, I think the reaction of them coming together releases energy.	Thermo-chemistry	Argument	Shared classroom knowledge, Newspaper
Emily	Oh, ok.			

Table 6.8 provides an example of Peter, Cooper, and Emily working in a small group predominantly participating in argumentation, specifically discussing the details of the main

reaction that occurs in a hydrogen fuel cell car. It was evident that Peter and Emily may have been confused about the difference between the main reaction that occurs in the car and the process that is required first to isolate hydrogen gas to fuel the car. But, it seemed that Cooper's contributions likely cleared up this confusion. Furthermore, while Cooper was the main contributor of content knowledge, this example also demonstrated that Peter's pertinent content related question was no less important to the classroom practices during knowledge sharing and construction within the community of practice. Without Peter's question, Cooper would not have worked out his thoughts about the chemistry content aloud to the benefit of Peter and Emily as well as himself.

Organic unit. The critical organic unit was introduced through the reading of a book chapter called "The Pill" (Le Couteur & Burreson, 2003). The book documented the importance of chemistry to the history of civilization. The chapter "The Pill" specifically discussed the socially relevant history of the development of the organic chemistry responsible for the female oral contraceptive. In this unit, students had to make sense of the organic chemistry presented in the chapter as well as to critically analyze the potential for bias in Western modern science specific to this topic and in general. To enhance the understanding of organic chemistry presented in the chapter, students worked in pairs or groups of three to create a model of a specific organic functional group. The guidelines for the model were to creatively build a three-dimensional representation of the functional group and to develop a short Power Point that would be used to present the model and how it connected to the chapter. Here, again the socially situated investigation of chemistry content knowledge provided students with a context to employ specific practices of science and participate a classroom community of practice.

Table 6.9 provides an example of four students working in a small group to critique and analyze the model of an alkyl group created and presented by Megan and Flinn. The model sparked a full discussion about different types of hydrocarbons.

Table 6.9
ARE map excerpt – Organic unit example

Student	Dialogue	Content Topics	Classroom Practices	Tools/ Resources
Flinn	Oh, yea, so alkane, what is the difference between alkane, alkene, and alkyne?	Organic chemistry/ Hydro-carbons	Question	Student model
Cassandra	Oh, oh alkanes are…		Discussion of chemistry facts	Shared classroom knowledge
Steven	Single bonds.			
Megan	Alkanes are single bonds.			
Flinn	Ok, alkenes are double bonds.			
Steven	And alkynes are triple bonds.			
Megan	Triple bonds.			
Cassandra	Alkanes are saturated.		Elaboration	
Megan	And then the other two are unsaturated.			
Flinn	Alkanes are saturated?		Clarification	
Megan	Yea, alkanes are saturated, which means they have the max number hydrogens per carbon.		Elaboration	
Cassandra	And…			
Flinn	Oh, so they are unsaturated because they have more than one bond.			

In this ARE excerpt, no students made a relatively full scientific argument, but their discussion of chemistry facts led to a deeper, group-shared understanding of these concepts as students worked together in a community of practice that was developed by the model critiquing activity, and grounded in the socially relevant context of birth control.

Acid/Base unit. The heartburn inquiry lab of the acid/base unit opened the door for students to share, develop, or further enhance their understanding of the content knowledge of acids and bases and kinetics within the socially relevant topic of preventative, healthy eating versus taking medication for heartburn after the fact. In particular, students used content knowledge to develop ways to scientifically measure their own personal definitions of "effective" for heartburn remedies and then investigated the effectiveness of both over-the-counter and cultural home remedies in terms of their definition. The results from the investigations were then used to discuss and analyze the products of pharmaceutical companies and their attempts to balance their financial competitiveness and their responsibilities to the people of the world. For example, Steven and Jake wanted to measure the effectiveness of two different over-the-counter remedies compared to each other and two different home remedies compared to each other by speed of relief in terms of how quickly the remedy neutralized acidity.

Table 6.10 provides a portion of their dialogue while they constructed their procedure. In this dialogue, it is evident how important understanding content knowledge is to experimental design. To construct their socially relevant experiment, Steven and Jake had to know that they could measure acid/base neutralization with pH, and that they could use the slope of a graph that measured pH per time to approximate the reaction rate. At the same time, working through these concepts within the context of the lab afforded them an opportunity to share and enhance their ideas about these topics with each other as members of a community of practice.

Table 6.10
ARE map excerpt – Acid/base, heartburn inquiry lab example

Student	Dialogue	Content Topics	Classroom Practices	Tools/ Resources
Steven	And what, record time of…		Inquiry	
Jake	Say using the pH probe, record the time…	Reaction rate, pH		Shared classroom knowledge
Steven	The time of what… the reaction…			
Jake	Yea… No, no we record change in… speed of change in pH.			

Scientific Expertise. Further zoomed out analysis at the immediate-level also suggested that students were moving from peripheral participants to full participants within the community of practice. First, the level of chemistry content related participation in the student-initiated AREs generally increased over the course of the year for 17 of the 25 student participants. This indicated that the classroom activities were not dominated by a select few students who were the only full members of the community. Second, for 12 students, the number of times they were the initiator of a content-rich ARE increased over the course of the year. This indicated that these students began to move from a more peripheral membership in the community to a more full membership in the community on their own as they became comfortable leading or initiating discussions.

Furthermore, this level of analysis revealed that all, but the first, of the critical units afforded students with the opportunity to take on the persona of scientific expert, which essentially prompted students to take on full membership in the community. There were 38 instances, spread across 20 students, when student pairs or small groups were documented to have taken on the role of scientific experts during the presentations of the kinetics, organic, and acid/base units.

Table 6.11 provides the number of instances coded per unit along with the number of transcripts that documented student presentations to provide a context for comparison. These instances were coded as such because students shared content knowledge with the class that had not been discussed before by the teacher. Students were the experts in the classroom of the content knowledge they shared, which they contributed to the community of practice through a formal presentation. In addition, these instances were only coded if student experts elaborated or articulated enough that their peers took notes to use for future assessments.

Table 6.11
Students as scientific experts and the number of presentations transcripts per unit.

	Metal	Kinetics	Organic	Acid/Base
Transcripts	2	1	2	2
Scientific expert	0	8	26	4

For example, Amanda was coded to have taken on the persona of a scientific expert when she and her partner presented their kinetics inquiry lab. During the presentation she stated:

> So the known theory is that when the temperature increases, the higher the reaction rate. And that is because the higher the temperature, the faster the particles are moving, and when particles are moving faster, they are more likely to collide, like the number of times, which is what increased the reaction rate. So our lab confirmed that, like agreed with that, because when we increased the temperature, the reaction rate also went up.

Her explanation of the effect of temperature on reaction rate was articulate, detailed, and connected to the lab results. This was the community's first and only formally presented exposure to this concept, which prompted Amanda's classmates to take notes as she talked and referenced the graph and data table contained in her Power Point slides. This demonstrated that Amanda was becoming more of a full member of the community of practice rather than only a peripheral member.

As a whole, zoomed in and zoomed out immediate-level findings suggested that students demonstrated a substantial amount of chemistry content knowledge in a classroom community of practice. Furthermore, the socially situated activities of CCE seemed to foster or at the very least ground the sharing of content knowledge between students and the teacher. Finally, increases in the number and degree of students' participation in the classroom community of practice suggested a number of students were beginning to move from peripheral to full members.

Close-level

We already saw how the presentations of some of the critical performance assessments (CPAs) of CCE afforded students with opportunities to take on the role of scientific expert in the classroom. Quantitative and qualitative close-level analysis of the five CPAs of the four critical units added a deeper understanding as to how and to what extent individual students demonstrated chemistry content knowledge within CCE. First, quantitative data from the five performance assessments are presented. Second, qualitative analysis of the work contained in the performance assessments provides more detail about the content knowledge demonstrated by students.

Table 6.12 provides the decimal average of the rubric-based scores of the five CPAs. The maximum score was 1.0 for each assessment. Table 6.12 shows performance on these five assessments fluctuated with the type of assessment and content area. The C range averages on the first two assessments and the organic model were lower than the general B- average for the class, while the newspaper analysis CPA was quite a bit higher than the general average. In addition, a closer look at individual student scores and the details of the content knowledge they demonstrated in the CPAs revealed an interesting pattern.

Table 6.12
Mean decimal scores of the five CPAs

	Metal Inquiry Lab	Kinetics Inquiry Lab	Critical Scientific Reading/ Writing Assignment	Organic Functional Group Model	Acid/Base Inquiry Lab
Mean	0.70	0.72	0.89	0.75	0.82
SD	0.07	0.08	0.09	0.12	0.08

While the variety of CPAs of CCE provided all students with rationalist-based, nontraditional ways to demonstrate their content knowledge, students who generally struggled on traditional forms of assessments seemed to benefit from the CPAs to an even greater extent than other students. First, ten students who consistently performed below the class average for the unit tests of these four critical units were selected and compared to the other 15 students. Table 6.13 documents the mean decimal scores for the five CPAs and the four units tests of these “lower achieving” ten students compared to the other 15 “higher achieving” students. In addition, Table 6.13 provides the results from correlated Wilcoxon *t*-tests run between the CPA scores and unit test scores for each group of students.

Table 6.13
Comparison of lower achieving students to higher achieving students

	CPAs	Unit Tests	*Z*	*p*	*ES*
Lower achieving					
Mean	0.75	0.64	*2.80	*0.005	2.2
SD	0.03	0.05			
Higher achieving					
Mean	0.79	0.80	*0.31	*0.757	–
SD	0.06	0.06			

Note. * Based on Wilcoxon test due to nonparametric data.

Table 6.13 indicates that students who consistently struggled on traditional forms of assessment achieved, with statistical significance, better results on the CPAs of CCE than on unit tests of CCE. On the other hand, there was not a statistically significant difference between the CPA scores and unit test scores of the students who generally did well on traditional forms of assessment. These results suggested that the CPAs of CCE potentially revealed abilities these "lower achieving" students had in contrast to the limited evidence that traditional forms of assessment are capable of recording; or alternatively, it may indicate that these students did know science and the content of chemistry to some extent, but were just not "good at taking tests."

As a reminder, the rubric-based scores of the CPAs did not only assess content knowledge, they also assessed students' overall critical scientific literacy for which content was only a part. With this in mind, a closer, qualitative analysis of the content knowledge exhibited in these CPAs was undertaken for the group of lower achieving students to add weight to the claim that they potentially learned chemistry to a certain extent that was not captured by traditional tests. Analysis revealed a total of 103 instances of elaborate, correct, pertinent content knowledge demonstrated by all ten students in the CPAs. Table 6.14 provides the number of instances per student per CPA.

Instances in Table 6.14 were coded as elaborate, correct, pertinent content knowledge if an explained chemistry fact or concept was used correctly to show completion of the CPA. For example, Steven wrote about the process of electrolysis in his analysis of the pros and cons of hydrogen fuel cell cars discussed in the two newspaper articles:

> [E]lectrolysis [is] a process that can split water with electricity to create hydrogen. This was relevant to the hydrogen car topic because it is one of the best options for producing hydrogen. But, the problem arises from where we get the electricity to create the hydrogen. Using this extra energy takes away from the green source of hydrogen in the first place.

Another example came from Brooke's kinetics inquiry Power Point presentation. She wrote:

> [T]he lower surface area at 4.0 cm^2 had an initial reaction rate of 0.056 C/s and a final reaction rate of 0.115 C/s and the higher surface area at 48.6 cm^2 had an initial reaction rate of 0.100 C/s and then a final reaction rate of .906 C/s… With an increased surface area, there will be an increase in the frequency of the collisions between particles. This happens because as there is more surface area, there will be more opportunity for reactions to occur. With more particles reacting at the same time, the overall reaction time will be shortened.

In both cases, students adeptly used content knowledge to explain their own work: the analysis of the potential benefits of hydrogen fuel cell cars and lab data collected to determine the effect of surface area on reaction rate.

Table 6.14
Instances of content knowledge per CPA

	Metal Inquiry Lab	Kinetics Inquiry Lab	Critical Scientific Reading/ Writing Assignme nt	Organic Functional Group Model	Acid/Base Inquiry Lab	Total
Chris	3	2	1	4	0	10
Bill	2	2	3	4	0	11
Thom	1	1	2	4	2	10
Jack	1	2	1	4	1	9
Brooke	3	1	0	4	2	10
Mike	2	1	3	4	0	10
Peter	3	2	1	2	2	10
Ashley	3	2	2	4	0	11
Megan	2	1	3	2	0	8
Steven	2	3	5	2	2	14

Note. The number of instances documented by CPA is more of an indication of the nature of the assessment rather than the level of content knowledge achieved by individual students.

Proximal-level

Proximal-level analysis of the pre and post unit tests of the critical units of CCE indicated that overall, individual students demonstrated a better understanding of the chemistry content knowledge contained in each unit after each unit was completed. Table 6.15 provides the mean decimal scores for each pre and post unit test pair, except for the metal unit test, which only had a post unit test due to time constraints in the school year. It also indicates the *t*-test results for the units that had both a pre and post test result. The *t*-test results demonstrated the statistically significant increase in students' content knowledge for each of these units.

Table 6.15
Pre and post unit test mean decimal scores

	Pre	Post	*t*	*p*	*ES*
Metal					
Mean	–	0.82	–	–	–
SD		0.09			
Kinetics					
Mean	0.54	0.77	*3.58	< 0.001	1.37
SD	0.17	0.17			
Organic					
Mean	0.26	0.58	7.07	< 0.001	2.54
SD	0.13	0.19			
Acid/base					
Mean	0.16	0.77	23.00	< 0.001	5.55
SD	0.11	0.08			

Note. The metal/reactions unit test did not have a pretest due to time constraints.
* Z-value based on Wilcoxon test due to nonparametric data.

In addition, a comparison of the post-test means of these CCE-developed, critical metal, kinetics, and acid/base units to the tests of the traditional content units I had taught over the previous four years at this school indicated they were all nearly identical: all in the C+ range. This indicated that the critical curricular transformations for these particular units were likely capable of developing the same level of content knowledge as traditional units for individual students. However, the 58% average for the posttest of the critical organic unit was well below the usual C+ average for the tests of this particular group of students as well as below the organic unit averages from years past. This indicated that this CCE unit was likely poorly designed or that the pre/post tests were poorly aligned to the unit. A more complete investigation of this issue is presented in the discussion section of the paper.

Distal-level

Finally, distal-level analysis was conducted on the traditional, final, cumulative chemistry exam that all 105 "regular level" students took at this school, including the 25 participants of this study. As a reminder, the other 80 students were taught by my chemistry department colleagues and experienced the same regular level, traditional chemistry curriculum this school had maintained with few variations for the five years I had worked there. The final exam covered the same content that appeared in my transformed, regular level classroom and the regular level, traditional classrooms of my colleagues (Note. My honors level classes and the honors level classes of my colleagues took a different final exam). The maximum score was 1.0. The mean final, cumulative score for students of the traditional curriculum was 0.794 and for my transformed classroom was 0.792. A *t*-test analysis indicated that there was not a statistically significant difference, $t\ (103) = 0.16$, $p = 0.87$, between the students who participated in CCE for this study ($M = 0.792$, $SD = 0.058$), and the students who participated in the traditional chemistry course ($M = 0.794$, $SD = 0.073$). This level of analysis supported proximal-level analysis, which indicated that, other than perhaps the organic unit, students of CCE likely learned the same amount of chemistry content as students of a traditional chemistry curriculum.

Discussion

Critical chemistry education (CCE) was developed and enacted for this study in the hopes of enhancing students' perceptions of chemistry and critical scientific literacy. However, it goes without saying that the development of students' chemistry content knowledge was also an important goal of CCE. In the following sections, I critically examine the achievement of this goal.

Comparable Chemistry Content Knowledge

First, it is likely that overall students at this setting learned a sound level of chemistry content knowledge through their participation in CCE that was comparable to that of students who experienced a traditional chemistry curriculum. This was based on evidence from the AREs, analysis of the content knowledge demonstrated in the CPAs, and student averages on post units tests and the cumulative final exam. Studies carried out by researchers investigating other forms of progressive, contextually situated science education have found similar findings (i.e. Aikenhead, 2005; Barker & Millar, 1996; Bennett, Lubben, & Hogarth, 2007). For example, the "Chemistry in the Community" or *ChemCom* curriculum was designed to contextually situate chemistry learning in socially relevant issues such as environmental pollution. Winther and Volk (1994) conducted a study to test if a *ChemCom* curriculum enacted in an "inner city" setting improved students' chemistry achievement to a greater extent than a traditional approach. They found a statistically significant difference in the achievement levels of the two groups indicating that the *ChemCom* approach did enhance student achievement to a greater extent than a traditional chemistry course. While the approach taken for this study was not one of experimental design comparison, the findings suggest that, in general, this type of contextualized chemistry education can support the learning of rigorous chemistry content in a private, suburban high school setting with students considered to be in regular chemistry and for students of "lower achieving" on traditional measures as well.

However, there are several issues to consider with respect to this conclusion. The largest factor to consider is that I was not able to completely transform the traditional chemistry curriculum of this school. I did mix critical approaches into my mainstream curriculum throughout the year, which quite often took the form of informal critical discussions when students asked questions in class that moved in these directions. But, I was only able to enact four formal critical units. This limits the impact of the *t*-test result that indicated that my students did as well as my colleagues' students on the final exam.

On the other hand, the student participants of this study demonstrated statistically significant increases in their content knowledge pre to post for the three critical units where a pre and post test were given. In addition, their posttest results were comparable to my students' performances in years past, except for the organic unit posttest. This suggests that students did not learn an adequate level of organic chemistry. However, event-based data collected from the classroom activities of the unit and the content knowledge students exhibited in the organic functional group model CPA of the unit indicate that students seemed to understand organic chemistry to a degree not captured by the test. This suggests that the pre and post unit tests were not aligned very well with the unit objectives. For example, the unit focused on the physical nature of organic molecules, but the pre and post unit tests contained questions that related to connections between common substances and specific types of organic molecules. Future enactments of this unit will have to address this issue.

Classroom Community of Practice

Second, the findings from this study suggest the pedagogy of CCE provided students with the opportunity to demonstrate socially situated chemistry content knowledge by adopting the practices of science that were the social norms of a classroom community of practice. According to Brickhouse (2001), this is paramount to good science learning because science itself is a cultural practice situated in social norms. Furthermore, Brickhouse suggests that participating in a classroom environment, like the one CCE seemed to promote in my classroom, can help students develop scientific identities that empower them to use science in practical ways, which could potentially improve their own lives and their communities. Lastly, she believes that developing scientific identities in all students allows them to play with gender identities in fluid ways that do not pigeon hole girls or boys into specific gender roles. While the findings of this study did not specifically look at identity formation, evidence of students participating in the classroom community of practice as scientific experts could certainly help students develop scientific identities.

Critical Performance Assessments

Third, the findings document evidence that the CPAs may have provided “lower achieving” students with alternatives to traditional forms of assessments to demonstrate chemistry content knowledge. According to Kincheloe (2005), critical pedagogy should promote opportunities for all students to see that they can be successful, which in this case means “doing science.” In this study, the variety of CPAs of CCE acted as student-centered ways for all students, with varying interests, backgrounds, and strengths, to succeed in chemistry class in one way or another, despite some of their struggles on traditional forms of assessment. In addition, this is important because it could also enable more students to develop scientific identities (Brickhouse, 2001). Furthermore, the variety of CPAs enacted in this study that prompted students to investigate chemistry and critically relevant issues through individual student lenses may have provided the few ethnically and culturally diverse students in my classrooms different access points to the language of science and ownership of science. This would be similar to Hildebrand’s (1998) findings about alternative writing methods in science class assessments that she found helped cater to diverse ways of knowing.

However, the conclusion that the CPAs seemed to have a greater effect on the ability of "lower achieving" students, as measured by traditional forms of assessment, to demonstrate their content knowledge is limited by the fact that students worked in pairs or groups of three in all but the critical scientific reading/writing CPA of the kinetics unit. Because the students worked in small groups that were assigned so that students would work with different partners on each CPA throughout the year, sometimes groups contained a "higher achieving" student partnered with a "lower achieving" student. Therefore, the lower achieving student's score on the CPA may have been increased by work done by the higher achieving student on his or her own outside of class. However, the fact that the students did much of the CPA work inside class diminishes the potential for this limitation.

On the other hand, assigning students with different partners on the CPAs through the year was an important part of the social nature of the classroom-learning environment of CCE. I did not want to create an environment where students were segregated by achievement within the classroom on the CPAs. I wanted to maintain the mindset that we were all participants in the classroom community of practice with equal potential to bring important unique perspectives to any type of assessment or activity. This helped enhance the zone of proximal development (ZPD) because at different times and in different circumstances, students of any achievement level could help scaffold their peers to unassisted performance through unique contributions to a specific CPA and the classroom community of practice as a whole.

CCE and Sociocultural Learning Theory

According to Driver and colleagues (1994), all learning occurs through social interaction regardless of the specific practices employed by the teacher in the classroom. Therefore, I still used traditional lecture methods to introduce the chemistry content discussed within the curricular transformations of CCE quite often. However, based on my sociocultural learning theory lens, I did not believe my students learned this material by just listening to my lectures and studying at home on their own. Students learned because the CCE activities and assignments, created for this study, provided them with real-world, socially relevant contexts to enrich and enhance their understanding of chemistry content through a community of practice where students shared and developed their understanding with their classmates and their teacher. Furthermore, CCE afforded students with the opportunity to use their chemistry content knowledge to evaluate and better understand real-world, socially relevant topics in a way that could potentially enhance their democratic citizenship. Moreover, the curricular transformations of CCE seemed to guide students from peripheral members to full members of the community of practice, allowing students to take on the persona of scientific expert, which potentially further developed or evolved the community of practice as a whole (Lave & Wenger, 1991).

Essentially, the idea is not that content is "taught" through a socially situated, critical perspective in the way that lecture is perceived to do from a transmission perspective (Blumenfeld et al., 1997), the idea is that a socially situated, critical perspective provides a venue or safe space for all students to connect scientific content, practice, and critical reflection to "learn" content meaningfully. Ultimately, this process resulted in students demonstrating a comparable level of chemistry content knowledge on a traditional form of assessment, the cumulative final exam.

Implications and Conclusion

Through Hickey and Zuiker's (2003) dialectical reconciliation, the overall claim that students demonstrated a comparable level of chemistry content knowledge working within CCE is highly supported from three evaluation perspectives: interpretive, event-based analysis, rationalist-based performance assessments, and empiricist-based multiple-choice tests. The in situ analysis of student participation in the CCE classroom community of practice indicates students adopted the community practices as their own and through scientific practices shared and developed chemistry content knowledge as they worked through the analysis of the intersections between content knowledge and socially relevant issues. In addition, the critical performance assessments (CPAs) of CCE seemed to have had a positive effect on students who consistently struggled on traditional, multiple-choice tests. The variety of CPAs provided them with alternative options to demonstrate their content knowledge in meaningful ways that tests did not capture for one reason or another. Finally, students took the content knowledge they shared and developed in the CCE classroom and applied it in new domain specific contexts, such as traditional, multiple-choice tests, equally as well as students who participated in traditional chemistry curricula. These results imply the power of sociocultural learning theory-aligned critical pedagogy to enhance the science learning experiences of all students while maintaining the development of domain-specific content knowledge in a rigorous secondary science course such as chemistry.

Furthermore, the fact that the in situ data collected from qualitative sources supported and provided context for the individual accomplishments of students documented in quantitative sources imply that the methodological framework of this study should mitigate the potential "tension" between the contemporary, sociocultural-based theory on knowing and learning used to construct the activities and assignments of the CCE units and more conventional views of assessment and accountability (Hickey & Zuicker, 2003). This is because the event-based data collected for this study "can be used to rule out charges of 'cherry picking' items when assembling multiple-choice tests, or selection bias when using performance assessments"

(Hickey & Zuicker, 2003, p. 557). Furthermore, the data from the multiple-choice tests limits concerns of conclusions being based on biased interpretations of event-based qualitative data alone.

Chapter 7

FINDINGS

CRITICAL SCIENCE EDUCATION AND STUDENT INTEREST IN A SUBURBAN CHEMISTRY CLASSROOM

Abstract

In an attempt to transform traditional, decontextualized, fact-based chemistry education that some students generally perceive as boring and socially irrelevant (Gilbert, 2006), this study describes the enactment of critical chemistry education (CCE) in a suburban high school classroom and gauges student interest developed by this approach. CCE contextualizes chemistry education in socially relevant issues and engages students in a critical analysis of the intersections between chemistry and society. The findings from qualitative and quantitative data sources are presented in two sections. In the first section, data from classroom video transcripts and Likert surveys describe how students from this setting were generally actively engaged in and interested in the critical aspects of the CCE units developed for this study. In the second section, data from open-ended questionnaires, focus group interviews, and Likert surveys are presented for an embedded case study of a smaller group of students. These data identified the specific sources of *situational*, or short-term interest in CCE. Case study students noted they were interested in: (1) CCE connections made to business, economics, and/or consumerism, (2) investigating diverse chemistry-related cultural practices and medicine related science, and (3) hearing diverse peer perspectives during classroom activities. Furthermore, findings presented in the second section indicated that CCE potentially increased this group of students' general interest in chemistry to a more sustained level by enhancing their perceptions of the relevancy and/or value of chemistry. The findings have implications for the development of critical, science curricula that work to incorporate students' personal interests and backgrounds to improve students' engagement and affective responses to science class.

Introduction

According to the National Research Council (NRC, 2012), *all* students must attain a high level of scientific literacy. They must understand core scientific ideas as they relate to the practices of science and engineering so that they can appreciate and knowledgeably participate in a democratic society that has to deal with increasingly challenging questions of major significance, including climate change, health care concerns, and other global science-related issues. To achieve this lofty goal as well as to improve the overall quality of science education for the twenty-first century, the NRC created *A Framework for K-12 Science Education* (NRC, 2012), which serves as the backbone of the *Next Generation Science Standards* (NGSS) created by Achieve and 26 lead states (NGSS Lead States, 2013a, 2013b). At their core, the NGSS;

> represent performance expectations (PEs) that require all students have a deep understanding of a smaller number of disciplinary core ideas (DCIs), are able to show evidence of that knowledge through scientific and engineering practices, and connect crosscutting concepts across disciplines. (Pruitt, 2014, p. 145)

Unfortunately, Title 1 and The No Child Left Behind Act (NCLB) still largely influence current science education across the country. States' curricula and their corresponding standardized assessments focus on students accumulating too many discrete scientific facts that are not interconnected hierarchically between grade levels or laterally between disciplines to develop deep understanding of core scientific concepts or practices (Pruitt, 2014). Furthermore, there is an absence of critical thought in current science education (Gilbert, 2013). These scientific facts are taught in a decontextualized way (Gilbert 2006), and a dominant positivist mindset leaves very little room for conversations about the social dynamics that underlie what happens in science, science classrooms, and in society at large (Calabrese Barton, 2001).

The effect of decontextualized learning in the science classroom on students' perceptions and feelings about science class has been quite negative. In particular, students' lack of interest in science class has been well documented over the last twenty years across school settings (Jack & Lin, 2014), from elementary schools (Murphy & Beggs, 2003) to high schools (Cordova & Lepper, 1996; Rennie, Goodrum, & Hackling, 2001), and especially for "young women and students marginalized on the basis of their culture" (Aikenhead, 2005, p. 2). In general, the "boring," fact-based education students are subjected to in high school science makes it hard for them to see science as relevant to their everyday lives and the struggle of adolescents to develop an individual identity (Gilbert, 2013; Hidi & Harackiewicz, 2000; Krapp & Prenzel, 2011).

Furthermore, specific to students' disinterest in the discipline of chemistry, Gilbert (2006) identified that content overload and isolated fact teaching have led to student perceptions that chemistry does not have relevance unless it is used as a steppingstone to reach a more interesting science such as medicine.

In the end, when students are bored with decontextualized, fact-based science education they "tend not to learn science content meaningfully, that is, they do not integrate it into their everyday thinking" (Aikenhead, 2005, p. 3). Indeed, developing student interest is important because it results in continued, engaged interaction with a topic, which can improve the overall understanding of a topic (Pintrich & Schunk, 1996; Renninger & Hidi, 2011). Furthermore, Jack and Lin (2014) claim that students' interest in science is critical to their lifelong learning of, and interaction with scientific content as well as to their development of scientific literacy.

In the hopes of breaking away from the test-driven curricula of NCLB and achieving the level of scientific literacy called for by the NRC for all students, teachers and researchers of *critical science education* have been developing innovative science curricula and programs and assessing their effects on student work in the classroom and students' perceptions of science. Fusco and Calabrese Barton (2001) write that critical science education (CSE) "questions… the nature of science and knowing science, the relationship between science and society, and the implications these belief structures have for how we view science as a school subject" (p. 338). Overall, work carried out within the constructs of critical pedagogy, (Freire, 2000), multicultural science education (MSE) (Atwater, 1993, 1995), feminist-framed science education (Brickhouse, 2001), and critical science reading and writing (Oliveras, Marquez, and Sanmarti, 2013, 2014) have all contributed important ideas to the framework of a broadly conceived CSE.

Researchers whose work was framed by the constructs of CSE have found that CSE can have positive impacts on students' perceptions of science and science class. For example, Basu and Calabrese Barton (2007) conducted a critical ethnography on the science interest levels of ethnically diverse, middle school students living in a high poverty, urban setting working in an after school science projects program. Their work was grounded in the concept of *funds of knowledge*, which are the knowledge, skills, and practices of the community or cultural background the students come from and enter school with (Gonzalez & Moll, 2002). They found that a sustained interest in science could be achieved in students if their science instructional experiences connected to their funds of knowledge and desires for their futures, as well as supported social relationships and student agency.

Science education work conducted from an interest research framework has also attempted to address documented trends in students' lack of engagement and interest in traditional science education. According to Jack and Lin (2014), in the last ten years there has been a movement in science interest research that focuses on studying students' *situational* or short-term interest in specific areas of scientific content and specific classroom activities. Some of these studies focus on factors that generate or improve students' situational interest. For example, a study by Palmer (2009) found that a ninth grade science lesson focused on inquiry skills generated substantial situational interest and that the main sources of the interest in the lesson were novelty, student choice, physical activity, and student collaboration.

In addition, some studies focused on students' situational interest in science have also addressed its potential effect on other classroom variables. The research of Lin, Hong, and Chen (2013) sought to document how situational interest can be sustained and how it might be developed into long-term interest in chemistry. First of all, they found that situational interest in chemistry was maintained by demonstrations and hands-on activities that incorporated novelty. Second, they found that attempts to consistently sustain students' situational interest in an experimental group led to higher perceived levels of interest and enjoyment in science class than in a control group.

The findings of these two bodies of work connect to studies that suggest that students may be interested in science content, but not the way it is traditionally taught as a school subject (van Griethuijsen et al., 2015), which has profound implications for science classroom pedagogy and curriculum design. However, researchers such as Renninger and Hidi (2011) and Jack and Lin (2014) note that more interest work still needs to identify classroom activities and instructional methods that go beyond developing situational interest to generating and sustaining general interest in discipline specific areas. Renninger and Hidi add that this research must continue in a variety of settings and across disciplines to strengthen our understanding of interest and the theoretical frameworks being used by researchers to explain it.

So while the valuable work of Basu and Calabrese Barton (2007) addressed the effect of a critical approach on students' interest in science, it focused on an after school program in a diverse, urban school setting, and it did not utilize an interest framework to ground the results. An extensive review of critical research did not reveal any work conducted in this area that had studied the effect of CSE in a suburban setting composed mostly of upper middle class, White students (Ryan, 2010) who were enrolled in a rigorous high school course in a core scientific discipline such as chemistry.

The purpose of this study is to document aspects of a critical approach to chemistry education that might generate and sustain interest in the specific discipline of chemistry for a group of students that largely come from the dominant cultural background. As such, I investigated a yearlong enactment of *critical chemistry education* (CCE) in two high school chemistry classes at a suburban New England private school where I had taught for five years. Essentially, the CCE learning experiences transformed the traditional chemistry curriculum at this school by combining the efforts of CSE, and science interest research with the PEs of NGSS to decrease students' passive learning and to enhance students' perceptions of chemistry.

There were two primary research questions for this study. A holistic, ethnographic approach was used to answer the first question to provide a classroom-setting context for answers to the second question. The first question was: what does student interest in CCE look like in the classroom? Two sub-questions elaborated on the first primary question:

1. How are students interested in CCE?
2. How does student interest in chemistry change during engagement in CCE?

An embedded case study of a smaller group of students was used to answer the second question: how do students describe their interest in CCE? Two sub-questions elaborated on the second primary question:

1. What are specific sources of student interest in CCE?
2. How does engagement in CCE foster the development of student interest in chemistry?

Theoretical Framework

The theoretical framework that grounded this study is composed of two conceptual constructs that grew to be very important to me through my high school chemistry-teaching career. The first is a critical lens, which framed my desire to curtail students' passive, decontextualized, fact-based science education and guided my conception of critical chemistry education. The second is a belief that some level of a learner's personally intrinsic interest in a topic is highly important to the development of a meaningful understanding of that topic.

Critical Chemistry Education

Critical chemistry education (CCE) is derived from a general critical pedagogy and critical science education. First, critical pedagogy "cultivates a rigorous, intellectual ability to acquire, analyze and produce both self-knowledge and social knowledge, [and it results in] individuals [who are] equipped to participate in the democratic process as committed and informed citizens" (Kincheloe, 2007, p.24). Specifically outlined by Kincheloe (2005), critical pedagogy is grounded in justice and equality, which makes it inherently political and dedicated to the alleviation of human suffering. It teaches students to read for subtext (revealing dominate ideologies), challenges students to engage with their teachers in a critical exploration of the world, and cultivates intellect through analysis and the rejection of fact memorization. Finally, critical pedagogy accounts for making adjustments to the cognitive and affective needs of individual students based on their initial skill sets, interests, and their cultural and social backgrounds.

In an interview with Calabrese Barton (2001), McLaren discusses in what ways critical pedagogy should be enacted in science classrooms. He believes that critical science pedagogy must address the subordination of science education to the goals of capitalism, and issues of gender, sexuality, class and culture in the science classroom.
This process should develop students' ability to question and critique the power structure of society that allows those with resources to use Western modern science (WMS) to control knowledge production and validity (Calabrese Barton, 2001; Kincheloe, 2005).

Gilbert (2013) outlines that critical science education (CSE) rejects an objective, value-free, fact-based science and embraces the fluid and dynamic, human endeavor that science is. CSE uses the beliefs and questions students bring to science classrooms to guide investigations that require students to use scientific knowledge and practice to empower their own lives. This requires teachers to situate science learning in the contexts of their students' lives. Furthermore, teachers must help all students learn the dominant Western discourse of science while also welcoming and using diverse modes of communication in the science classroom that can enhance the overall communication between teachers and students. Corresponding to this, CSE also requires the examination of important knowledge contributions from peoples outside the influence of WMS.

Other CSE researchers (Dalke & Franklin, n.d.; Ramesh & Patel, 2013) agree that not only should students be able use the practices of science to learn the content of science, they should also be able to use these practices to critically exam the intersections between science and society. Essentially, this adds a critical component to traditional definitions of scientific literacy as conceived of by the NRC. For the purposes of this study, I refer to CSE's elaboration of scientific literacy as critical scientific literacy (CSL).

To achieve the goal of CSL for all students, CSE and specifically for this study, CCE, motivates students to critique their positions as producers and consumers of chemistry-related products, such as automobiles and over-the-counter health remedies, within the global capitalist culture. CCE also helps students understand both the positive and oppressive nature of science and chemistry's role in society. It opens their minds to different perspectives on the nature of science and diverse cultural ways of knowing and communicating about science and chemistry-related ideas, such as understanding and sharing scientific ideas through narrative and story telling (Hildebrand, 1998). Finally, CCE develops students' ability to create their own, chemistry-based knowledge that can be used to respond to personally and/or locally relevant needs (Fusco & Calabrese Barton, 2001).

Interest

Student interest has been a major concern of progressive education since Dewey (1913) who believed it is paramount to engage students in their education by connecting teaching to their interests. McLaren (2009) agrees that to engage students, building their critical evaluation of the society they live in, motivating them to positive social action, critical pedagogy must start with students' interests and develop their interest in their education. Indeed, Palmer (2009) asserts that motivation is a prerequisite for learning according to constructivist learning theory and that interest is an effective motivator. Essentially, constructivist theory holds that an individual constructs or builds his or her own knowledge by fitting new experiences in with prior knowledge (Driver, Asoko, Leach, Mortimer, & Scott, 1994). Knowledge construction is successful when it is useful to the individual to make sense of the world and compatible with the knowledge accepted by others (Wiser, Smith, & Doubler, 2012).

Motivation and interest. To begin, interest research is firmly grounded in theories and research in motivation. Research in motivation, a psychological state that describes a person's desire to do something (Molden & Dweck, 2000), generally suggests that interest is the result of learning goals and the development of intrinsic motivation that is guided by factors separate from external consequences (Deci & Ryan, 2000; Swarat, Ortony, & Revelle, 2012). Swarat and colleagues continue that interest researchers, on the other hand, generally suggest that interest is the precondition for learning goals and intrinsic motivation. Furthermore, some authors generally describe interest and intrinsic motivation as one in the same (Deci & Ryan, 2000), while others distinguish between the two by suggesting that intrinsic motivations lead to general patterns in behavior and that interest leads to a very specific set of behaviors (Hidi & Renninger, 2006). For the purposes of this study, interest is regarded as an intrinsic, multidimensional, "motivational variable that refers to the psychological state of engaging or the predisposition to reengage with particular classes of objects, events or ideas over time" (Hidi & Renninger, 2006, p. 112), which is fully described by the person object theory of interest.

Person object theory of interest. According to Krapp (2007), interest is essentially a personal attitude towards a specific object. The term object can represent anything from a tangible physical object, such as a computer to an abstract concept or topic, such as the discipline of chemistry. The attitude produced by interest can be positive or negative as long as there is desire to cognitively engage with and affective satisfaction derived from engaging with the object, which indicates that interest is distinct from enjoyment (Krapp & Prenzel, 2011). A person's interest is displayed during his or her response to different stimuli produced by the object. Therefore, interest is a relational concept: it describes a relationship between a person and an object. This is referred to as the person object theory of interest (POI) (Krapp, 2007). According to Hidi and Renninger (2006), there are three key elements of POI that distinguish interest from other motivational variables. First, interest describes a very specific person–object relationship, guided by very specific rather than general content. Second, interest is guided by both cognitive and affective components. Third, the cognitive and affective components of interest have biological roots.

This relationship between the individual and object can be fleeting or short-termed. Researchers refer to this as *situational interest* (Hidi, 1990; Krapp, Hidi & Renninger, 1992). Situational interest is usually motivated by extrinsic (externally located) factors connecting the person to the object, but can be motivated by the intrinsic (internally located) traits of the object as well (Krapp & Prenzel, 2011). Situational interest can be triggered by the perception that the object is relevant or valuable, or by surprising, incongruous information (Krapp, 2007). The relationship between the object and the individual can also be long lasting, and deeply personal. Hidi and Renninger (2006) call this *individual interest* and describe it as “a person’s relatively enduring predisposition to reengage particular content over time” (p.113). This level of interest is usually only motivated by the intrinsic traits of the object and relates to a person’s long-term goals, creating a sense of value in the person’s life. Dewey (1913) describes this level of interest as a personal identification with an object that maintains self-initiated activity. Essentially, the object of interest is incorporated into the identity of the person.

The psychological principles that guide interest development according to POI are both affective and cognitive and stem from a sense of self (Krapp, 2007). A sense of self can be considered the result of the interplay between regulation systems that exist in varying levels of consciousness. The first system has a more biological route, is more subconscious, and corresponds to emotional experiences (affective). The second system is more conscious and intention based (cognitive). Neurological studies suggest that these two systems, affective and cognitive, work independently from each other but simultaneously affect how interest is developed and maintained (Hidi & Renninger, 2006). If a person sees their interaction with an object as meaningful, personally relevant, and in line with long term goals (cognitive) and provides them with a positive sense of satisfaction emotionally (affective), then that object will be considered interesting (Krapp, 2007).

Interest development. Two similar theoretical models describe the development of interest from situational to personal in terms of POI in the literature: one proposed by Krapp (2007) and one proposed by Hidi and Renninger (2006). Krapp’s model is slightly more streamlined than the later and consists of three levels. To begin, interest is always initialized by the interaction between personal factors, notions about the object’s value or relevancy, and situational factors, like surprising or incongruous information. This interaction is what can cause curiosity and situational interest to develop, the first level. The second level is characterized by a stabilization of the interest due to conditions that strengthen personal relevancy or the object's perceived value. The third level of interest development, personal or individual interest, is described as a person's long lasting desire to continually interact with the object, which can be established with repeated positive interaction that develops personal cognitive understanding of the object as well as self-efficacy in engaging with the object.

In this study, I used the construct of CCE to develop the curricular transformations of the traditional chemistry curriculum at the research setting, which consisted of four integrated units. In addition, I used the interest construct to guide my enactment of the curriculum, to develop the methods, and to ground the analysis of the data for this study.

Methodology

Case Study Embedded Critical Ethnography

This study was framed as a critical ethnography; namely, a research approach that includes an advocacy perspective that is responsive to current issues in society that are controlled or manipulated by groups in power to their benefit and to the detriment of other groups (Creswell, 2013). The CCE curricular transformations enacted at the research setting during this study constituted an applied, critical aspect of this study that hoped to empower all students and enhance their perceptions of chemistry. Furthermore, an embedded case study approach was also used to establish a more detailed understanding of student interest (Creswell, 2013).

Field Setting and Participants

This study occurred during one school year in two sophomore chemistry classes ($N = 25$, mean age 15 years), enrolling boys and girls, at an independent (private) school in a highly resourced suburb of New York City in New England. To increase the socioeconomic and ethnic diversity, the school recently provided aid for approximately 22% of the students enrolled yearly. In 2012, 25% of the student body identified themselves as students of color. Furthermore, nine of the twenty-five students were purposefully sampled (Creswell, 2013) based solely on their self-reported increase in chemistry interest and bounded as a single embedded case study. Other than their shared increase in chemistry interest, they did not have any other common characteristics. There were four girls, three of Western, White backgrounds and one Latina, and five boys, four White and one African American. Amanda, Annabel, and Bill came from Section 1, and Anthony, Chelsea, Cooper, Jack, and Sam came from Section 2 of the general chemistry class.

The Critical Curricular Transformations of CCE

For the purposes of this research, four critical transformations of the chemistry curriculum or units, containing a variety of activities and assignments, were formally created using interest research in science and critical science education research. The two main goals of these curricular transformations were to improve students' perceptions of interest in chemistry, and to improve their ability to use chemistry content knowledge to critically analyze the intersections between chemistry and society. As such, I had informally conducted an interest questionnaire at the beginning of the school year that allowed me to emphasize components of the CCE curriculum I had already created that would promote student interest. This led me to focus on critical topics that prompted the use of chemistry content knowledge to analyze socially relevant issues related to business, economics, or consumerism. Table 7.1 provides an outline of the objectives and assignments of each unit.

Table 7.1
Outline of The Four Units

	Content Objectives	Critical Objectives	Assignments
Metal	• Metal properties • Single replacement reactions • Activity series	• Metallurgy in ancient and modern cultures • Gender equality in science • Steel manufacturing and modern day economics	• Cultural practices of metallurgy research assignment • Metal activity series inquiry lab
Kinetics	• Reaction rate • Collision theory • Factors that affect reaction rate	• Science's potential to benefit and oppress • Critical analysis of scientific content presented in media • Critical, chemistry analysis of consumer goods	• Factors that affect reaction rate inquiry lab • Critical, science reading/writing assignment
Organic	• Simple organic molecules • Functional groups	• Male-biased and value- laden nature of scientific research	• Functional group modeling project • Peer critique assignment
Acid/Base	• Definitions • pH • Titration	• Acid rain and environmental protection • Cultural /home remedies and over-the-counter remedies	• Acid rain and emissions trading debate • Heartburn inquiry lab

Note. See Appendices B through I for complete unit maps and materials

Data Collection and Analysis

A mixed methods, concurrent triangulation approach where qualitative methods share approximately equal weight with quantitative methods was used to collect and analyze data within this critical ethnography and embedded case study (Boeije, 2010). The four curricular transformations served as check in points to gauge developing answers to the two primary research questions: (1) What does student interest in CCE look like in the classroom? (2) How do students describe their interest in CCE?

Qualitative Data Collection. Qualitative data collection consisted of video recordings, open ended questionnaires, focus group interviews, and a researcher journal.

Video recordings. The hour-long classroom periods that had the most student participatory involvement within the classes where the critical transformations were used were video recorded (See Appendix A for Study Timeline). In addition, when students were working in small groups around the room, they made their own audio recordings of their work using their laptop computers. These audio recordings were then matched with the video recordings. I personally transcribed the recordings for each day to document complete classroom events from multiple angles.

Questionnaire. An open-ended questionnaire, developed from the work of Haussler and Hoffman (2000), Krapp and Lewalter (2001), and Krapp and Prenzel (2011), was administered using Qualtrics at the end of each of the critical transformations. In addition to asking students specific questions about each unit, the questionnaires also asked students to discuss their current level of interest in chemistry. Finally, the last questionnaire of the year asked students a final question to describe their overall feelings about the critical approach enacted in their chemistry class (See Appendix L).

Focus group interview. Focus group interviews were conducted and digitally audio recorded within a week of each unit with several randomly selected student participants. On average, there were about six students per interview. The recordings from the interviews were personally transcribed. While the interview protocols were loosely structured by some of the same interest-based questions on the questionnaire, they were conducted in a way that prompted students to drive the direction of the conversations (See Appendices M – Q).

Researcher journal. I kept a journal during the entire school year to help guide the process of data collection and analysis and to keep track of my thoughts during the study. The journal helped me to reflect upon ways to improve data collection procedures, to balance my roles as a teacher and researcher, to reflect upon my own biases, and to communicate with the administration at the school setting. It also especially helped me to evaluate the comfort level of my student participants as they worked through a very rigorous critical chemistry education (Creswell, 2013).

Qualitative Analysis. Qualitative data analysis started with the video and audio transcripts of the classroom activities. Analysis of the classroom transcripts began with a dialogue or event mapping technique similar to the one employed by Brown (2004) in his ethnographic study. The dialogue was organized into columns represented by four units or layers that fully documented and described the interactions in the classroom. First, phase units organized the video transcripts by segmenting the specific classroom activities of each class period. Second, each phase unit was further described by a chronological sequence of what the teacher and students were generally doing in the classroom called sequence units. Third, message units documented the "individual utterances, changes in the intonation, and alterations in the pitch of the speaker" (p. 815). Fourth, within each message unit there was subtext, which was documented by action units. Action units "document the secondary message that accompanies a message unit, which may be communicated in nonverbal form, including alterations in intonation, pitch, wait-time, and body movements" (p. 816).

After the dialogue maps were constructed, I used NVivo, a qualitative analysis software tool, to open code the action units of the maps from a student interest-based perspective. I used the concept of *personal excursions* to guide my analysis and provide a framework for identifying what student interest looked like in the classroom. "Personal excursions are episodes when students 'bend' or leave the activity-as-framed in order to pursue personal agendas and interests… that [relate], to a greater or lesser extent, to the activity-as-framed, but which [do] not fully align with its framed goals" (Azevedo, 2006, p. 82). For example, a curiosity-based question from a student that leads to a new, tangential exploration or elaboration of an important topic in the classroom that does not necessarily or specifically help him or her, or the class as a whole, perform well on an assessment would be coded as a personal excursion. In this way, the coding process was more deductive and applied in nature in that I used theory to guide the process (Boeije, 2010).

Next, a data analysis approach to ethnography suggested by Fetterman (2010) was implemented on the video transcript data. In this process, multiple data sources are compared or evaluated against each other to identify patterns or themes in participant behaviors and thoughts that focus on key instances in the activities of the group (as cited in Creswell, 2013). To accomplish this task, nodes were categorized, word frequency queries were run, and node matrices were created, all in NVivo, and used to identify broader patterns in students' interest demonstrated in the video transcripts.

A very similar process was used to analyze the questionnaires and focus group interview transcripts. However, in this case, deductive coding and theme development was guided by gauging interest in context, content, and activity (Haussler & Hoffman, 2000), and assessing interest related affective and cognitive valences such as positive feelings, comfort, confidence, surprise, persistence, value, goals, and relevancy (Krapp & Lewalter, 2001; Krapp & Prenzel, 2011).

Quantitative Data Collection. Quantitative data collection consisted of a Likert-type interest survey.

Likert-type survey. Using Qualtrics, a Likert-type survey on student interests, modified from Schiefele, Krapp, Wild, and Winteler (1993), was administered before and after each of the curriculum critical units, except for the organic unit, due to time limitations (See Appendices R - U). The reliability of the interest surveys was supported by the previously performed Rasch analysis conducted on the survey by Schiefele and colleagues. However, there was a potential limitation in the modified version of the survey used in this study in that the valences of "uncomfortable," "fun," and "annoying" were added post Rasch analysis.

Overall, the survey was constructed with three sets of items that sought to gauge students' perceived interest in three different interest categories: (1) chemistry content of the unit, (2) socially relevant, critical components of the unit, and (3) general chemistry class interest. Each category on the surveys contained about five interest items. Table 7.2 provides an example of a chemistry content interest item from the acid/base unit survey.

Table 7.2
Likert Survey Example

Learning about pH and pH indicators is:	Completely Disagree (0)	Disagree (1)	Somewhat Disagree (2)	Somewhat Agree (3)	Agree (4)	Completely Agree (5)
1. Boring						
2. Stimulating						
3. Interesting						
4. Uncomfortable						
5. Fun						
6. Annoying						
7. Meaningful						
8. Worthless						
9. Valuable						
10. Useless						

Note. The version on Qualtrics had bubbles for students to click on within the empty boxes under the scale.

Quantitative Analysis. Quantitative analysis of the Likert surveys consisted of two inferential statistical tests: analysis of variance (ANOVA) and time series regression. First, a mean interest level for each individual student ($N = 25$) was determined from the ten interest valences scored from 0 to 5 for each question on the pre and post surveys. (Note: the negative valences on the survey were reverse scored). Next, each student's mean interest level in (1) the specific chemistry content of the unit, (2) the specific critical components of the unit, and (3) chemistry class in general was determined from the questions that addressed those interest categories for each pre and post unit survey. Finally, histograms and Shapiro-Wilk's tests were used to confirm the normal distribution of all the categories of data and a Bartlett's test was used to confirm homogeneity of variances.

A two-way ANOVA was run to test the main effects of two independent variables, unit and category of interest, on the one dependent variable, interest ($N = 25$). In addition, this evaluated if there was an interaction between the categories of the two independent variables.

The categories of interest were (1) chemistry content, (2) critical components of the unit, and (3) general interest in chemistry class. The four units were (1) critical metal activity series lab, (2) critical kinetics unit, (3) critical organic unit, and (4) critical acid/base unit. To conduct this initial analysis of the interactions between the categories of interest and the different units, only the post unit surveys were used so that there was an equal N for each unit because the organic unit did not have a pre unit survey due to issues with time. The results for this test suggested that there was a statistically significant difference between the interest categories, $F = 4.1$, $p = 0.018$, but not a statistically significant difference between the student interest in the units of CCE, $F = 0.88$, $p = 0.452$. In addition, there was nearly an interaction effect between interest category and unit on students' interest, $F = 2.06$, $p = 0.058$. Based on the results of this two-way ANOVA, a one-way, correlated ANOVA was run between the different categories of interest for all seven surveys for all the students ($N = 175$). The results from this ANOVA are presented in the findings.

A time series regression was used to evaluate how much students' general interest level in chemistry and chemistry class varied in relationship to the days of the school year, numbered 1 through 160. (Note: there were 5 days cancelled due to snow that were not made up.). There were seven chemistry class interest levels from the seven separate surveys conducted throughout the year for each of the 25 students ($N = 175$). This same process was then used to develop a time series regression for the chemistry interest of the bounded nine students in the case study.

Elements of Rigor and the Role of Researcher

The *credibility* (Guba & Lincoln, 1989) of the data reported in this study was supported by several factors. First, because I had been a teacher, coach, and adviser at this school setting for five years, and the teacher/researcher for this study, I was truly embedded and capable of recording a true emic or insider perspective (Merriam, 2009). Second, I used a researcher journal to reflect on my privileged position as a White, Christian, heterosexual male of Western European descent as I enacted CCE and delicately navigated some of the more challenging issues that arose from this work. Furthermore, I used the journal to reflect on my bias for the tenets of critical pedagogy as I made interpretations of students' perceptions and work. Third, my embedded nature at the setting and the researcher journal helped me with *member checking*, co-constructing interpretations of data sources with my student participants throughout the year, both informally, during quick chats before or after class, and formally, during focus group interviews (Creswell, 2013). Finally, data from three qualitative sources and one quantitative source were concurrently triangulated (Boeije, 2010) to develop the answers to the research question.

Findings

The findings are presented in two sections. In the first section, qualitative data from the video transcripts and quantitative data from the Likert surveys are presented to address what student interest looked like in the setting as a whole. In the second section, qualitative data from the questionnaires and focus group interviews and quantitative data from the Likert surveys are presented for the embedded case study to identify the specific sources of student interest in CCE, and describe how engagement in CCE fosters student interest in chemistry.

The Setting as a Whole

Analysis of the video transcript data indicated that students were generally actively engaged in the classroom, as judged by both the quality and quantity of student contributions, when they participated in the four curricular transformations or units of CCE. More specifically, students were coded to have exhibited *personal excursions*, behaviors that indicated their interest in CCE, during CCE classroom activities such as small- and whole-group discussions, student presentations, and teacher-orchestrated debates that either used socially situated contexts to ground the teaching of chemistry content and/or required students to use chemistry content knowledge to critically analyze socially relevant issues. Personal excursions were coded 16 times in 12 different classroom video transcripts that documented the CCE activities. In general, individual and group personal excursions added to the teacher's preplanned intentions and positively enhanced the classroom dynamic in student-centered ways. Descriptions of two of these personal excursions provide a picture of what student interest looked like during the enactment of CCE.

The first example of a personal excursion was identified in the sequence units of a dialogue map that documented a small group activity during the kinetics unit. In this activity, students had to critically analyze the content in the two newspaper articles that described the potential future of hydrogen-fueled cars as a consumer product that could be beneficial to the environment. During this activity, Brooke, Bill, and Shane (all names are pseudonyms) took the time to Google image search Toyota's hydrogen car and assimilated aspects of two images to draw a single picture on their activity poster paper that explained the synthesis reaction of hydrogen and oxygen gas to produce water that takes place within a hydrogen fueled car. Their work went well beyond the scope of the teacher's initial plans and greatly enhanced their contributions to the whole class share out of the poster papers. This was interpreted as a personal excursion and an indication of interest because they knew they were not going to be graded on these mini presentations, which minimized the possibility of extrinsic motivation behind their activity extending-actions.

The second example of a personal excursion occurred during the acid rain activity and emissions trading debate of the acid/base unit. Initially, I intended for students to consider the ethical dilemma of imposing pollution restrictions on developing countries to improve the environment for the world versus considering the rights of the marginalized peoples of these countries to develop and prosper the way the Western world did without having to deal with pollution restrictions. After some initial student responses to this debate, Bill and Thom took comprehensive control of the conversation and moved it in a direction that completely engaged their classmates and prompted many different student contributions to the discussion. The students meaningfully debated the issue of whether or not the Western world is obligated to help the developing world prosper while following acid rain pollution restrictions through a student-created metaphor:

Thom: Life is not fair. If I got ice cream and you don't got ice cream, are you going to get mad?

Bill: But then if you say I can't get ice cream, then that makes no sense… If you are saying… Ok, so if you have the best ice cream, and you won't let me have any, then that makes no sense. So basically, you are saying make my own ice cream.

Thom: Yea.

Chris: Yea.

Bill: But, you are also saying I can't make the ice cream the way I want, so what am I…

Thom: But the ice cream that I had that was so good, but now I got diabetes. You still want it? (Lot's of student and teacher laughter.)

Teacher: Now, I think you guys have taken it too far… So Bill, you are saying that you can't have the great ice cream, you have to make your own great ice cream, but you can't make it without us telling you how you have to make it?

Bill: Yes.

Kent: But, Mr. Ashby, I think I know what Thom is saying. Is it because it has a negative effect like on the environment?

Annabel: Yea.

Thom: Yea.

Teacher: Oh, the diabetes thing was good then. Ohhh, my bad.

Annabel: That is what I thought he was saying.

Teacher: Thank you Kent for catching that.

Bill: But how am I going to make the ice cream?

Thom: You can make a different, better ice cream, sweeter, with Splenda or something that maybe won't give people diabetes.

Bill: But if I don't know how and I don't have the resources, how am I going to find that out?

Thom: You figure it out how we figured it out.

Bill: That is my point!

The conversation continued with many students building upon the ice cream metaphor for several additional minutes. In this case, Bill and Thom's personal excursion led to a whole class excursion that was student-centered and meaningfully relevant to the task at hand. However, because the class' actions were not exactly what the teacher intended or part of a graded assignment, this excursion was again coded as a sign of interest, rather than a sign of extrinsic motivation.

Personal excursions provided the first level of evidence that suggested in general students appeared to be interested in the critical, socially situated chemistry learning of CCE. The quantitative analysis results of the Likert surveys added a small degree of weight to this claim in that they suggested that students seemed to be somewhat more specifically interested in the critical components of each unit than the chemistry content alone of each unit and chemistry class in general. As reminder, the Likert surveys had three interest item categories: chemistry content, critical components, and chemistry class in general. An example of a content item was: Learning about kinetics is? An example of a critical component was: Critiquing the viewpoints and chemistry content of newspaper articles is? And an example of a chemistry class item was: In general, inquiry-style lab work in chemistry class is?

ANOVA showed there was a statistically significant difference, $F\ (2, 172) = 15.84$, $p < 0.0001$, between student interest in chemistry content, student interest in critical components, and general student interest in chemistry class. Post hoc Tukey tests indicated a statistically significant difference, $p < 0.01$, between student interest in critical components ($M = 2.93$, $SD = 0.73$) and chemistry content ($M = 2.70$, $SD = 0.73$). However, the effect size was not large, $ES = 0.32$. Post hoc Tukey tests also indicated a statistically significant difference, $p < 0.01$, between student interest in critical components ($M = 2.93$, $SD = 0.73$) and chemistry class in general ($M = 2.68$, $SD = 0.76$). Although, here again the effect size was minimal, $ES = 0.33$. There was not a significant difference between student interest in chemistry content and student interest in chemistry class in general. However, it is important to note that while the comparison means were all greater than 2.50, the neutral point on the 0 to 5 point scale, they still always fell within the range of 2, which corresponded to the "somewhat disagree" category on the Likert item scale. Therefore, the differences must be interpreted within this context. As a whole, the students had less than enthusiastic interests in any of the comparison categories. So, keeping the small effect sizes and the low mean values in mind, these data only somewhat support the video transcript, personal excursion data that suggested in general, students were interested in the critical, socially relevant learning of CCE.

In addition, as a whole, the Likert survey data suggested that the apparent student interest in CCE documented above had no impact on students' interest in chemistry class at this setting as a whole. A time series regression of the Likert surveys revealed $r = 0.048$, $r^2 = 0.002$, $t = 0.63$, and $p = 0.53$. Figure 7.1 provides a graph of the regression line. Clearly, there was not a statistically significant variation in all students' interest in chemistry class over the course of the year. In addition, from the trend line in Figure 7.1, we can see that students' mean chemistry interest never exceeded the "somewhat disagree" category on the 0 to 5 point Likert scale.

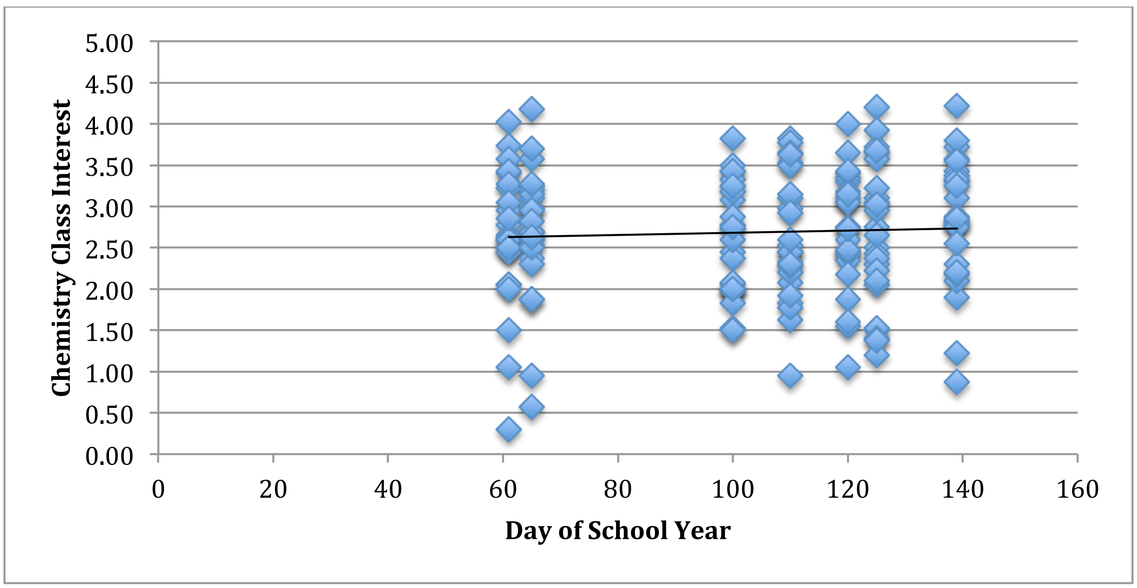

Figure 7.1. Student interest in chemistry class. This figure illustrates how total student interest in chemistry class varied by the day of the school year ($N = 25$).

Overall, looking at the video and Likert survey data from the setting as a whole only provided a contextual picture of what student interest in CCE generally looked like at this setting. Furthermore, the Likert data indicated that CCE did not have an impact on students' general interest in chemistry measured as a whole. However, these data did not provide an account of how CCE specifically impacted individual student perceptions in positive or negative ways. For this reason, a case study approach was used to tease out these important details.

The Case of Nine Students

In developing a case study approach to better understand student interest in CCE, a negative case did not present itself, as no students claimed that CCE had a negative impact on their perceptions of chemistry. Therefore, a single case of a group of nine students was embedded in this overall ethnographic study, bound and defined by how they described CCE to have positively affected their perceptions of chemistry. This section provides data from the open-ended questionnaires, focus group interviews, and Likert surveys to describe (1) the specific sources of these students' interest in CCE, and (2) the development of their interest in chemistry.

Sources of CCE interest. While the video transcript and Likert survey data from the two classes as a whole indicated that students were generally interested in the critical components of each of the CCE curricular transformations, I wanted to know more specifically what about these critical components did students find interesting. Analysis of the four questionnaires and the four focus group interviews revealed three themes in these nine students' interest in CCE: (1) chemistry connections made to business, economics, and/or consumerism, (2) investigating diverse chemistry-related cultural practices and medicine related science, and (3) hearing diverse peer perspectives during classroom activities. Table 7.3 provides the numbers of times each of these themes were documented in the coding matrices of NVivo for questionnaires and interviews. In addition, it provides the number of different students that mentioned these themes as a source of interest. Student responses were coded for interest in an item when they specifically identified it as interesting or when they described interest in an activity that focused on an item.

Table 7.3
Number of codes per CCE interest source

	Business	Diverse Practices	Peer Perspectives
Number of codes	15	10	9
Number of students	7	7	6

Business, economics, consumerism. Table 7.3 indicates that in 15 instances on the questionnaires and focus group interviews, seven different students in this case study framed their thoughts on what interested them about CCE around ideas or topics related to business, economics, and/or consumerism. This stemmed from the fact that a major critical component of the curricular transformations of CCE was the use of chemistry knowledge to better understand socially relevant issues that could be viewed from a business, economics, and/or consumerism lens, which, as I noted in the methods, was something that I emphasized after the informal analysis of the interest questionnaires I employed at the beginning of the year.

For example, during the metal unit students used their understanding of pure metal reactivity and the stability of alloys to make sense of the importance of steel production and use on the global economy. At the end of this unit, Jack wrote in the metal unit questionnaire:

> I thought it was interesting seeing how metal has an [e]ffect on [the] U.S. economy and talking about global markets and production because it felt more real then writing equations for something you'll never really see in the real world.

In the acid/base unit, the small and full class discussions that occurred after students presented their heartburn inquiry lab results focused on using acid/base content knowledge to be an informed consumer of heartburn remedies and how these informed decisions could affect the business practices of pharmaceutical companies. By the end of these conversations, students extrapolated that their consumer decisions could then have implications for the healthcare of marginalized groups of people across the globe. For example, if people became healthier eaters or decided they did not need to spend money on over-the-counter remedies for heartburn, then pharmaceutical companies might spend less on heartburn remedy advertisements and more on HIV or malaria research, both of which affect people from developing countries more than the Western world.

In reference to these discussions, Sam noted in the acid/base questionnaire, "The discussions were particularly interesting compared to the rest of the unit." In the same questionnaire, and related to the same conversations, Chelsea wrote, "I found our classroom discussions… and the lab to be very interesting." Finally, again, in reference to these same exchanges, Bill declared simply, "Yea, debating this stuff makes it a whole lot more interesting," during the acid/base unit focus group interview.

Diverse chemistry-related cultural practices and medicine related science. The second source of student interest in CCE was in investigating diverse, chemistry-related cultural practices and medicine related science. Table 6.3 shows that this theme was coded 10 times, spread across seven students in the case study. These codes were largely documented in the metal unit and in the acid base unit. During the metal unit the concepts of metallurgy and metal reactivity were situated in the context of different historical/cultural practices of metallurgy. For example, the unit began with a short video about the relatively advanced coppersmith work of the ancient Mississippian people of central North America. In addition, students researched other historical/cultural practices of metallurgy that were part of their own cultural backgrounds or that they felt an affinity for.

At the end of the metal unit, students in this group claimed that they found these topics particularly interesting. For example, Jack noted in the metal unit questionnaire, "I thought it was interesting that the Mississippians didn't know why the metal acted how it did, but knew how to change its shape." In the same questionnaire, in response to a question about whether there was anything interesting enough from the unit to spend extra time studying, Jack added, "I did [extra] research on native cultures and the metals they used." In a similar vein, on the same question, Amanda claimed, "When I was looking up [historical/cultural practices] of metals, I got very interested and continued looking for more information even after I had enough."

During the acid/base unit, students investigated how diverse home/cultural remedies for heartburn could be considered effective in terms of acid/base chemistry during an inquiry-based lab. Again, students in the case study group expressed interest in this cultural aspect of the unit. For example, in response to what she thought was particularly interesting about this unit, Amanda wrote in the questionnaire:

> I found the inquiry lab the most interesting part of this unit. I honestly had never heard of any of the [home/cultural] remedies before. My family always just goes to the pharmacy. It was especially interesting because the pH group found out that it was actually baking soda that was the most basic and so was the most effective at neutralizing the acid.

The home/cultural remedies for heartburn Amanda referred to were things such as aloe juice, slippery elm tea, and just mixing baking soda with some water. In addition, she noted her interest in the results of one of her peer lab groups that indicated that just mixing baking soda with some water might be a more effective remedy than over-the-counter remedies like Tums because it had a greater ability to neutralize the pH of hydrochloric acid used to simulate stomach acid.

Additional student responses indicated interest in this diverse/cultural aspect of the acid/base unit. In the same acid/base questionnaire, Annabel expressed similar thoughts:

> I thought the home remedies vs the over-the-counter medications was interesting because we discovered that a lot of the home remedies were more effective than

> the store bought, which is surprising consider[ing] so many people spend a lot of money buying medications when they could use stuff in their own home that would do a better job in relieving heartburn than any medication they could buy.

Finally, during the acid/base focus group interview, Bill remarked that he tried slippery elm tea at home for his heartburn. He mentioned this after completing the unit, when we were discussing if students had talked about things we did in the classroom outside of the classroom with friends or family, which were considered an indication of interest.

Diverse peer perspectives. The last major theme in the sources of student interest in CCE was not a specific topic prompted by CCE. In this case, six students expressed at one point or another in questionnaires and interviews that they were generally interested in the critical activities and discussions of CCE because they provided students with the opportunity to hear and to become aware of their classmates' different perspectives; perspectives they had not considered before. For example, in the post kinetics unit questionnaire, Amanda wrote, "I found the discussions interesting because I like hearing other points of view." In the same questionnaire, Chelsea noted, "It was also interesting to hear what others have to say about the topic and see their viewpoints, especially if it went against your own view of the topic." Finally, Bill claimed in the acid/base unit interview, "Yea, hearing what my friends have to say is interesting." In all of these quotes, students indicated that rather than any particular focus of CCE, they were just generally interested in hearing their classmates "viewpoints." Chelsea in particular noted that if the viewpoint was something she had not considered before, it was especially interesting to hear.

The development of chemistry interest. The fundamental reason these nine students were sampled as an embedded case study is because each of them at one point or another during the school year claimed that not only were they interested in particular aspects of the curricular transformations or units of CCE, but that more importantly, their interest in CCE fostered the development of their interest in chemistry and/or chemistry class. There were a total of 20 instances when these nine students made this claim in the qualitative data. While there was some evidence for this conclusion found in the video transcripts and focus group interviews, most of the evidence came from the last five questions on the questionnaires that asked students to express their current level of interest in chemistry and chemistry class in general and to elaborate on why they felt the way they did.

While each of these nine students claimed their interest in chemistry increased in some way due to CCE, specific reasons initially varied. Some of the students in this group noted that CCE activities, such as class discussions and inquiry labs, were integral to the development of their chemistry interest. For example, Chelsea claimed on the organic unit questionnaire, "I have learned more about the concept of chemistry and have begun to enjoy it more, especially with the way it is being taught in open discussions along with fun labs." In addition, Cooper reported on the acid/base questionnaire, "I have become a little more interested in [chemistry] because the [CCE] inquiry labs have spiced things up a bit."

Other students in this group mentioned that the topics discussed in the CCE units were important to their perception of increased interest in chemistry. For example, Sam noted on the acid/base unit questionnaire, "I think [my chemistry interest] has pretty much been the same but at a high level and if not gotten higher due to interesting [CCE] topics we discuss that I never knew [were] involved in chemistry before." In addition, Amanda stated on the organic unit questionnaire, "I think that chemistry is interesting and I did not think that at the beginning of the year," and "I found one of the topics, on the lack of male contraceptives, very interesting because I had never thought of it before." While Amanda did not tie her two sentences together, the fact that she mentioned her interest had increased since the beginning of the year in the same questionnaire that she described a specific interest in a topic of the organic unit is a good indication that the interesting topics of CCE were likely the reason for her increased interest in chemistry.

However, by the end of the year, it became evident that there was an overall, underlying root cause shared by all the students in this group as to why they believed CCE increased their perceptions of interest in chemistry. At some point in the year, each of these nine students, elaborated in some way that their interest in chemistry increased along with the fact that CCE enhanced their perceptions of the relevancy and/or value of chemistry. While in most cases, students did not actually use the words relevancy or value, they did describe the reason for their interest in ways that were fundamentally interpreted as an increase in perceived relevancy or value.

In many instances, students in this group of nine noted their interest in chemistry increased because CCE helped them see how chemistry was so intimately connected to many “real world” or “everyday life” issues. These instances were interpreted as increases in their perceptions of relevancy and/or value of chemistry because the students noted how they saw chemistry as important to understanding the real world after the curricular transformations of CCE or that seeing the connections alone made chemistry more tangible in some way. For example Jack stated in the kinetics questionnaire, “[My interest in chemistry] has changed because I can see how many things happening in the world today have some ties to chemistry.” In other words, CCE made chemistry more relevant for Jack.

Other cases of these attitudes were more elaborate. For example, at the end of the acid/base, heartburn inquiry lab, Bill remarked:

> [CCE] is a good way to relate to the real world… I feel like if we didn't relate this stuff to real world situations, it would be a complete waste of time. Since this is something we can actually use, like if we get heartburn, if we don't use Tums, we can use something else.

During the focus group interview, I asked Bill to elaborate upon this sentiment. He responded:

> I mean it is a whole lot better than just reading chemistry all the time. Because when it is like a straight trying to memorize the stuff, it's not fun. But it is a whole lot more interesting this way. [CCE] makes you actually care.

In these two statements, Bill remarked that CCE related chemistry to the real world and that if it did not, learning chemistry would be a waste of time. In other words, learning chemistry through CCE made chemistry relevant, valuable, or worthwhile. Furthermore, he compared the traditional chemistry curriculum to the curricular transformations of CCE and identified that he perceived the traditional curriculum to be about memorization, which he did not think was fun. Finally, he noted that the overall approach of CCE made him actually care about chemistry, which implied that the overall approach of the traditional curriculum did not make him care about chemistry.

Annabel echoed Bill's feeling during the same focus group interview. She stated:

> It kind of puts a new perspective on it because when you are learning it in the classroom, the chemistry and stuff, I feel like some people are just not interested in it. But when you talk about [chemistry] and involve like everyday life – the real world, I think it brings it alive more.

In a very similar way to Bill, Annabel compared the traditional curriculum to CCE, and identified the traditional curriculum as disinteresting, while noting that CCE connected chemistry to everyday life, which made chemistry come alive.

After Ashley had noted in the acid/base questionnaire that she had been interested in chemistry all year and that CCE had increased this interest, she wrote, "[CCE] makes a lot of sense because people always complain about learning things that they would never apply to real life, and in class we make those connections and it's pretty cool and makes a ton of sense." The connections between "real life" and chemistry made by CCE made a lot of sense to Ashley because it answered the question as to why it was important to learn chemistry. In other words, CCE made her perceive chemistry to be valuable to learn.

On other occasions, students said that the real world connections made by CCE were useful, which is essentially synonymous with valuable. For example, in the acid/base unit questionnaire, Amanda wrote:

> Chemistry is interesting… I think [CCE] made chemistry seem a lot more useful. For example, when I was younger, math was very hard for me, but it was obvious why I had to learn it. I needed math so I could buy things, to count, etc. Unfortunately with other classes, like usual chemistry, it is very hard sometimes to see a reason why we need to learn the information other than just because it is information that we are being tested on. That's why I liked it when we related chemistry to real life.

In a similar way, Sam elaborated on his increased interest in chemistry when he wrote in the acid/base questionnaire, "[CCE] is pretty interesting. It has to do a lot with the outside world and it's very useful to connect chemistry with other social issues so we [are] familiar with how things work and the mechanics/science behind it." Both students indicated their newfound appreciation for chemistry was due to the fact that it became useful in their minds after engaging in CCE. Furthermore, like Bill and Annabel, Amanda also contrasted CCE to the traditional chemistry curriculum and noted that the traditional chemistry curriculum generally did not make her feel like chemistry was relevant to know.

Anthony did use the term valuable to describe his fresh perspective on chemistry caused by CCE.

> Yes, [my interest in chemistry has increased]. I know that chemistry is the basis of everything. Everything that's anything has a chemistry of it's own… [CCE] helps me value the information more. It's a good way to get students to share their thoughts on other topics to make them feel more comfortable with the chemistry information at hand.

Furthermore, Anthony elaborated that not only did CCE make him value chemistry more, but that he thought it could make students feel more comfortable learning chemistry.

Finally, quantitative Likert survey data from the group of nine students provided a very small degree of support for the qualitative data that indicated these students' interest in chemistry increased by the end of the year as a result of their interest in CCE. Table 7.4 provides the mean Likert survey scores of these nine students' chemistry interest over the course of the seven surveys documented by the day of the school year. A time series regression of this group's Likert interest data revealed $r = 0.189$, $r^2 = 0.036$, $t = 1.51$, and $p = 0.136$. Figure 7.2 provides a graph of the regression line.

Table 7.4
Interest Likert Survey Results by Day of School Year

	61	65	100	110	120	125	139
Mean	2.60	2.97	2.86	2.94	2.89	3.03	3.36

Note: Survey items were scored 0 to 5.

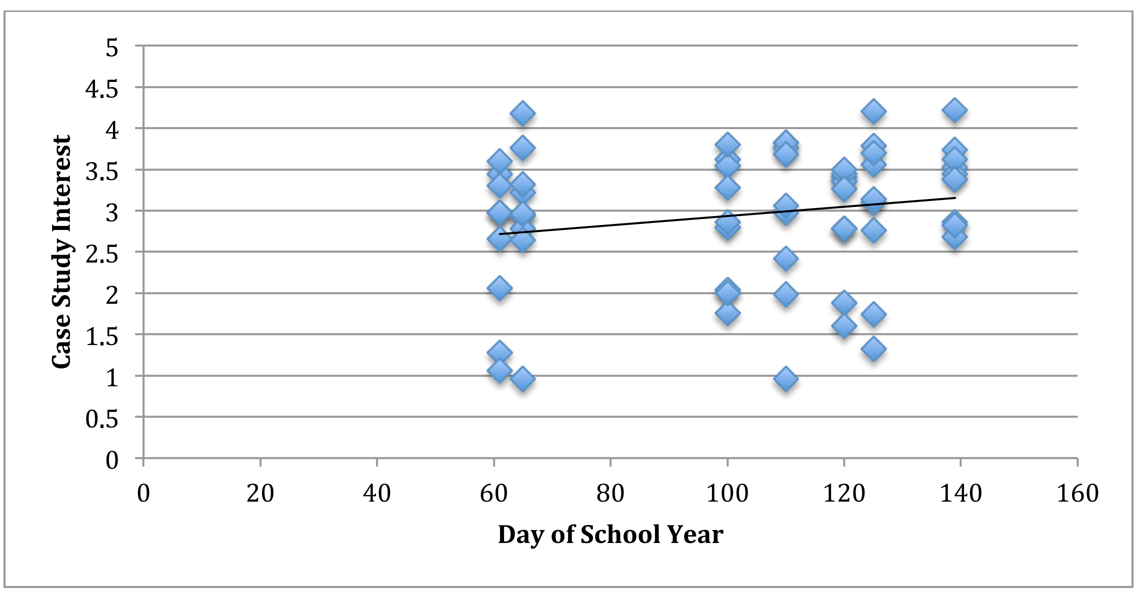

Figure 7.2. Student interest in chemistry class. This figure illustrates how this group's interest in chemistry class varied by the day of the school year ($N = 9$).

While grouping this set of nine students had a negligible effect on the correlation and statistical significance of the chemistry interest trend, likely in part due to such a small *N* value, Table 7.4 reveals that by the end of the year, the mean chemistry interest level for this group of students generally trended upwards and exceeded the "somewhat disagree" category on the Likert survey and entered the "somewhat agree" category. In addition, Figure 7.2 shows that the bottom half of this group experienced larger gains in interest than the top half. This was especially true for Cooper and Bill whose initial interest in chemistry started very low.

Overall, despite the fact that the quantitative data did not add much weight to the qualitative data documented within this case study, it seems likely that CCE had a strong impact on this group of nine students' interest in chemistry. These students were clear and articulate about the major sources of their interest in CCE. In addition, they elaborated on how their interest in CCE corresponded to their perceptions of increased interest in chemistry. Finally, they all touched upon the idea that their interest in chemistry developed because CCE enhanced their perceptions of the relevancy and/or value of chemistry. In the end, the data analyzed for the case study provided a much more detailed picture of how CCE affected the attitudes of individual students.

Discussion

A primary component of critical pedagogy is nurturing a student-centered environment where students' backgrounds and interests ground engagement in their learning (Brickhouse, 2001; McLaren, 2009). With this important goal in mind, I developed and enacted four critical, curricular transformations or units as part of my critical chemistry education (CCE) approach and gauged student interest. As a result of these efforts, several positive outcomes of CCE were documented in the data that address the two primary research questions of this paper: (1) What does student interest in CCE look like in the classroom? (2) How do students describe their interest in CCE?

First, the documentation of students' personal excursions in the video transcripts suggests that CCE did indeed provide a student-centered classroom, where students were free to explore chemistry content in ways that were guided by their own personal interests and/or backgrounds. Personal excursions were meaningful, productive departures from the intended activities of the classroom that were student directed (Azevedo, 2006). Because these excursions were not motivated by grades, they were interpreted as intrinsically motivated by interest (Deci & Ryan, 2000). The fact that these personal excursions occurred while students were using chemistry content to critically exam the intersections of chemistry and society suggests that they were generally interested in the critical aspects of the units of CCE, which was somewhat supported by the analysis of the Likert-survey data as a whole.

Second, a closer look at the data from a purposefully sampled case study provided three clearer insights into student interest in CCE. (1) CCE provided some students with a variety of sources of interest in the activities and topics of the curricular transformations. (2) CCE potentially developed some students' interest in chemistry. (3) CCE enhanced perceptions of the relevancy and value of chemistry for some students. Overall, the findings from this study can be interpreted and explained by several aspects of the interest literature. In the next section, I explore these connections.

Situational Interest and the Development of Sustained Interest

Sources of student interest in CCE included the chemistry connections made to business, economics, and/or consumerism, discussing diverse, chemistry-related practices, and hearing the diverse perspective of peers during critical conversations. These sources of student interest can be considered sources of *situational interest* in chemistry class because they were incited by the specific classroom activities of the units. In other words, student interest was more aligned with the extrinsic factors of the pedagogical strategies used in the classroom rather than intrinsic to the discipline of chemistry itself. This level of interest is usually short-term and identified as situational (Hidi & Renninger, 1992).

However, beyond situational interest, this study documented some gains in longer lasting interest in chemistry and chemistry class for the case study group of students, which can be explained by the person object theory of interest (POI) and Krapp's (2007) model of interest development. First, according to POI, both affective and cognitive systems in the brain affect perceptions of interest (Hidi & Renninger, 2006). In other words, meaningful, critical cognitive investment or engagement and corresponding positive emotional responses foster the feeling or perception of interest. As a result, the documentation of these responses can be used as evidence of longer lasting interest (Krapp & Prenzel, 2011). The chemistry interest quotes documented in the findings for this group of students contained these important cognitive and affective valences. For example, Chelsea's statement in the organic unit questionnaire referenced learning more, a cognitive response, and a feeling of enjoyment, an affective response.

Moreover, Krapp's (2007) model of interest development explains that situational interest, the first level, will grow into a more sustained second level of interest if there are conditions that strengthen perceptions of relevancy and value in the object of interest. Statements from the case study group of students that identified their interest was based in "important" and "useful" "real world" chemistry connections made by CCE indicated that CCE enhanced their perceptions of the relevancy and value of chemistry. For example, Annabel claimed the direct reason for her perception of increased interest in chemistry was because CCE personalized the subject, in other words, made it more relevant. Claims like this and the others noted above provide evidence that these nine students may have begun to reach Krapp's more stabilized second level of interest in the discipline of chemistry itself.

Assessing Interest

In general, accurately assessing affective student outcomes, such as interest, can be a very complex endeavor because students sometimes have a hard time articulating their interest in surveys, questionnaires and interviews (Krapp & Prenzel, 2011; Renninger & Hidi, 2011). This issue came up and was one that I had to consider while I gathered and analyzed the data for this study. First of all, while the quantitative analysis of the Likert surveys revealed some patterns in the overall interest of the students at this setting, it did not provide much information about what specifically impacted student interest. Furthermore, even when analysis of these surveys was focused on the case study participants, it provided little in the way of support for what these students were clearly stating in the questionnaires and focus group interviews. Part of the reason for this discrepancy could be that students talked about a general level of annoyance with taking the surveys later in the year because of the number of boxes they had to keep checking over and over again. A feeling of annoyance can certainly decrease the level of an affective response like interest, leading to lower levels of interest being reported than they might have actually felt later in the school year. Another reason for the discrepancy could be that these nine students were more capable of articulating how CCE worked to enhance their chemistry interest in the less directed qualitative sources that perhaps the quantitative surveys were not sensitive enough to capture.

Another likely reason for the differences displayed in the students' qualitative interest data and their Likert interest data was that the new, previously untested interest valences I added to the surveys potentially washed out students' interest scores. For example, while comfort with a topic or object is considered to be tangentially a part of a person's interest in that topic or object (Krapp & Lewalter, 2001; Krapp & Prenzel, 2011), this valence may have been too far removed from assessing interest and should not have been included as one of the ten valences used to develop an overall interest score in a survey item stem on the survey.

Furthermore, students may not have had an opportunity to clearly indicate their overall interest in CCE in the Likert surveys because of the way the item stems of the survey questions were separated into three distinct categories: (1) chemistry content, (2) critical activities, and (3) chemistry class in general. In other words, if a chemistry content topic was integrated into a critical activity related to a chemistry classroom practice all in one stem on a survey question, students may have been more capable of expressing their level of interest for what I was attempting with CCE. For example, instead of only including stems on the survey such as "Learning about single replacement reactions is," or "Learning about the sociohistorical significance of alloys to civilization is," I could have stated a single stem as "Learning about single replacement reactions within the context of the sociohistorical importance of alloys to civilization in an inquiry lab is?" The second stem ties together elements from all three Likert survey categories, which could potentially better evaluate student interest in CCE. Future iterations of this research should continue to employ some separated stem categories as well as some combined category stems to attempt to describe a more nuanced picture of student interest.

Moreover, it is important to note that my bias or affinity for a critical approach may have affected my students' responses on questionnaires and interviews, confounding the conclusions made in the study. These nine students could have known how invested I was in the project and may have said things they thought would please me as the researcher. However, this was likely minimized by the fact that students originally took the questionnaires anonymously. It was not until the end of the school year that IRB approval allowed me to determine which students were linked to which questionnaire with students' expressed permission. In addition, my own biases may have affected my interpretations of students' interest in the classroom, on questionnaires, and focus group interviews. However, careful self-reflection through the use of a researcher journal hopefully minimized this potential issue.

Overall, it is important to note that despite the shortcomings of the quantitative data and the potential for researcher bias, the interpretations and reported findings of the study are still well supported by the interest research-guided, concurrent triangulation methodology of the study. Some interest researchers (Krapp & Prenzel, 2011; Renninger & Hidi, 2011) believe that because students may not exactly know what about a classroom experience made them interested or not, it is important to document student behaviors in the classroom to support student responses about their perceptions of interest. On the other hand, interpreting student behaviors in the classroom as indications of interest is a difficult endeavor. Hard work can easily be motivated by extrinsic factors, like a desire for a good grade, rather than by intrinsically motivated interest that is guided by factors separate from external consequences (Deci & Ryan, 2000). Therefore, interpretations of interest in student actions in the classroom should be supported by student perceptions of interest reported in questionnaires. The construct of personal excursions (Azevedo, 2006) used to analyze behavioral data and the triangulated qualitative and quantitative sources provided the balance these researchers suggest one needs to make conclusions about student interest.

Implications and Conclusion

Overall, individual students at this setting reacted to critical chemistry education (CCE) in different ways. While there were no negative cases, CCE seemed to only truly positively affect a group of nine students. Furthermore, even within this smaller group, the themes identified in the sources of students' situational interest in CCE were not universally held. Viewed from this perspective, CCE did not appeal to *all* students at *all* times or in the same ways. However, what CCE did do is provide a variety of new and diverse ways for different students with different backgrounds and interests to become situationally interested in the chemistry classroom. Furthermore, this situational interest became the launching point for some students to develop a more substantial or lasting interest in the discipline of chemistry. From a critical perspective, the fact that CCE did not profoundly, positively affect all students is no less important. Teachers must recognize and support the diversity of students and student interests they encounter in their classrooms, even in classrooms that may appear to be somewhat homogeneous like the ones at this school setting (Kincheloe, 2005).

One of the implications of this study is that it is very difficult to derive meaningful interest-related data from large groups of participants. It appears that employing smaller scale, case study approaches may yield more significant and intriguing interest-related results. However, the holistic, critical ethnographic approach taken at the outset of the study was important to identifying a case study that would provide meaningful results and helped provide context for the embedded case. Therefore, this method of interest research continues to be important as well.

Another implication of this study is that the student-centered curriculum and pedagogy of CCE have the potential to develop situational interest into a more sustained general interest in the discipline of chemistry. This adds important information to the science interest-related literature that is working to fill the gap on ways to sustain student interest in scientific fields (Jack & Lin, 2014). However, it would also be very interesting to see how, if at all, the chemistry interest developed by CCE in this study continued beyond the school year and how it may affect students' long-term understanding of the critical connections between chemistry content and society. Longitudinal research with this same set of student participants may be able to answer these questions.

Finally, however homogeneous the students at this setting may appear to be, this study indicates that there was still much variation in their specific interests and the effect these interests have on their chemistry learning. This suggests the necessity of some level of a needs assessment utilized at the beginning of the school year to determine specific ways teachers can reach their students in the science classroom, similar to the informal interest survey I conducted at the beginning of the study. The results of such a survey should then be used to connect CCE to specific student interests to maximize student engagement and interest in the discipline of chemistry.

Chapter 8

DISCUSSION, IMPLICATIONS, AND CONCLUSIONS

In this dissertation, 25 students from a privileged, suburban, private high school setting participated in the enactment of critical chemistry education (CCE). CCE engages students in a critical exploration of intersections between chemistry content, the practices of science, and complex, socially relevant issues. CCE was based on the concepts of critical pedagogy and critical science education, sociocultural learning theory, and the NGSS. Based on a critical approach to education, CCE was designed in student-centered ways to equally reach and educate all students with different backgrounds, interests, and abilities (Kincheloe, 2005). In addition, the critical approach framed examinations of scientifically based, socially relevant issues from the perspective of social justice (Freire, 2000). From a critical science education perspective, CCE engaged students in a critical exploration of the dominant culture's control over the practice and products of science and the implications this has for their positive science-based participation in our democratic society (Calabrese Barton, 2001). From a sociocultural learning theory perspective, CCE activities and assignments were created to enhance opportunities for students to learn through social interaction in a classroom community of practice (Hickey & Zuicker, 2003). Finally, the performance expectations of the NGSS guided the creation of the critical performance assessments (CPAs) that were designed to assess students' *critical scientific literacy* (CSL), which is the ability to demonstrate chemistry content understanding through the practices of science (NGSS Lead States, 2013b), as well as their ability to use their work to critically investigate the intersections between socially relevant issues and Western modern science (WMS). Overall, the two main goals of CCE are the development of students' CSL and their perceptions of interest in chemistry. As such, the overall purpose of the dissertation was to gauge students' development of CSL and interest as they engaged in CCE. The three main research sub-questions addressed in each of the three findings chapters were (See Appendix J for Research Design Matrix):

1. How and to what extent do students develop and demonstrate critical scientific literacy (CSL) within critical chemistry education (CCE)?
2. What level of chemistry content knowledge do students demonstrate within CCE and how do they demonstrate it?
3. What does student interest in CCE look like in the classroom and how do students describe their interest in CCE?

Review of Findings

Chapter 4

While chapter four does not present findings, in detailing the CCE curriculum developed and enacted for this study, it provided an important context for understanding the three findings chapters. In chapter four, the process of integrating the performance expectations of the NGSS, sociocultural learning theory, and critical science education was used to ground the creation and enactment of the four critical curricular transformations or units of CCE and the five critical performance assessments (CPAs).

Chapter 5

In chapter five, students' demonstration and development of CSL was addressed from two angles. To do this, CSL was conceived of being composed of three facets or components: (1) content knowledge, (2) practices of science, and (3) the critical examination of intersections between WMS and socially relevant issues. First, qualitative data was used to document how students developed along the third, critical facet of CSL while they engaged in CCE. These data revealed three themes. Theme 1: students began to develop the ability to critically analyze the products of WMS from multiple perspectives, considering their potential benefits and their potential to be oppressive. However, it was also noted that students were not recorded to have taken this ability and used it outside the classroom in socially positive (or negative for that matter) ways. Theme 2: students began to integrate diverse knowledge bases with WMS in their classroom thinking. However, again, it was inconclusive as to how this might affect their behaviors outside of the classroom. Theme 3: students began to develop an understanding of the bias inherent in WMS and the implications this has for women and other groups that have been marginalized by WMS. On the other hand, it was also revealed that students largely framed this understanding from a historical perspective that likely limited their ability to understand the implications of bias in the present. Second, quantitative data was used to document students' integrated demonstration of all three facets of CSL in the critical performance assessments (CPAs). These data revealed that over the course of the year, students likely made some small gains in their complete, integrated CSL.

Chapter 6

While the main focus of chapter six was specifically to address students' development of chemistry content knowledge as they engaged in CCE, the chapter essentially addressed the first two facets of CSL together: content knowledge and the practices of science. The findings from this paper were presented in four levels (Barab et al., 2007). At the immediate-level, students demonstrated content knowledge through a variety of scientific practices, such as modeling, argumentation, and inquiry as they critically examined the intersections between chemistry and society. They also began to adopt these practices as their own as they moved from peripheral to full members of the classroom community of practice (Lave & Wenger, 1991). At the close-level, it was revealed that students generally did pretty well demonstrating chemistry content knowledge in the CPAs. In addition, it appeared that the CPAs might have provided students who generally struggled on traditional forms of assessment an alternative mode of assessment to demonstrate a more meaningful understanding of the content of chemistry. At the proximal-level, students generally performed well on the traditional, content unit tests of CCE, demonstrating significant increases in chemistry content knowledge pre to post unit. Finally, at the distal-level, students who participated in the enactment of CCE did as well as students who engaged in a traditional chemistry curriculum on a cumulative, year-end, final chemistry exam. Together, these four levels of analysis revealed students of CCE learned a comparable amount of chemistry content knowledge to students of a traditional curriculum and in addition integrated the practices of science into their examination of chemistry and society.

Chapter 7

One of the important goals of CCE is to improve students' perceptions of chemistry, especially their interest in chemistry, which has been documented to be low for students in general (Gilbert, 2006). Therefore, in chapter seven, student interest in CCE and students' developing interest in the discipline of chemistry were investigated. To thoroughly complete this undertaking, class data were examined as a whole and then data for a subset of nine students, who were purposefully sampled based on their individual interest data alone, was looked at in more detail. Qualitative data from the classroom transcripts revealed that in the classroom, students generally behaved as though they were interested in the critical activities of the CCE curriculum, such as the examination of the chemistry content presented in newspaper articles. These behaviors were defined as *personal excursions*, behaviors that likely indicate interest because they appear to be intrinsically motivated by the activity at hand, rather than extrinsically motivated by external factors such as grades (Azevedo, 2006). However, quantitative data from Likert surveys indicated that this potential classroom interest in CCE had no effect on interest in the discipline of chemistry for the 25 student participants as a whole. On the other hand, qualitative data from the questionnaires and focus group interviews suggested that CCE did have an effect on student interest in chemistry for a subset of nine students. Three themes were noted in these nine student's specific reasons for being interested in CCE: (1) connections made between chemistry and business, (2) diverse knowledge bases, and (3) learning about diverse peer perspectives. In addition, these data revealed that CCE enhanced these nine students' perceptions of the relevancy and value of chemistry, which in turn seemed to increase their interest in the discipline itself. However, Likert survey data for the nine students only provided a very small level of support for the qualitative data.

Challenges of Enacting CCE

Enacting CCE at this private school setting posed many challenges for the students and the teacher/researcher, which have been similarly documented by other researchers (Aikenhead, 2005; Smith, 2013). These challenges are presented in three sections: (1) student challenges, (2) teacher/researcher challenges, and (3) mutual challenges.

Student Challenges

It is highly unlikely that the students at this setting had ever seen anything like CCE before unless perhaps they came from different school settings before entering the upper school (high school). While the overall science curriculum at this school can be quite inquiry-based at times, especially in the lower and middle schools, overall, it is very traditionally constructed.

Furthermore, in the later middle school years and certainly in the upper school, students are almost exclusively taught through didactic lecture-based methods.

As a result, not only did students have to adjust to the overall ethos of CCE, which at times they expressed discomfort with, they also had to adjust to the structure of the classroom activities and assignments. They were not accustomed to doing lab work and projects with partners or small groups that carried on for over a week in science class. They had never had a scientific writing assignment in a high school science class. They had never done as much group work during class time in a high school science course, which required them to share sensitive opinions while being respectful of their peers' sensitive opinions. Furthermore, compounding all of this was the difficulty I encountered enacting the critical curricular transformations while simultaneously working with the traditional chemistry curriculum I was expected to teach. The timing and scheduling issues that arose due to the integration of the CCE units with the existing curriculum added to the issues the students had to adjust to. For example, sometimes there were gaps between critical units and the due dates of related CPAs that were filled with work related more to the traditional curriculum. This could have had an impact on student learning and comprehension of chemistry. Therefore, the CCE units, the pedagogical approaches, and the expectations of learning for the students were new and had some influence on the enactment and outcomes of the CCE.

Teacher/Researcher Challenges

While the science department chair and school administration at the school allowed for CCE to be implemented and researched at the school, both were still quite uncomfortable with the endeavor at times. This discomfort was largely focused on whether or not my students would be exposed to the same amount of traditional content as the students in other chemistry classes rather than discomfort with what I was teaching my students. The work of Carlone, Haun-Frank, and Kimmel (2010) provided me with an excellent framework for navigating this issue while I was teaching and researching CCE. I worked as a "tempered radical," a person that delicately balances his inclusion and acceptance in the school community with his desire for reform. Tempered radicals use "improvisations" in their teaching that balance historic traditions with reformed science education (Carlone et al., 2010).

The first improvisation I used occurred in my development of the critical curricular transformations. I only chose four transformations to make sure I still had time to cover the entire traditional chemistry curriculum. In addition, for the most part, I elaborated upon units and specific labs that already existed in the traditional curriculum. In these ways, I did not add or subtract content, which satisfied the administration at the school. Second, the critical units were designed in a graduated way to incrementally increase the amount and level of critical work I expected from my students. Furthermore, I spaced out the critical units to give students a chance to reflect upon what we had done before moving on to the next unit.

Another complex challenge of enacting CCE as the teacher/researcher was in maintaining a student-centered classroom where students would be free to develop their own critical scientific literacy (CSL), essentially a scientifically based Freirian critical consciousness (Freire, 2000), without having my beliefs and biases thrust upon them, while at the same time challenging the majority of my students to consider their positions of privilege. Critical pedagogues agree (Brickhouse, 2000; Freire, 1998; hooks, 2009; Kincheloe, 2005) that critical analyses can only be carried out in student-centered classrooms that nurture students' exploration of complex issues that they can view through their own diverse backgrounds and ways of thinking. Students discuss these issues through their own diverse ways of communicating to ultimately develop their own critical consciousness without feeling pressure from the teacher's opinions. In order to accomplish this, I had to maintain a classroom-learning environment that would promote discussion of their ideas while not imposing my own.

On the other hand, critical pedagogues are emphatic that teaching is a political act and that teachers must not attempt a so-called objective neutrality in their teaching (Freire, 2000; Hinchey, 2004). Teachers, more than any other agents of education, have the power to transform the system of education currently designed to maintain the privilege of the dominant cultural group and the oppression of all others. For this transformation to occur, teachers must seek to promote social justice in their classroom actions and lesson plans, "no matter the discomforts and risks inherent in such work" (Hinchey, 2004, p. 128). A strong belief in this philosophy is what led to my adoption of a critical stance as a teacher and researcher in the first place.

First, walking the line between a student-centered classroom and one challenged to social action by the teacher was difficult during the creation of the activities of the curricular transformations. I wanted to spark conversations about important complex social issues, rife with the oppression of diverse cultural groups, as they relate to the nature and practice of WMS without leading students in any obvious directions. But, the very act of sparking certain conversations is a biased undertaking in of itself. Second, there were many times during the enactment of these activities when students would be on the cusp of an interesting analysis, and I would want to step in to encourage them to pursue a particular line of thought, but I would restrain myself. On the other hand, there were some occasions when my motivations overtook me, and I did push my students in specific directions that I felt enhanced the level of critical insight achieved by my students that could potentially lead them to positive social action. However, at the same time, I tried to be very careful and always attempted to play devil's advocate, addressing opinions or ideas from multiple sides without making a case for one in particular. Ultimately, my successes and failures at navigating this complex back and forth likely had a large impact on the student outcomes measured in this study.

Mutual Challenges

The rich tradition of Freirian critical pedagogy (2000), grounded in the critical analysis of the roots of oppression, its perpetuation through traditional schooling, and a dialogical pedagogy that can empower students to challenge and socially improve the capitalist-driven power structure of the world, was a major impetus for this research project in this setting. Fundamentally, in the same way that Trueba (1999) believes critical pedagogy should focus on the development of a critical consciousness in the oppressed and oppressors alike, I hope CCE will help all students – the oppressed and the oppressors – understand how the nature and products of Western modern science can be both positive and at the same time oppressive, maintaining the existing power structure of society. Moreover, I hope CCE will empower all students to make socially positive, chemistry-based decisions in their lives that could potentially deconstruct the oppressive nature of the intersections between science and society.

For example, helping students understand that while pharmaceutical companies produce many drugs that can help people live better lives, pharmaceutical research agendas that focus on the afflictions of Western, White males continue the oppression of all other groups of people. Therefore, arming students with chemistry content knowledge they can then use to eat in healthier ways or decide on alternative and equally effective heartburn remedies versus over-the-counter remedies (OTC) could actually change the amount of money pharmaceutical companies spend on researching and advertising OTC heartburn remedies. As a result of chemistry-motivated socially responsible decisions, pharmaceutical companies may then spend more money on more devastating afflictions that affect less resourced people at home and across the globe, such as HIV/AIDs.

However, enacting CCE as a Western, White male teacher in a classroom setting composed largely of highly resourced, Western, White students made this research project very difficult. My students and I had to confront and reflect upon our roles as privileged, oppressors in the power structure of society and then grow to understand that we too could be empowered as agents of science-based, positive social change. From the very beginning I knew this journey with my students was going to be a difficult one, which is one of the reasons I kept a researcher journal.

Initially, my own discomfort with self-reflection caused me to largely use the researcher journal as a way to reflect upon my students' comfort and growth. Of course, this was an important endeavor in its own right. I needed to pay close attention to my students' levels of discomfort with the project both in terms of the logistics of data collection and with the ethos of the CCE curriculum they were participating in. However, later reflection allowed me to see that in some ways this was a superficial use of my journal and a way to avoid confronting my own growth as a teacher and researcher of CCE.

As the year progressed though, with my journaling, I began to see some of my students' discomfort in my own actions as the teacher/researcher. In general, my students were initially uncomfortable with many of the aspects of the CCE curriculum, including discussing gender, race, and ethnic bias in Western modern science (WMS). They were most uncomfortable discussing how their positions of privilege gave them special access to participate in the practice of WMS and reap the rewards of the products of WMS. I documented evidence of this discomfort in my journal quite often. It was recorded as a low level and/or lack of enthusiasm in student participation during specific activities. At the same time, I noticed in my journal, I too had trouble expressing myself during these discussions. I hesitated with word choice and even avoided using terms such as race.

In addition, I realized that at least on one occasion I cut an activity short because of what I projected to be student discomfort, but was actually mutual discomfort felt by my students and me. More specifically, I realized that my decision to have my students critically analyze more global science-based issues like hydrogen fuel cell cars, protecting the environment, or the importance of steel manufacturing to the global economy, positioned us to talk about towns far away from our school community. This likely made it easier for my students to participate in these activities without facing the difficult challenge of self-critique, and it also made it easier for me to frame these conversations. In this way, my students and I did not have to confront or investigate locally relevant, science-based, and potentially oppressive issues related to the huge economic disparities between our school community and nearby neighborhoods less than 10 miles away.

However, by the end of the year, we had grown together in meaningful ways. As my students began to get more comfortable with CCE and see the validity of what we were trying to do together, they began to make some of the progress noted in the critical scientific literacy findings (chapter 5), such as developing the ability to analyze the products of WMS from multiple perspectives, considering the positives and potential for oppression. At the same time, I began to adjust the CCE curriculum so that is was even more student-centered, giving students more freedom to identify what they wanted to investigate and define how they wanted to investigate it, like in the heartburn inquiry lab (chapter 7). My development as the teacher/researcher allowed me to start to confront how my discomfort with critically analyzing my own position of privilege likely caused weaknesses in the CCE curriculum development and enactment for this study. Nonetheless, my continued reflection has allowed me to identify ways to improve the CCE units for future iterations, which is explored in the next section.

Implications

Together, the positive outcomes and challenges of enacting CCE have implications for critical science education curriculum design and research design.

Critical Science Education Curriculum Design

Grounding the CCE curricular transformations or units created for this study in sociocultural learning theory had a powerful effect on students ability to construct and share understandings of chemistry content knowledge, the practices of science, and the critical ways chemistry and real world social issues are connected in a classroom community of practice. Furthermore, grounding CCE in the performance expectations of the NGSS provided students with a variety of ways to demonstrate their critical understandings of chemistry through authentic practices of science. Future iterations of critical science education in high school science classes should continue to employ these methods in curriculum design.

However, the critical scientific literacy (CSL) findings of this study, as well as the findings from other studies (Haviland, 2008; Picower, 2009; Suriel & Atwater, 2012), suggest that students from privileged, dominant cultural backgrounds have difficulty truly understanding bias and developing critical insights. This implies the need for critical science education to be expanded. While a single exposure to it in chemistry class provided a starting point for the student participants of this study, lasting success might prompt students to engage in positive scientifically based social action. Therefore, critical approaches to science education must begin much earlier than sophomore year of high school and should be enacted across scientific disciplines. For critical education to make a lasting impact on these students, it should be coordinated across subject areas from the humanities to the sciences in these students' longitudinal educational experiences (Picower, 2009).

In addition, while the curriculum for this study was developed to be student-centered by connecting chemistry education to student interests and personal backgrounds, providing students with opportunities to develop scientific identities by participating in authentic practices of science, and minimizing the teacher's voice in the classroom, there were still shortcomings in this area that possibly hampered students development of CSL. For example, while students were encouraged to ask their own questions about complex socially situated, science-based issues, many of the classroom activities developed for CCE were prompted by questions directed by the teacher. These questions could have made students uncomfortable and defensive, which would decrease the level of critical analysis they achieved. On the other hand, some of the activities created for CCE in this study started with activities that prompted students to ask their own questions and define their own interpretations of socially situated science-based issues in a lets "unpack" this issue together-type way (Haviland, 2008). These activities seemed to be more successful at developing students' CSL. For example, the heartburn inquiry lab seemed to really help students integrate diverse knowledge with their Western-dominated scientific thinking. This lab started with students watching and then asking their own questions about the motivations of the creators of a TV commercial for an over-the-counter heartburn remedy. Future iterations of CCE, and critical science education in general, should employ more introductory activities that prompt student questions like the heartburn inquiry lab did.

Finally, an important aspect of CSL included students taking what they discussed and learned in the classroom and using it to act in socially positive ways outside the classroom in the now. Birmingham and Calabrese Barton (2014) call this *educated action*. While this study was not constructed to gauge what students did outside the classroom to a great extent, there was no documentation of educated action, most likely a reflection of how the CCE curriculum was developed. It was designed to instigate students into thinking about how understanding chemistry could better prepare them to understand socioscientific issues and possibly make socially positive decisions outside of the classroom. It was not designed to prompt students to identify locally relevant science-based issues that students could use chemistry content knowledge to better understand and to take action. Future iterations of CCE should incorporate ways for students to get involved in positive ways in their own communities so that they can reach the level of educated action in their CSL.

Research Design

Overall, the critical, ethnographic research design undertaken in this study provided valuable insights into what the enactment of CCE looked like at this setting. These insights were largely the result of the abundance of both qualitative and quantitative data collected for this ethnography. The multiple video and audio recordings of each classroom activity were especially helpful in answering the research questions. This method ensured that nothing was missed in the classroom. In addition, the concurrent triangulation of qualitative and quantitative data enhanced the stories told in this study by providing support for conclusions from multiple angles that potentially widened the audience of readers of the study (Hickey & Zuicker, 2003). Finally, with its ability to facilitate the organization and analysis of large amounts of qualitative data, NVivo certainly helped reveal the insights documented in this study. Especially now, with the ease that laptop computers and even smart phones can collect audio/visual data in the classroom, and the speed and power with which computers can store, organize, and analyze large amounts of not only quantitative data, but qualitative data as well, future ethnographic studies should continue to utilize the methods employed in this study to collect data from many angles. Studies framed in this way can develop rich, insightful understandings of CCE.

Plans for Future Research

First, the implications outlined above indicate the need for future research to specifically address if and how students transfer their CCE-developed classroom understandings to positive, science-based actions outside the classroom. This should also entail longer-term, longitudinal research to determine if CCE has a lasting effect on students' thoughts and actions later in life. In other words, I want to know if CCE has a lasting effect on students science related participation in our democratic society. In addition, this longitudinal research should gauge if the improved perceptions of chemistry interest developed by CCE in some students is at all lasting. This will require using the same questionnaires and Likert surveys to assess students' future levels of interest and a comparison to the levels documented in this study. This process could also reveal more meaningful interest data, as participants may have a better understanding of their interest in retrospect (Renninger & Hidi, 2011). Moreover, this future research could reveal whether or not CCE affected students' future choices to study or not to study chemistry and/or other science, technology, engineering, and mathematics (STEM) based fields in college.

Second, I want to study teachers as they enact critical science education. It would be important to learn how they grow and evolve as teachers and as people as they struggle through enacting CCE. Future research focused on the teachers of CCE, and critical science education in general, should provide valuable insights for future enactments of CCE to be shared for preservice teacher training and in service professional development.

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Appendix A
Study Timeline

Critical Metal Activity Series Inquiry Lab – December

1. Day 1: Pre Likert survey
2. Days 1-4: Video recording of unit/activity
3. Day 5: Post unit test
4. Day 6: Post Likert survey and post questionnaire
5. Within a week of day 4: Two focus group interviews
6. About a week after day 5: Student artifact collection
7. Preliminary analysis of first unit data

Critical Kinetics Unit – March

1. Day 0: Pre unit test
2. Day 1: Pre Likert Survey
3. Days 1-6: Video recording of unit/activity
4. Day 6: Post unit test
5. Day 7: Post Likert Survey
6. Day 7 homework: Post questionnaire
7. Within a week of day 7: One focus group interview
8. About a week after day 7: Student artifact collection
9. Preliminary analysis of second unit data

Critical Organic Unit – April

1. Day 1: Pre unit test
2. Days 1-4: Enactment of unit. However, only days 3 and 4 were video recorded.
3. Day 4: Post unit test
4. Day 5: Post Likert Survey
5. Day 5 homework: Post questionnaire
6. Within a week of day 4: One focus group interview
7. About a week after day 4: Student artifact collection
8. Preliminary analysis of third unit data

Critical Acid/Base Unit – May

1. Day 0: Pre unit test
2. Day 1: Pre Likert survey
3. Days 1-13: Enactment of unit. However, only days 4, 6, 8, 9, and 13 were video recorded.
4. Day 12: Post unit test
5. Day 14: Post Likert survey
6. Day 14 homework: Post questionnaire
7. Within a week of day 13: One focus group interview
8. About a week after day 13: Student artifact collection
9. Preliminary analysis of fourth unit data

Appendix B
Critical Metal Unit Map

<u>Day 1</u>

Tangential connection(s) to Science and Engineering Practices for Physical Science from *Framework for K-12 Science Education* (NRC, 2012).

- Construct explanations based on a variety of sources, including reliable Internet sites and student generated sources of evidence.

Content Topics

- Physical properties of metals
- Metallurgy/alloys
- Metal single replacement reactions

Key Points and Experiences
Classroom Activity:

1. Critical analysis of ancient Native American metallurgy video.
2. Discussion of conceptions of nature of science.
3. Discussion of personal associations with ancient and modern cultures and their use of metal in art and other artifacts of the culture.
4. History of metallurgy/alloys, and metal single replacement reactions mini lecture and inquiry lab intro.

Homework: (due in two class periods)

1. Learn about the history of metallurgy and use of metals in the art and other artifacts an ancient or modern culture you belong to or feel connected to. You can interview family members or members of your community or use Wikipedia to learn this information. Write a one page (double spaced) summary of what you learned. Be prepared to briefly and informally share what you learned in class.

<u>Day 2</u>

Tangential connection(s) to the *Next Generation Science Standards* (NGSS Lead States, 2013b**).**

- HS-PS1-1
- HS-PS1-3

Tangential connection(s) to Science and Engineering Practices for Physical Science from *Framework for K-12 Science Education* (NRC, 2012).

- Plan an investigation collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (quality of measuring tools, and number of trials).
- Conduct student planned investigation according to the above criteria.

Key Points and Experiences

Classroom Activity:

1. Inquiry Lab development
   a. Predict relative reactivity of the pure metals provided in the lab using prior knowledge about the trends on the Periodic Table.
   b. Identify independent, dependent, and constant variables
   c. Write hypothesis
   d. Construct procedure for testing hypothesis using metal single replacement reactions
2. Begin collecting data using the provided materials

Homework:

1. Finish Day 1 homework assignment.

<u>**Day 3**</u>

Tangential connection(s) to the *Next Generation Science Standards* (NGSS Lead States, 2013b**).**

- HS-PS1-3

Tangential connection(s) to Science and Engineering Practices for Physical Science from *Framework for K-12 Science Education* (NRC, 2012).

- Conduct student planned investigation according to the above criteria.

Key Points and Experiences

Classroom Activity:

1. Finish collecting data
2. Begin data analysis
   a. Discussion of observations
   b. Use of bar charts
3. Students share their Day 1 homework assignments

Homework:

(due in two class periods)

1. Finish data analysis
2. Write conclusion
3. Prepare answers to discussion question set to participate in critical discussion of steel manufacturing

<u>**Day 4**</u> (two days after Day 3)

Tangential connection(s) to Science and Engineering Practices for Physical Science from *Framework for K-12 Science Education* (NRC, 2012).

- Present results of student planned investigation according to above criteria.
- Debate unanticipated effects of scientific work on society.

Content Topics

- Metal single replacement reactions
- Metal Activity Series

Key Points and Experiences
Classroom Activity:

1. Students discuss inquiry lab results in conjunction with Metal Activity Series
2. Students participate in peer review of the presented results.
3. Critical classroom discussion of steel manufacturing and the future of the American job market

Homework:

1. Prepare for chemical reactions unit test

<u>Duplicated from NGSS Lead States, 2013b</u>

HS-PS1-1. Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms. [Clarification Statement: Examples of properties that could be predicted from patterns could include reactivity of metals, types of bonds formed, numbers of bonds formed, and reactions with oxygen.] [Assessment Boundary: Assessment is limited to main group elements. Assessment does not include quantitative understanding of ionization energy beyond relative trends.]

HS-PS1-3. Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles. [Clarification Statement: Emphasis is on understanding the strengths of forces between particles, not on naming specific intermolecular forces (such as dipole-dipole). Examples of particles could include ions, atoms, molecules, and networked materials (such as graphite). Examples of bulk properties of substances could include the melting point and boiling point, vapor pressure, and surface tension.] [Assessment Boundary: Assessment does not include Raoult's law calculations of vapor pressure.]

Appendix C
Critical Metal Unit Materials

Appendix C contains:
I. The guidelines of the critical metal inquiry lab (the Corrosion Inquiry Lab).

I. Corrosion Inquiry Lab

What metal would you use to build a footbridge on beach-front property based on its resistance to corrosion?

Day 1: Intro Activity

1. Discuss with your partner the following questions. Don't worry about being right or wrong. Just answer them to the best of your ability. Write your answers on a separate piece of paper.
   - What do you think about when you think of metal and history?
   - What is metallurgy?
   - What are your conceptions of who developed metallurgy?
   - Who invented swords?
   - Do you think the use of metal developed in one place and then spread from there or did it develop independently in different ancient cultures? Have you learned anything about this in other classes?

Class discussion of answers.

2. Watch video of Mississippian Indians at https://www.youtube.com/watch?v=AVtuxtIP4g4

First, we will watch the video as a class together and discuss what it was about. Then you can watch it on your own to think about and answer the following questions.
   - What did they say about the scientific knowledge of the Mississippian Indians? What is scientific knowledge? What can be categorized as scientific knowledge? How is scientific knowledge produced? Did the Mississippians do science or were they scientists?
   - Who were the modern scientists? Did they look like scientists? What do scientists look like? What are the scientists doing?
   - Go back and look at the dramatized conversation between the young woman and the older man sitting at the table discussing the copper metal. What roles did they have? What was the body language that implied the roles? What societal norms are governing your impressions of the roles they are fulfilling? Is the professor the one talking because he is older, wiser, or because he is the man? Do you think it would be different if he were not a man talking to a young woman? Do you think the director would choreograph the scene the way he or she did if the people were different, like if it were two males, two women, people of the same age?

Class discussion of answers.

3. History of Metallurgy, Alloys, and Single Replacement Reactions

- Gold
- Copper
- Bronze
- Iron & Steel
- Single replacement reactions occur for metal cations when a more reactive metal is reacted with a compound that contains a less reactive metal. If the free state metal is the more reactive metal, it will replace the metal in the compound. A single replacement reaction *will not* occur if the more reactive metal is already in the compound. Metal cation single replacement reactions generally take place in aqueous solutions and can be observed when the less reactive metal begins to form on to the more reactive metal. If there does not appear to be a new metal forming on the surface of the metal in the solution, then no reaction is taking place. See teacher demo.

4. Day 1 Homework: Look up an ancient, historical culture or modern day culture you feel connected to and learn about the history of metallurgy and use of metals in the art of that culture. Write a one-page (double spaced) summary of what you learned. Be prepared to share in class. Cite your sources.

Day 2:

In this lab, the reactivity of five different metals (Pb, Cu, Mg, Zn, and Fe) will be tested using single replacement reactions. The most reactive metal is the one that would corrode the most. The reactivity of a metal depends on its electron configuration and stability. Metals that are stable are less reactive and therefore less likely to corrode. A metal's stability can be *predicted* by its placement on the Periodic Table. An existing series of metal reactivities from highest to lowest is referred to as The Activity Series.

Materials		Equipment
Small pieces of	Copper	Well Plate
	Magnesium	Pipettes
	lead	Forceps
	Iron	Toothpicks
	Zinc	
1 M Solutions of	$Cu(NO_3)_2$	
	$Mg(NO_3)_2$	
	$Fe(NO_3)_2$	
	$Pb(NO_3)_2$	
	$Zn(NO_3)_2$	

Hypothesis

Write a formal "If.., then.., because" hypothesis that predicts the likelihood of corrosion from most likely to corrode to least likely to corrode for the five metals (Pb, Cu, Mg, Zn, and Fe) tested in this lab based on their positions on the Periodic Table.

Procedure

Write a procedure to test the hypothesis using single replacement reactions and the materials and equipment listed above. You do not need to use all the equipment, but you will need to use all the materials. Consider the combinations of reactions will have to do to determine how reactive each metal is. You do not need to do multiple trials. Consider the data table you will use in conjunction with your procedure. Type your procedure here and make sure teacher checks it before you leave for day 1.

You will not be evaluated on the accuracy of your hypothesis or your data.

Day 3

Perform your procedure with your partner.

Data and Observations

List observations here and create a data table to record whether reactions occurred for each of the possible combinations of metals and solutions.

Analysis

Create a bar graph for each of the metals' reactivity by graphing the number of reactions each had on the y-axis. The name of the metal goes on the x-axis.

Conclusion

Write a proper conclusion that notes the purpose, evaluates your hypothesis with your data, compares your data to the known Activity Series, and answers the question: "Which metal would you use to build the bridge?" Make sure you explain your answer using your data. Finally, discusses possible experimental errors.

Extension Questions (You may need to research the Internet to answer some of these. Also, some may be opinion based. Please do your best.)

1. Chose one of the reactions that did occur and write a complete, balanced formula equation with phase subscripts. Then assign oxidation numbers to each atom. Identify which atom is oxidized and which atom is reduced. Finally, write the oxidation and reduction half-reaction.

2. Assume you are building the bridge in a dry desert. Would you choose a different metal? Why or why not?

3. Why doesn't the least reactive metal in this lab get used more extensively in building bridges? Give two reasons. Cite your sources.

4. Why was the least reactive metal in this lab one of the first metals used by civilization? How was it important to civilization?

5. What material is used most often to construct bridges and buildings? Why? Find as many reasons as possible. Why aren't any of the pure metals tested in this lab used to build bridges?

6. What materials are required to make steel? How is steel produced? What other industries are involved in the production of steel?

7. Where is steel produced in the US? Who works in a steel mill? What type of person generally works in a steel mill? Is there a general type of person? What does a steel worker look like? What do steel workers get paid? Does it provide a comfortable life? Would you want to work at a steel mill?

8. Who produces the most steel worldwide? Who uses the most steel worldwide? Where is the US on these lists? What are the implications of this for US manufacturing jobs?

9. What kind of jobs do US citizens need to be trained in for the future? What does this mean for US education? What does this mean for the education of all US students?
How does this connect to issues of social, economic status or class in the US?

10. What is your opinion about major US industries moving overseas? Why?

11. Think of two questions you will ask your classmates about the results they present on Day 4. For example, you could ask them how they got their results or what steps they used to get their results. Be prepared to ask them in class on Day 4. This is to enhance audience participation.

12. Look over the other requirements for Day 4.

Day 4: Mini Presentations of Lab Work

1. Be prepared to project and discuss your graph with the class.

2. Be prepared to share your answers to the extension questions with the class.

3. Be prepared to discuss how your results connect to the extension questions. In other words, what does single replacement reactions and corrosion have to do with steel production?

3. Be prepared to politely ask questions of your classmates about where they got their information for the extension questions, and why they feel the way they do. Write out at least two questions to ask your classmates.

Appendix D
Critical Kinetics Unit Map

Day 1

Tangential connection(s) to the *Next Generation Science Standards* (NGSS Lead States, 2013b**).**

- HS-PS1-5

Tangential connection(s) to Science and Engineering Practices for Physical Science from *Framework for K-12 Science Education* (NRC, 2012).

- Plan an investigation collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (quality of measuring tools, and number of trials).

Content Topics

- Chemical kinetics
- Reaction rate
- Collision theory
- Factors that affect reaction rate

Key Points and Experiences
Classroom Activity:

1. Chemical reactions demonstration of reaction rate.
2. Reaction rate and collision theory lecture.
3. Research design variable brainstorming session.
4. Inquiry lab development
   a. Formulate research question.
   b. Predict effect of student chosen independent variable on reaction rate.
   c. Identify constant variables.
   d. Write hypothesis.

Homework:
(due next class)

1. Finish research design guideline sheet if not already completed in class.

Day 2

Tangential connection(s) to the *Next Generation Science Standards* (NGSS Lead States, 2013b**).**

- HS-PS1-5

Tangential connection(s) to Science and Engineering Practices for Physical Science from *Framework for K-12 Science Education* (NRC, 2012).

- Plan an investigation collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (quality of measuring tools, and number of trials).

- Conduct student planned investigation according to the above criteria.

Key Points and Experiences
Classroom Activity:

1. Inquiry Lab development
   a. Construct procedure for testing hypothesis using either the decomposition of hydrogen peroxide and a pressure probe or the single replacement reaction of a metal with hydrochloric acid and a temperature probe.
2. Begin collecting data.

Homework:

1. None

Day 3

Tangential connection(s) to the *Next Generation Science Standards* (NGSS Lead States, 2013b**).**

- HS-PS1-5

Tangential connection(s) to Science and Engineering Practices for Physical Science from *Framework for K-12 Science Education* (NRC, 2012).

- Conduct student planned investigation according to the above criteria.

Key Points and Experiences
Classroom Activity:

1. Finish collecting data
2. Begin data analysis
   c. Discussion of observations
   d. Use of bar charts or scatter plot graphs with a best fit line

Homework:
(due in three class periods)

1. Finish data analysis
2. Write conclusion
3. Prepare answers to discussion question set to participate in critical discussion of science's potential to benefit some people while marginalizing or excluding others.
4. Prepare Power Point presentation.

Day 4

Content Topics

- Reaction rate
- Types of chemical reactions
- Energy transformations and conservation

Key Points and Experiences

Classroom Activity:

1. The *before reading* phase
   - The two newspaper articles on the hydrogen fuel cell car are introduced
   - Individually answer prediction questions about the two articles and then discuss as a whole class
2. The *during reading* phase
   - Read the two articles in small groups and collaboratively answer the critical reading question set

Homework:

1. None

Day 5

Content Topics

- Reaction rate
- Types of chemical reactions
- Energy transformations and conservation

Key Points and Experiences
Classroom Activity:

1. The *during reading* phase
   - Whole class sharing and discussion of previous day's work
2. The *after reading* phase
   - Individually construct and write a personal stance or conclusion based on the content of the articles using provided rubric

Homework:

1. Finish the *after reading* phase activity

Day 6

Tangential connection(s) to Science and Engineering Practices for Physical Science from *Framework for K-12 Science Education* (NRC, 2012).

- Present results of student planned investigation according to above criteria.
- Debate unanticipated effects of scientific work on society.

Content Topics

- Collision theory
- Factors that affect reaction rate

Key Points and Experiences
Classroom Activity:

1. Student presenters act as the scientific expert for their particular variable and its effect on reaction rate by explaining their results with collision theory.
2. Students participate in peer review of the presented results.
3. Critical classroom discussion of science's potential to benefit certain groups of people while marginalizing or excluding others

Homework:

1. Prepare for kinetics unit test using the information learned from classmates presentations.

<u>Duplicated from NGSS Lead States, 2013b</u>

HS-PS1-5. Apply scientific principles and evidence to provide an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs. [Clarification Statement: Emphasis is on student reasoning that focuses on the number and energy of collisions between molecules.] [Assessment Boundary: Assessment is limited to simple reactions in which there are only two reactants; evidence from temperature, concentration, and rate data; and qualitative relationships between rate and temperature.]

Appendix E
Critical Kinetics Unit Materials

Appendix E contains:
I. The guidelines of the critical kinetics inquiry lab.
II. The guidelines of the critical science reading/writing Assignment – Evaluation of science-related newspaper articles

I. Kinetics Inquiry Lab

In this lab, you will be investigating one of two reactions, and testing one factor that affects the rate of the reaction.

Reaction 1: $2H_2O_2 \rightarrow 2H_2O + O_2(g)$ (Nothing visual will occur without a catalyst)

Reaction 2: Metal + HCl(aq) → ??

Predict and observe what happens when the teacher places an aluminum foil ball in hydrochloric acid. (write your observations below)

Materials List
Aluminum foil (.5 to 1.5 g)
Aluminum (granular .5 to 1.5 g)
Zinc strips (.5 to 1.5 g)
Zinc Filings (.5 to 1.5 g)
Magnesium strips (.5 to 1.5 g)
HCl solutions (6M, 3M, 1M, 0.5M) (20 mL max)
H_2O_2 solution (8.8M) (1 to 2 mL plus 25 to 50 mL distilled water)
KI (0.5M catalyst) (1 to 8 mL)

Equipment Available
LabQuest
Temperature probes
Pressure probes
Stopper/Luer-lock tubing
125 mL Erlenmeyer flask (make sure pressure does not exceed 135 kPa)
Graduated cylinders (varying sizes)
Balance
Hot Plate/Stirrer/Magnetic stir bar
Ice water bath

Experimental Design

Research Question (choose the factor you want to test, and the reaction you want to carry out):

Independent Variable (specify units of measurement):
Dependent Variable (specify units of measurement) :
Constants: (all other factors not selected as independent variable)

Hypothesis: (use "If …, then…., because" format)

Procedure

Brainstorm with your partner a detailed procedure for determining the relationship between your independent variable and the dependent variable.

- Write your procedure in bullet point steps.
- Make sure you include the specific lab equipment you will use in the procedure steps and the specific units.
- Include steps that indicate a change in your independent variable, and how it will be measured. Indicate specific units.
- Include multiple trials for every measurement you make in the procedure.
- Create a data table after the procedure to record both quantitative data (make sure it indicates the units), and written qualitative observations (should also be accompanied by pictures) of the reactions.
- Make sure there are no calculation steps in your procedure. Only record measurements you can see without doing any math in your head.

Check with the teacher after this step.

Data Analysis

The data should be presented in a clear, concise manner (data table, graph (dependent variable vs independent variable), and visual representation) and properly labeled.

- This may require calculations.
- If you have a qualitative independent variable, use a bar graph.
- If your independent variable is quantitative, use a line graph (best fit line).
- Photos or diagrams of the experiment.

Conclusion

Write a conclusion. A conclusion contains a general overview of the lab purpose, a summary of your results, and an explanation of how your results either confirm or disconfirm your hypothesis. This section should include any changes you made in your procedure with an explanation for why, and also include your sources of error. There are potential sources of error for EVERY laboratory. Think of at least **two** possible sources of error and make a note of them here. Make sure they are specific to the lab and its procedure. Do not just say "calculation" or "measuring" errors. How exactly may it have been difficult to measure?

- 1 point for reference to purpose of the lab and the research question
- 5 points for the evaluation of the hypothesis using specific observations and data points

- 5 points for drawing conclusions from the lab that relate to the scientific theories or concepts based upon evidence from the experiment (compare your evidence to the information found on pages 598-601 in the text)
- 2 points for the two sources of error
- 2 points for addressing how you might improve the experiment if you were to do it again in the future

Critical Question Set
(To be discussed in class after presentations.)

1. Summarize, in your own words, all the steps you took to complete this assignment and in the order you did them in, including how you will share your results. You do not need to include the details of your procedure, just an overview of all the things you did to complete the entire assignment.

2. What skills did you use to complete this assignment? To what extent did you use your writing and math skill sets? Did you need to be creative? How so?

3. Even if scientific community already knows what you determined for yourselves during this assignment, you produced scientific knowledge. Does all scientific knowledge have to be produced in the way that you did? Who decides or who gets to decide if what you produced was scientific knowledge?

4. Does all knowledge have to be produced in the way you produced it in this assignment? What are some other knowledge bases or types of knowledge? What are some other ways knowledge can be produced and accepted by a community?

5. What are the benefits to society of the knowledge you produced? Who in particular could profit from your knowledge production?

6. Does scientific knowledge always benefit people? Do you know of any examples where it does not? If you do not, use the Internet to explore examples of science hurting or oppressing people?

7. Who might not benefit from the knowledge you produced in this assignment? Could the knowledge you produced in this assignment oppress or hurt people? How so?

8. Could the scientific process you used in this assignment exclude certain people? Has the process of science excluded certain people through history? What group or groups of people still seem to be in control of science? Who is still marginalized by science?

9. Think of two questions you will ask your classmates about the results they present on Day 4. For example, you could ask them how they got their results or what steps they used to get their results. Be prepared to ask them in class on Day 4. This is to enhance audience participation.

Presentations of Lab Work

1. Be prepared to project and discuss your graph with the class.

2. Be prepared to share your answers to the extension questions with the class.

3. Be prepared to politely ask questions of your classmates about where they got their information for the extension questions, and why they feel the way they do. Write out at least two questions to ask your classmates.

Project Presentation Grading Rubric
Types of Presentations include Poster or PowerPoint

(2 pts.) Research Question and Title ______

(5 pts.) Experimental Details ______
Includes:
- Independent variable (include units of measurement)
- Dependent variable (include units of measurement)
- Constants
- Hypothesis ("if…, then…., because" format)

(15 pts.) Procedure _______

(15 pts.) Analysis of Results _______
Includes:
- Data Tables (properly labeled, with appropriate title)
- Graphs (properly labeled, with appropriate title)
- Calculations (if applicable)
- Visual representation (photo or diagram of experiment)

(15 pts.) Conclusion _______
Includes:
- 1 point for reference to purpose of the lab and the research question
- 5 points for the evaluation of the hypothesis using specific observations and data points
- 5 points for drawing conclusions from the lab that relate to the scientific theories or concepts based upon evidence from the experiment (compare your evidence to the information found on pages 598-601 in the text)
- 2 points for the two sources of error
- 2 points for addressing how you might improve the experiment if you were to do it again in the future

(10 pts.) Extension Questions (not included in slides, just handed in and discussed in class)
____
Includes:

- Addressing all the components of each question.
- The level of detail you include.
- The level of self reflective, critical thought you put into the questions.

(8 pts.) Overall Appearance of presentation _________

Includes:

- Neatness
- Organization of data

II. Critical, Science Reading and Writing Assignment – Evaluation of Science-Related Newspaper Articles

Day 1

1. Before reading the two articles (Chang, 2014; Soper, 2015), scan the titles and any graphics of the two articles, and then answer the following prediction questions.
   - Why are we reading these articles in chemistry class?
   - What do you think the articles are about?
   - What opinion do you think the author of each article will have about the topic?

2. Full classroom discussion: students will be asked to share some of their predictions.

3. In small groups, collectively read and at the same time answer the following questions about the two articles.
   - Who wrote these articles?
   - What are the main ideas of the two texts?
   - What are the purposes of the two writers?
   - What are the writers' assumptions and viewpoints? Are the assumptions justifiable?
   - Whose interests do the writers' viewpoints serve?
   - Whose interests do the writers' viewpoints possibly hurt or even oppress? How or in what ways?
   - Identify the evidence the authors use to support their claims.
   - Distinguish between scientifically collected evidence and opinions in the articles.

Day 1 Homework: If you run out of the time reading the two articles and answering the questions, please complete for homework.

Day 2

1. Full classroom discussion: student groups will be asked to share their answers to reading questions and note the responses of their peers to help them with their writing assignments.

2. Begin constructing an essay that addresses the guidelines outlined below.

Day 2 Homework: If you do not finish your essay in class, please complete for homework.

Writing Assignment Guideline

Structure your essay around the following six sections. Make sure you address each question within a section.

(1) Identify the main ideas of the two texts.
(2) Identify the writers' purposes.
(3) Identify the writers' assumptions and viewpoints.

- Clearly identify in your own words the writers' viewpoints.
- Whose interests do the writers' viewpoints serve?
- Whose interests do the writers' viewpoints possibly hurt or even oppress? How or in what ways?

(4) Formulate a scientific question which the writers answer in their articles.
(5) Identify data and evidence given in the texts.

- Clearly identify the evidence the writers use to support their viewpoints.
- Clearly distinguish between scientifically collected evidence and opinions in the articles and in your own arguments.

(6) Draw your own conclusions based on the evidence.

- You may choose to agree with the claims made in one, both, or neither of the two articles.
- Support your claims with evidence from multiple credible sources. You may use the Internet, but make sure you use credible sites that you cite.
- Whose interests do your conclusions support? In other words, who benefits from your conclusions?
- Whose interests do your conclusions possibly hurt or even oppress? How or in what ways?"

Writing Assignment Rubric

Category	Scoring Rubric
1. Identification of the main ideas of the text	0 – They cite non-relevant information or do not reproduce the information 1 – They only identify one of the key ideas or concepts 2 – They mention more than one key idea or concept 3 – They express in their own words the most important information. They identify some of the key ideas and concepts used in a way showing understanding. They make connections between ideas 4 – They express in their own words the most important information in a way showing understanding. They identify all the key ideas and concepts used in a way showing understanding
2. Identification of the writer's purpose	0 – They cite irrelevant information 1 – The information they express cannot be inferred from the text 2 – They assume that news stories are only used to inform in a neutral and unbiased manner 3 – They identify the writer's purpose but in a not very precise way because they do not express themselves well or because they are not specific enough

	4 – They communicate the purpose that they believe the writer has well. They realize that the writer has other intentions besides providing information (creating controversy...)
3. Identification of the writer's assumptions and discussing how they might benefit or oppress certain groups of people	0 – They do not answer or cite irrelevant information or they do not identify the writer's viewpoint 1 – They make unreasonable assumptions based on evidence and do not identify the writer's viewpoint or justify the point of view expressed 2 – They cite sentences word for word from the text without inferring the writer's viewpoint 3 – They make reasonable assumptions, identifying the writer's viewpoint, and the people it benefits ***or*** hurts, but they do not justify it 4 – They make reasonable assumptions, identify the writer's viewpoint, the people it benefits, ***and*** the people it hurts or oppresses, and they justify it based on the text
4. Formulation of a scientific question that the writer answers	0 – They pose questions that are not very coherent 1 – They pose the question without being specific 2 – They ask questions which are not answered in the text 3 – They formulate reasoned important questions from a science standpoint, only analyzing one of the variables 4 – They formulate reasoned important questions from a science standpoint, analyzing all of the variables to be taken into consideration
5. Identification of data and evidence given in the text	0 – They validate the information due to their confidence in the newspaper (they do not judge the credibility of the source) or because they think that the writer is informed 1 – They cite information in the text with basic or imprecise reasoning or draw conclusions based on irrelevant information in the text or do not mention whether it is evidence or not 2 – They mention whether the text provides evidence or not, or whether the information it provides is scientifically valid without giving further explanation or giving very basic arguments or without looking for an argument to validate the information in the text 3 – They draw reasoned conclusions based on the information provided in the text (facts, data, evidence, ...), without identifying the type of source (fact, opinion, scientific source, ...) 4 – They distinguish between facts, scientific arguments and opinion in the text. They draw conclusions taking into account the information available and using sensible reasoning they demonstrate the ability to analyze and evaluate the information objectively
6. Arguing conclusions based on evidence and discussing how they might benefit or oppress certain groups of people	0 – They cite irrelevant arguments 1 – They reach conclusions based on daily knowledge without activating scientific knowledge 2 – They activate their knowledge of science and demonstrate the ability to argue agreement and disagreement, disagreement, although they do not challenge their knowledge using information in the text 3 – They challenge the information in the text using their scientific knowledge and show reasonable agreement and disagreement without giving explicit grounds. They also identify groups of people that benefit from ***or*** are hurt by their conclusions.

	4 – They challenge the information in the text with their scientific knowledge citing at least two other reliable sources, showing an ability to argue agreements and disagreements in a reasoned manner. They also identify groups of people that benefit from ***and*** groups of people that are hurt by or oppressed by their conclusions

Appendix F
Critical Organic Unit Map

<u>Day 1</u>

Content Topics
- Organic chemistry terminology
- Alkanes
- Organic chemistry functional groups

Key Points and Experiences
Classroom Activity:
1. Introduction to the organic chemistry presented in the book chapter "The Pill"
2. Discussion of history of the pill
3. Critical analysis of the gender tensions behind the science of the pill
4. Discussion of male bias in western modern science

Homework:
(due in two class periods)
1. Textbook reading assignment about simple organic molecules

<u>Day 2</u>

Content Topics
- Introduction to organic chemistry terminology
- Classifying simple organic molecules
- Alkanes, alkenes, alkynes, and cyclic hydrocarbons

Key Points and Experiences
Classroom Activity:
1. Student-driven Q and A related to organic chemistry presented in "The Pill" and the textbook
2. Lecture: Introduction to organic chemistry and simple organic molecules

Homework:
1. Textbook reading assignment about organic functional groups

<u>Day 3</u>

Tangential connection(s) to Science and Engineering Practices for Physical Science from *Framework for K-12 Science Education* (NRC, 2012).
- Use a model to predict the relationships between the components of a system.

Content Topics
- Organic functional groups and their molecules
- Socially relevant organic compounds
- Real-world uses of organic chemistry

Key Points and Experiences
Classroom Activity:

1. Student-driven Q and A related to the functional groups presented in "The Pill" and the textbook
2. Lecture: Organic functional groups and there real-world applications
3. Explanation of model building project

Homework:
(due in a week from day 3)

1. Build model of a functional group from "The Pill" with a partner. Explain the model with a three slide Power Point
2. Prepare questions to participate in peer critique of models

<u>**Day 4**</u> (a week after day 3)

Tangential connection(s) to Science and Engineering Practices for Physical Science from *Framework for K-12 Science Education* (NRC, 2012).

- Use a model to predict the relationships between the components of a system.

Content Topics

- Organic functional groups and their molecules

Key Points and Experiences
Classroom Activity:

1. Students present their functional group models
2. Students participate in peer review and critique of models
3. Students revise their models based on peer critique

Homework:

1. Prepare for organic chemistry unit test

Appendix G
Critical Organic Unit Materials

Appendix G contains:
I. A reading guideline for the book chapter "The Pill" (Le Couteur & Burreson, 2003).
II. A classroom discussion guide for the book chapter "The Pill."
III. The guidelines for the critical organic functional group model project.
IV. A classroom guideline for the presentations and peer critic of the model project.

I. "The Pill" Reading Guideline

1. Who are the authors?

2. What is the main purpose of the chapter "The Pill?"

3. What is the main purpose of each of the chapter subheadings or sections? Please list each subheading and its main purpose.

4. Try to identify as many organic functional groups as you can that appear on the following compounds in the chapter.

Cholesterol
Androsterone
Estrone
Stanozolol
Progesterone
Cortisone
Norethindrone

5. Note any questions you have about the organic chemistry presented in the chapter

6. Note any questions you have about the history presented in the chapter.

7. While you are reading, reflect upon whether or not you feel like the authors present a fair account of the history of the pill and carefully acknowledge multiple perspectives on the issue.

II. "The Pill" Classroom Discussion Guide

Part I

Discuss within your group some of your answers to the reading guide HW sheet for the chapter "The Pill."

Part II

Discuss the following questions within your group. You may want to refer back to the chapter. Summarize your answers on the provided poster paper.

1. Who determined or influenced the research agenda described in the chapter: men, women, or both to varying degrees?

2. Who do you think should have influenced the research agenda described in the chapter?

3. Who do you think usually determines the research agendas of science, men or women? Can you think of any other examples of what might be described as a research agenda?

4. How are the women and men portrayed in the chapter?

5. Do you think stories in science portray women and men differently? How so? Do you think gender defines these portrayals? How so?

6. Have you ever felt like your gender defined you in science class? How so? Are you comfortable sharing a personal experience (without sharing specific names)?

Part III

One of the following categories of question sets will be assigned to you by the teacher. Just discuss the questions in that set within your groups. You may want to refer back to the chapter. Summarize your answers on the provided poster paper.

A. Historical oral contraceptives

1. What were some the historical, mystical oral contraceptives presented at the beginning of the chapter?

2. How are these mystical, oral contraceptives portrayed by the authors? Are they portrayed as scientific?

3. Are they scientific? Why or why not?

B. Motivations of the scientists

1. Was the research being conducted trying to give women more autonomy or to make money or was it just the byproduct of looking for something else? Why?

2. Is the pill liberating for women? Is the pill the only thing that sparked the women's movement? Connect this to things you've learned in history class.

3. Could women do all the things that are mentioned at the end of the chapter without the pill? Why or why not?

C. Male oral contraceptives

1. Why isn't there a popular male oral contraceptive?

2. Is it chemically safer or easier for women to take a pill?

3. Do you think male scientists were motivated by the fact that they did not want to alter their ability to procreate or deal with side effects?

Part IV

Discuss the following questions within your group. You may want to refer back to the chapter. Summarize your answers on the provided poster paper.

1. What are some of the positive and negative, perhaps oppressive results of the research presented in the chapter?

2. Overall, was the work to produce a contraceptive pill for females a positive or negative (oppressive) endeavor? Why or why not?

3. What are some other questions this chapter and discussion raise for you in terms of gender and science?

III. Functional Group Modeling Project and "The Pill"

You and your partner will build a model of one of the following functional groups. Your model should be a creative representation of the functional group that accurately represents the science. You should use your personal interests to help guide your creative choices. For example, being a food lover could help guide how you approach building the model. You should also employ skill sets you have developed in other areas to help you build your model. For example, you might be an excellent sculpture or 2D graphic designer. Both of these skills could help you with your model. However, less obvious skill sets could also be used to help you with your model. Being a good athlete, singer, or writer could also help you frame how you want to approach your model. Any personal interest or skill set can be used as long as the model accurately portrays the functional group.

Methyl	$-CH_3$
Hydroxyl	-OH
Amino	$-NR_2$ or $-NH_2$ or -NHR (Reminder R = C bonded to other elements)
Carbonyl	>C=O
Ether	R-O-R (Reminder R = C bonded to other elements)
Alkynyl	-C≡CH

Your model should include a Power Point with three slides. The first slide should define the functional group. The second slide should describe some of the common substances the functional group appears in. The third slide should contain a neat drawing or picture of one of the organic compounds from the chapter "The Pill" that contains your functional group with the functional group highlighted in some way.

Be prepared to share your three-slide Power Point in class along with the model. In addition, please print a copy of your Power Point with all three slides on one sheet of paper. (You can do this from the Power Point Print Menu where it says "Print What" select "handouts 3 slides per page.")

When you present your model, be prepared to discuss how you incorporated your personal interests and skill sets into the model's design.

Finally, use the guidelines below to prepare questions (before coming to class to present) to ask your classmates about their models in small group discussions.

1. If you are unclear about some portion of your classmate's model, think of a polite way to ask them for specific clarification.

2. If you believe your classmate's model is incorrect in some way, think of a polite way to challenge their claim.

3. Be prepared to ask classmates to elaborate on how their skill sets and personal interests helped them to make creative decisions in the building of their functional groups or on the other hand, perhaps, were difficult to incorporate into their project.

IV. Functional Group Modeling Project Small Group Discussions

*Tell them their group pairings first so they can pay closer attention to their pairings' presentations.

1. Students present their models – about 3 minutes each.

2. Small groups made of 4 people – 2 people from 2 different presentations.

3. Each group asks the other group the three questions they prepared for the day and records their own responses into their power points.

a. If you are unclear about some portion of your classmate's model, think of a polite way to ask them for specific clarification.

b. If you believe your classmate's model is incorrect in some way, think of a polite way to challenge their claim.

c. Be prepared to ask classmates to elaborate on how their skill sets and personal interests helped them to make creative decisions in the building of their functional groups or on the other hand, perhaps, were difficult to incorporate into their project.

4. Each group makes one suggestion to the other group for how they could improve their model. Each group records the other group's suggestion into their power point and thinks of a way to incorporate it if they were to revise their model.

Appendix H
Critical Acid/Base Unit Map

Day 1

Tangential connection(s) to Science and Engineering Practices for Physical Science from *Framework for K-12 Science Education* (NRC, 2012).

- Develop a model for a concept and use it to determine or predict relationships between systems.
- Construct explanations based on a variety of sources, including reliable Internet sites and student generated sources of evidence.

Content Topics

- Properties of acids and bases.

Key Points and Experiences
Classroom Activity:

1. Intro to Acids/Bases Lab Activity.
    - Discover properties of acids/bases.
    - Determine acidic/basic nature of common household goods.
2. Formative Assessment: What do you already know about acids and bases?

Homework:

1. Read introduction to Acids/Bases chapter in textbook

Day 2

Content Topics

- Acid/base definitions
- Acid/base equations.

Key Points and Experiences
Classroom Activity:

1. Theoretical foundations of acids/bases lecture (connected to results of Day 1 formative assessment).

Homework:

1. Read p. 647-651 (Skip Lewis Acids/Bases)
2. p. 652 #7,8
3. Read p. 653-659

Day 3

Tangential connection(s) to the *Next Generation Science Standards* (NGSS Lead States, 2013b**).**

- HS-PS1-6

Content Topics

- pH
- Ionization of water
- Chemical equilibrium

Key Points and Experiences
Classroom Activity:
1. Review HW from previous night.
2. pH lecture.
3. pH calculations group work.

Homework:
1. p. 684 #63, 64, 65

<u>Day 4</u>

Tangential connection(s) to the *Next Generation Science Standards* (NGSS Lead States, 2013b**).**
- HS-PS1-6

Tangential connection(s) to Science and Engineering Practices for Physical Science from *Framework for K-12 Science Education* (NRC, 2012).
- Develop a model for a concept and use it to determine or predict relationships between systems.
- Construct explanations based on a variety of sources, including reliable Internet sites and student generated sources of evidence.

Content Topics
- pH indicators
- Chemical equilibrium

Key Points and Experiences
Classroom Activity:
1. pH indicators activity
   - Develop indicators color chart/graph
   - Use chart to determine approximate pH of unknown substances
2. Acid Rain HW assignment prep and critical debate guidelines orientation for following class.

Homework:
1. Summarize the following topics in the Acid Rain article on Wikipedia.
   - Intro and Definition
   - History
   - Emissions
   - Chemistry
   - Adverse Effects
   - Prevention Methods
2. Summarize the following topics in the Emissions Trading article on Wikipedia
   - Definition

- Pros
- Cons

Day 5

Key Points and Experiences
Classroom Activity:

1. Critical Debate within the context of acid rain: Developing countries' rights to develop vs environmental protection

Homework:

1. Read p. 664-669.
2. p. 669 #30, 31

Day 6

Tangential connection(s) to the *Next Generation Science Standards* (NGSS Lead States, 2013b)**.**

- HS-PS1-6
- HS-PS1-7

Tangential connection(s) to Science and Engineering Practices for Physical Science from *Framework for K-12 Science Education* (NRC, 2012).

- Construct explanations based on a variety of sources, including reliable Internet sites and student generated sources of evidence.

Content Topics

- Acid/base strength
- Chemical equilibrium

Key Points and Experiences
Classroom Activity:

1. HW Review.
2. Acid/Base Strength Lecture.
3. Ka, Kb, and pH calculations group work.

Homework:

1. Calculations worksheet.
2. Write a paragraph to explain the difference between concentration, solubility, and acid/base strength. Use an example of an acid, and an example of a base to help clarify your explanation.

Day 7

Tangential connection(s) to Science and Engineering Practices for Physical Science from *Framework for K-12 Science Education* (NRC, 2012).

- Construct explanations based on a variety of sources, including reliable Internet sites and student generated sources of evidence.

- Design methods for collecting evidence to support explanations and critiques.
- Collect evidence to support their explanations and critiques.

Key Points and Experiences
Classroom Activity:

1. Critical analysis of heartburn commercial.
2. Discussion of conceptions of heartburn.
3. Discussion of personal/cultural associations with heartburn remedies.
4. Discussion of strategies for gathering evidence to support critical analysis of the media's portrayal of heartburn and its remedies and to support the use of personal/cultural heartburn remedies.

Homework:
(due in two class periods)

1. Gather evidence to support critical analysis of media's portrayal of heartburn and its remedies
2. Define personal definition of what makes a heartburn remedy effective in terms of pH, time, temperature, volume of foam, etc.
3. Document cultural/home remedies for heartburn through interviews.

<u>Day 8</u>

Tangential connection(s) to the *Next Generation Science Standards* (NGSS Lead States, 2013b**).**

- HS-PS1-6

Content Topics

- Acid/Base Neutralization
- Salts
- Salt Hydrolysis
- Chemical Equilibrium

Key Points and Experiences
Classroom Activity:

1. Acid/base Reactions, Neutralization, and Salt Hydrolysis Lecture

Homework:

1. Finish HW from day 7.

<u>Day 9</u>

Tangential connection(s) to the *Next Generation Science Standards* (NGSS Lead States, 2013b**).**

- HS-PS1-6

Tangential connection(s) to Science and Engineering Practices for Physical Science from *Framework for K-12 Science Education* (NRC, 2012).

- Plan an investigation collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (quality of measuring tools, and number of trials).
- Refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations

Key Points and Experiences
Classroom Activity:
1. Day 7 HW discussion
2. Inquiry Lab development
    a. Ask research question based on personal definition of effective heartburn remedy in terms of pH, time, temperature, volume of foam, etc., and *cultural home remedies chosen to test
    b. Identify independent, dependent, and constant variables in terms of the reactions they will test
    c. Write hypothesis
    d. Construct procedure for testing hypothesis

Homework:
1. Finish inquiry lab procedure if necessary

Day 10

Tangential connection(s) to the *Next Generation Science Standards* (NGSS Lead States, 2013b**).**
- HS-PS1-2
- HS-PS1-5
- HS-PS1-7

Tangential connection(s) to Science and Engineering Practices for Physical Science from *Framework for K-12 Science Education* (NRC, 2012).
- Conduct student planned investigation according to the above criteria.
- Use mathematical representations of phenomena to support claims.

Key Points and Experiences
Classroom Activity:
1. Collect data for inquiry lab using
    a. pH probes
    b. temperature probes
    c. stop watches
    d. graduated cylinders

Homework:
(due over a week later)
1. Analyze data and document results
    a. quantitatively (equation calculations, and unit analysis)

    b. qualitatively (discussion of recorded observations)
    c. visually (charts and graphs)
2. Write conclusion
3. Prepare creative presentation to share results
4. Answer critical analysis questions associated with lab results

<u>**Day 11**</u>

Tangential connection(s) to the *Next Generation Science Standards* (NGSS Lead States, 2013b**).**

- HS-PS1-7

Tangential connection(s) to Science and Engineering Practices for Physical Science from *Framework for K-12 Science Education* (NRC, 2012).

- Use mathematical representations of phenomena to support claims.

Content Topics

- Titrations

Key Points and Experiences
Classroom Activity:
1. Titration Lecture
2. Titration Animation Group Activity

Homework:
1. Finish group activity
2. p. 684 #73

<u>**Day 12**</u>

Key Points and Experiences
Classroom Activity:
1. Acid/Base Unit Review

Homework:
1. Prepare for Acid/Base Test.

<u>**Day 13**</u> (A week after day 10)

Tangential connection(s) to Science and Engineering Practices for Physical Science from *Framework for K-12 Science Education* (NRC, 2012).

- Present results of student planned investigation according to above criteria.
- Debate unanticipated effects of scientific work on society.

Key Points and Experiences
Classroom Activity:
1. Inquiry lab results presentations

2. Critical discussion of results in terms of “Western,” over the counter remedies and cultural home remedies

Homework:

1. None

<u>Duplicated from NGSS Lead States, 2013b</u>

HS-PS1-2. Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties. [Clarification Statement: Examples of chemical reactions could include the reaction of sodium and chlorine, of carbon and oxygen, or of carbon and hydrogen.] [Assessment Boundary: Assessment is limited to chemical reactions involving main group elements and combustion reactions.]

HS-PS1-5. Apply scientific principles and evidence to provide an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs. [Clarification Statement: Emphasis is on student reasoning that focuses on the number and energy of collisions between molecules.] [Assessment Boundary: Assessment is limited to simple reactions in which there are only two reactants; evidence from temperature, concentration, and rate data; and qualitative relationships between rate and temperature.]

HS-PS1-6. Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium.* [Clarification Statement: Emphasis is on the application of Le Chatlier’s Principle and on refining designs of chemical reaction systems, including descriptions of the connection between changes made at the macroscopic level and what happens at the molecular level. Examples of designs could include different ways to increase product formation including adding reactants or removing products.] [Assessment Boundary: Assessment is limited to specifying the change in only one variable at a time. Assessment does not include calculating equilibrium constants and concentrations.]

HS-PS1-7. Use mathematical representations to support the claim that atoms, and therefore mass, are conserved during a chemical reaction. [Clarification Statement: Emphasis is on using mathematical ideas to communicate the proportional relationships between masses of atoms in the reactants and the products, and the translation of these relationships to the macroscopic scale using the mole as the conversion from the atomic to the macroscopic scale. Emphasis is on assessing students’ use of mathematical thinking and not on memorization and rote application of problem-solving techniques.] [Assessment Boundary: Assessment does not include complex chemical reactions.]

Appendix I
Critical Acid/Base Unit Materials

Appendix I contains:
I. The acid rain homework guidelines.
II. A classroom guideline for the acid rain discussion/debate.
III. The critical acid/base heartburn inquiry lab day 1 worksheet.
IV. The critical acid/base heartburn inquiry lab day 1 homework.
V. The critical acid/base heartburn inquiry lab guidelines.

I. Acid Rain Homework

1. Summarize and take notes on the introduction section (the first section) and definition section of the Acid Rain page on Wikipedia.

http://en.wikipedia.org/wiki/Acid_rain

2. Note your group number listed above and complete the following.

- If you are in a group numbered 1 or 5, summarize and take notes on the history section of the Acid Rain page on Wikipedia.
- If you are in a group numbered 2 or 6, summarize and take notes on the emissions section of the Acid Rain page on Wikipedia.
- If you are in a group numbered 3 or 7, summarize and take notes on the chemistry section of the Acid Rain page on Wikipedia.
- If you are in a group numbered 4 or 8, summarize and take notes on the adverse effects section of the Acid Rain page on Wikipedia.

3. Read the prevention methods section at the end of the Acid Rain page on Wikipedia. Pay particular attention to emissions trading.

4. Summarize and take notes on introduction section of the Emissions Trading page on Wikipedia.

http://en.wikipedia.org/wiki/Emissions_trading

5. Note your group number listed above and complete the following.

- If you are in an odd numbered group, use the rest of the Emissions Trading page on Wikipedia to list as many pros for emissions trading as you can find. Concentrate your search on the public relevance, public opinion, and comparison of cap and trade with other methods of emission reduction sections.
- If you are in an even numbered group, use the rest of the Emissions Trading page on Wikipedia to list as many cons for emissions trading as you can find. Concentrate your search on the public relevance, public opinion, comparison of cap and trade with other methods of emission reduction, and criticism sections.

6. Based on what you've read to complete this assignment, formulate an opinion as best as you can on the following issue. Summarize your opinion in 2 to 3 sentences.

Developed countries (mainly in North America and Europe) polluted the environment to a significant extent during the industrial revolution as they were becoming developed. Currently developing countries (South America, Asia, Africa) are attempting to develop while the international community attempts to curtail environmental pollution. Should developing countries be free to develop as North America and Europe did without pollution restriction, or should the international community monitor their development for pollution perhaps hindering their efforts to develop? Is this fair?

II. Acid Rain Discussion Debate

1. 10 min. Small group discussion and poster paper. Groups 1 and 5 work together to create a quick poster paper presentation of the history section to share with class.

2. 10 min. Groups share out poster papers.

3. 10 min. Small group discussion of pros and cons of emissions trading. Odd numbered groups summarize pros on poster paper. Even numbered groups summarize cons on poster paper.

4. 15 min. Groups share out pros and cons.

5. 15 min. Whole class discussion and share out of opinions to question 6 in the HW.

III. Heartburn Inquiry Lab Day 1 Worksheet

Heartburn commercial analysis.

You may watch the commercial several times to answer the following questions.

1. Who had heartburn in the commercial? What were the surface characteristics of that person?
2. Who gets heartburn? What kinds of people get heartburn?
3. Did the advertisement clearly explain to the public what their product does to treat heartburn?
4. What kind of food was in the commercial? What kind of food causes heartburn?

Heartburn and you.

1. Are the foods in the commercial available in your neighborhood? Are they advertised in your neighborhood? Do food ads target any particular type of person? Do you or your family eat these foods?
2. Do you or does anyone you know get heartburn? Who?
3. Are you aware of any other methods for treating heartburn? Are any of these alternatives home remedies? Do you and your family practice any home or cultural remedies for heartburn or upset stomach? Or, do you use the advertised remedies?

IV. Heartburn Inquiry Lab Day 1 Homework

DIRECTIONS:
Please perform and document at least three tasks to collect more information about heartburn. You must perform the two required tasks and one of the optional tasks. Type all your work on this sheet and attach any other supporting work like photos. Please email to me by the due date posted on the syllabus.

Required

1. Perform at least one of the ways suggested for collecting more evidence about heartburn generated by students and documented on the board in class today.
2. Brainstorm some ways that heartburn remedies are considered "effective." In other words, define "effective" in terms of the chemistry of heartburn remedies. Explain you measure the effectiveness in the lab.

Optional (choose one)

3. Conduct a family member or friend interview that asks them what heartburn is, if they get it, what foods they generally eat, and if they take advertised remedies or take or know of any home remedies for heartburn.
4. Take and document pictures of food billboards and restaurants in your neighborhood.
5. Document the details of at least two more heartburn remedy commercials online or on TV.
6. Briefly summarize what Wikipedia says about heartburn in its main definition and treatment.
7. Bring in to class a cultural, home remedy for heartburn that you know of or use in your own home.

V. Heartburn Inquiry Lab Guideline

Which is the Most Effective Heartburn Remedy?

Day 1

- See Day 1 worksheet

- Heartburn discussion.
- Analysis of heartburn commercial.
- Heartburn and you – discussion of heartburn as it relates to students' families and home remedies.
- Prelab HW assignment (see class site for due date).

Day 2

- Prelab HW assignment discussion.
- Inquiry lab development using the experimental design guidelines below

Experimental Design Guidelines

Materials List
HCl solution (0.05 M)
Tums
Rolaids
Pepto Bismol
Milk of Magnesia
Other Home Remedies

Available Equipment
Mortar and Pestle
LabQuest
pH probes
Graduated cylinders
Temperature probes
Test tubes
Beakers

Research Question (Choose how you want to measure "effectiveness" ; also identify the heartburn remedies you want to test- should include at least 4, and one should be a home remedy)

Independent Variable (could include units of measurement):
Dependent Variable (specify units of measurement):
Constants (all other factors not selected as independent variable):

Hypothesis (use "If …, then…., because" format):

Procedure
Brainstorm with your partner a detailed procedure for determining the relationship between your independent variable and the dependent variable.

- Write your procedure in bullet point steps.
- Make sure you include the specific lab equipment you will use in the procedure steps and the specific units.

- Include steps that indicate a change in your independent variable, and how it will be measured. Indicate specific units if applicable.
- Include multiple trials for every measurement you make in the procedure.
- Create a data table after the procedure to record both quantitative data (make sure it indicates the units), and written qualitative observations (should also be accompanied by pictures) of the reactions.
- Make sure there are no calculation steps in your procedure. Only record measurements you can see without doing any math in your head.

Check with the teacher after this step and finish for HW if needed.

Day 3

- Perform the experiment and collect data.
- Day three homework includes data analysis, conclusion and presentation. See guidelines below.

Data Analysis and Results

The data should be presented in a clear, concise manner (data table, graph, and visual representation) and properly labeled.

- This may require calculations.
- If you have a qualitative independent variable, use a bar graph.
- If your independent variable is quantitative, use a line graph (best fit line).
- Photos or diagrams of the experiment.

Conclusion

Write a conclusion. A conclusion contains a general overview of the lab purpose, a summary of your results, and an explanation of how your results either confirm or disconfirm your hypothesis. This section should include any changes you made in your procedure with an explanation for why, and also include your sources of error. There are potential sources of error for EVERY laboratory. Think of at least **two** possible sources of error and make a note of them here. Make sure they are specific to the lab and its procedure. Do not just say "calculation" or "measuring" errors. How exactly may it have been difficult to measure?

- 1 point for reference to purpose of the lab and the research question
- 5 points for the evaluation of the hypothesis using specific observations and data points
- 5 points for drawing conclusions from the lab that relate to the scientific theories or concepts based upon evidence from the experiment
- 2 points for the two sources of error
- 2 points for addressing how you might improve the experiment if you were to do it again in the future

Critical Question Set

DIRECTIONS:

Discuss the following questions with your partner. Type your responses below each question. Be prepared to share your answers with the class.

1. Did our ancestors get heartburn? Explain your answer.

2. Why do we get heartburn?

3. What's a simpler solution to the problem of heartburn than using a remedy?

4. How can we prevent heartburn?

5. Why don't we see heartburn prevention commercials?

6. What are the possible consequences of antacid overuse in society? Who or what institutions benefit from an overuse? Who or what is hurt by overuse?

7. Why do pharmaceutical companies spend so much money on heartburn remedy research and advertisement? (Why do companies do anything?)

8. Should pharmaceutical companies spend so much money on heartburn remedy research and advertisement? Can you think of any other diseases they could spend more money researching? If not, investigate diseases that still affect world populations. Argue the rational for spending money elsewhere. In addition, put yourself in the shoes of an owner of a pharmaceutical company and think of these questions from that perspective.

Day 4 Presentations of Lab Work (see class site for due date)

1. Be prepared to project and discuss your graph with the class.

2. Be prepared to share your answers to the extension questions with the class.

3. Be prepared to politely ask questions of your classmates about where they got their information for the extension questions, and why they feel the way they do. Write out at least two questions to ask your classmates.

Project Presentation Grading Rubric

Types of Presentations include Poster or PowerPoint

(2 pts.) Research Question and Title ______

(5 pts.) Experimental Details ______

Includes:

- Independent variable (include units of measurement, if applicable)
- Dependent variable (include units of measurement)
- Constants
- Hypothesis ("if…, then…., because" format)

(15 pts.) Procedure _______

(15 pts.) Analysis of Results _______

Includes:

- Data Tables (properly labeled, with appropriate title)
- Graphs (properly labeled, with appropriate title)
- Calculations (if applicable)
- Visual representation (photo or diagram of experiment)

(15 pts.) Conclusion _______

Includes:

- 1 point for reference to purpose of the lab and the research question
- 5 points for the evaluation of the hypothesis using specific observations and data points
- 5 points for drawing conclusions from the lab that relate to the scientific theories or concepts based upon evidence from the experiment
- 2 points for the two sources of error
- 2 points for addressing how you might improve the experiment if you were to do it again in the future

(8 pts.) Overall Appearance of presentation _________

Includes:

- Neatness
- Organization of data

(10 pts as separate quiz grade) Answer critical question set on separate Word Doc.

Appendix J
Research Design Matrix

Research Sub-questions	Data Collection Procedure	Data Analysis
1. How and to what extent do students develop and demonstrate critical scientific literacy (CSL) within critical chemistry education (CCE)?	Video recording	Dialogue mapping, coding, and theme analysis
	Student artifacts	Rubric scoring, and time series regression
	Post questionnaires	Coding, and theme analysis
	Focus group interviews	Coding, and theme analysis
2. What level of chemistry content knowledge do	Video recordings	Dialogue mapping, coding, and theme analysis

students demonstrate within CCE and how do they demonstrate it?	Student artifacts	*t*-Tests, and coding
	Pre/Post unit tests	*t*-Tests
	Focus group interviews	Coding, and theme analysis
	Cumulative final chemistry exam	*t*-Test
3. What does student interest in CCE look like in the classroom and how do students describe their interest in CCE?	Video recording	Dialogue mapping, coding, and theme analysis
	Pre and Post Likert surveys	ANOVA, and time series regression
	Post Questionnaires	Coding and theme analysis
	Focus group interviews	Coding and theme analysis

Appendix K
Beginning of the School Year Interest Questionnaire

1. What are some of your academic interests in school?

2. What are some of your interests outside of academic school?

3. How do you know when you are interested?

4. What words would you use to describe interest?

5. How would you describe your interest in chemistry? What words would you use?

6. Do you think chemistry fits into your personal goals, your future goals? If so, how? If not, why not?

Appendix L
Questionnaire

*The phrase "the unit" was replaced by unit specific language for each questionnaire.

1. What are some of your thoughts and feelings about the critical unit we just completed?

2. Describe your comfort level with the unit we just completed.

3. Describe your confidence level in what you accomplished in the unit in terms of your contributions to the classroom discussions and your assignments.

4. Describe the level of value you place on the things we learned about in the unit.

5. How relevant was the unit to you personally? Please elaborate.

6. Describe any aspects of the unit (the discussions, the assignments, or the content of the unit) you found particularly ***interesting***.

7. Describe any aspects of the unit (the discussions, the assignments, or the content of the unit) you found particularly ***disinteresting***.

8. Did you find any part of the critical, unit particularly surprising or incongruous? If so, how did the surprise make you feel? Please elaborate.

9. Given more time, would you elect to further explore some of the content and ideas we discussed in the unit? Please elaborate.

10. Did you ever find yourself thinking about or discussing with a friend or family member what we did in the unit outside of class? Please elaborate.

11. How would you describe your interest in chemistry? What words would you use? (Later in the year this question was used: At this point in the year, has your level of interest in chemistry changed? If so, how? Can you elaborate by identifying specific reasons? If not, why not?)

12. How does chemistry fit into your personal goals? Is chemistry relevant? (Later in the year this question was used: At this point in the year, does chemistry fit more or less than before with your personal goals?)

Two questions developed from students' words.

13. At this point in the year, do you ever find yourself studying or investigating chemistry a little longer than an assignment requires on your own, spending extra time? Please explain.

14. Many of you used words like "fascinating," "captivating," and "intriguing" to describe your personal interests. In what ways and to what extent would you use these words to describe your interest in chemistry at this point in the year?

Only on last questionnaire of the year.

15. Overall, how do you feel about the non-chemistry content discussions we have had this year? Do you feel like they have changed how you think about the interconnections between chemistry and other societal issues? How so?

Appendix M
Focus Group Interview Protocol Part 1
Critical Metal Unit

Researcher reminders:

- Remind participant about general research topic.
- Ask permission to audiotape and remind them they can refuse to answer anything they do not feel comfortable answering.
- Leave quiet time after questions to allow for thoughtful answers.
- Tell them they can pick pseudonym.
- Remind participants to keep what was discussed by their classmates private.

Names and Pseudonyms:

Date & Time:

Setting:

1. How was the metal and alloy knowledge base of the Mississippian Indians portrayed in the video?

2. Did the Mississippian Indians do science, were they scientists?

3. What is considered scientific knowledge?

4. Who gets to decide what constitutes scientific knowledge?

Appendix N
Focus Group Interview Protocol Part 1
Critical Kinetics Unit

Researcher reminders:

- Remind participant about general research topic.
- Ask permission to audiotape and remind them they can refuse to answer anything they do not feel comfortable answering.
- Leave quiet time after questions to allow for thoughtful answers.
- Tell them they can pick pseudonym.
- Remind them to keep what was discussed by classmates private.

Names and Pseudonyms:

Date & Time:

Setting:

1. Who wrote the articles discussed in class and why were they written?

2. Who benefits from the viewpoints held in the articles? Who does not benefit or is even hurt by the viewpoints held in the articles?

3. What assumptions did the writers make in their texts and are they justifiable?

4. What were the sources of evidence the authors used to support their claims? Are these reliable sources?

Appendix O
Focus Group Interview Protocol Part 1
Critical Organic Unit

Researcher reminders:

- Remind participant about general research topic.
- Ask permission to audiotape and remind them they can refuse to answer anything they do not feel comfortable answering.
- Leave quiet time after questions to allow for thoughtful answers.
- Tell them they can pick pseudonym.
- Remind them to keep what was discussed by classmates private.

Names and Pseudonyms:

Date & Time:

Setting:

Part I

1. Is the pill liberating for women? Is the pill the only thing that sparked the women's movement? Connect this to things you've learned in history class.

2. What are some of the positive and negative, perhaps oppressive results of the research presented in the chapter?

3. Overall, was the work to produce a contraceptive pill for females a positive or negative (oppressive) endeavor? Why or why not?

4. What are some other questions this chapter and discussion raise for you in terms of gender and science?

Appendix P
Focus Group Interview Protocol Part 1
Critical Acid/Base Unit

Researcher reminders:

- Remind participant about general research topic.
- Ask permission to audiotape and remind them they can refuse to answer anything they do not feel comfortable answering.
- Leave quiet time after questions to allow for thoughtful answers.
- Tell them they can pick pseudonym.
- Remind them to keep what was discussed by classmates private.

Names and Pseudonyms:

Date & Time:

Setting:

1. Why do we get heartburn?

2. What's a simpler solution to the problem of heartburn than using a remedy?

3. How can we prevent heartburn?

4. Why don't we see heartburn prevention commercials?

5. What are the possible consequences of antacid overuse in society? Who or what institutions benefit from an overuse? Who or what is hurt by overuse?

6. Why do pharmaceutical companies spend so much money on heartburn remedy research and advertisement? (Why do companies do anything?)

Appendix Q
Focus Group Interview Protocol Part 2
For All Three Curricular Transformations

*The phrase "the unit" was replaced by unit specific language.

1. Looking back, what aspects of the unit do you recall the most or are still on your mind? What about the unit, if anything, resonated with you?

2. Looking back, how comfortable or uncomfortable were you during the unit? Please elaborate.

3. Do you feel like you learned about valuable topics and/or ideas during the unit? Please elaborate.

4. How relevant was the unit to you personally? Please elaborate.

5. Since the end of the unit, have you found yourself thinking about or discussing with a friend or family member what we did? Please elaborate.

Appendix R
Pre/Post Likert Survey
Critical Metal Unit

- The version on Qualtrics had bubbles for students to click on within the empty boxes under the scale.
- Every question had the same set of statements and format as the first question on Qualtrics.
- Data for boring, uncomfortable, annoying, worthless, and useless was reverse scored.

Directions: Choose your level of agreement for each of the statements below the question.

Learning about the properties of metals and alloys is:	Completely Disagree (0)	Disagree (1)	Somewhat Disagree (2)	Somewhat Agree (3)	Agree (4)	Completely Agree (5)
1. Boring						
2. Stimulating						
3. Interesting						
4. Uncomfortable						
5. Fun						
6. Annoying						
7. Meaningful						
8. Worthless						
9. Valuable						
10. Useless						

2. Learning about single replacement reactions is

3. Learning about the activity series for metals is

4. Discussing and researching the history of metallurgy in different cultures is

5. Discussing what constitutes scientific knowledge and practice and who determines these standards is

6. Critiquing issues of gender and cultural diversity in media presentations of scientific content is

7. Discussing the importance of alloy production, especially steel production to the world's economy is

8. Discussing the global movement of manufacturing jobs and its implications for issues of economic status and science education in the U.S. is

9. In general, chemistry classroom discussions are

10. In general, homework assignments in chemistry class are

11. In general, inquiry-style lab work in chemistry class is

12. In general, student presentations in chemistry class are

13. In general, chemistry is

Appendix S
Pre/Post Likert Survey
Critical Kinetics Unit

- The version on Qualtrics had bubbles for students to click on within the empty boxes under the scale.
- Every question had the same set of statements and format as the first question on Qualtrics.
- Data for boring, uncomfortable, annoying, worthless, and useless was reverse scored.

Directions: Choose your level of agreement for each of the statements below the question.

Learning about thermodynamics is:	Completely Disagree (0)	Disagree (1)	Somewhat Disagree (2)	Somewhat Agree (3)	Agree (4)	Completely Agree (5)
1. Boring						
2. Stimulating						
3. Interesting						
4. Uncomfortable						
5. Fun						
6. Annoying						
7. Meaningful						
8. Worthless						
9. Valuable						
10. Useless						

2. Learning about kinetics is

3. Learning about energy conservation is

4. Learning about alternative energy sources is

5. Reading newspaper articles with chemistry content is

6. Critiquing the viewpoints and chemistry content of newspaper articles is

7. Identifying how scientifically based viewpoints can benefit some people while oppressing others is

8. Developing my own viewpoint supported by scientific evidence is

9. In general, chemistry classroom discussions are

10. In general, homework assignments in chemistry class are

11. In general, inquiry-style lab work in chemistry class is

12. In general, student presentations in chemistry class are

Appendix T
Pre/Post Likert Survey
Critical Organic Unit

- The version on Qualtrics had bubbles for students to click on within the empty boxes under the scale.
- Every question had the same set of statements and format as the first question on Qualtrics.
- Data for boring, uncomfortable, annoying, worthless, and useless was reverse scored.

Directions: Choose your level of agreement for each of the statements below the question.

Learning about organic chemistry is:	Completely Disagree (0)	Disagree (1)	Somewhat Disagree (2)	Somewhat Agree (3)	Agree (4)	Completely Agree (5)
1. Boring						
2. Stimulating						
3. Interesting						
4. Uncomfortable						
5. Fun						
6. Annoying						
7. Meaningful						
8. Worthless						
9. Valuable						
10. Useless						

2. Learning about organic functional groups is

3. Learning about different kinds of organic compounds and their real world uses is

4. Learning about the history of the birth control pill is

5. Discussing male bias in science is

6. Critiquing different viewpoints presented in a book about chemistry is

7. Identifying how scientifically based viewpoints can benefit some people while oppressing others is

8. Creatively modeling an organic functional group is

9. In general, chemistry classroom discussions are

10. In general, homework assignments in chemistry class are

11. In general, inquiry-style lab work in chemistry class is

12. In general, student presentations in chemistry class are

13. In general, chemistry is

Appendix U
Pre/Post Likert Survey
Critical Acid/Base Unit

- The version on Qualtrics had bubbles for students to click on within the empty boxes under the scale.
- Every question had the same set of statements and format as the first question on Qualtrics.
- Data for boring, uncomfortable, annoying, worthless, and useless was reverse scored.

Directions: Choose your level of agreement for each of the statements below the question.

Learning about reaction rates and equilibrium is:	Completely Disagree (0)	Disagree (1)	Somewhat Disagree (2)	Somewhat Agree (3)	Agree (4)	Completely Agree (5)
1. Boring						
2. Stimulating						
3. Interesting						
4. Uncomfortable						
5. Fun						
6. Annoying						
7. Meaningful						
8. Worthless						
9. Valuable						
10. Useless						

2. Learning about pH and pH indicators is

3. Learning about the concepts of acids and bases is

4. Learning about acid/base calculations is

5. Learning about titrations is

6. Learning about environmental issues related to acids and bases is

7. Debating issues of government policy and industrial practices in terms of acid rain and environmental protection is

8. Learning about heartburn and heartburn remedies in chemistry class is

9. Analyzing advertisements for heartburn remedies and discussing pharmaceutical companies obligations to global healthcare is

10. Considering cultural home remedies as alternatives to pharmaceutical companies' over-the-counter remedies is

11. In general, chemistry classroom discussions are

12. In general, homework assignments in chemistry class are

13. In general, inquiry-style lab work in chemistry class is

14. In general, student presentations in chemistry class are

15. In general, chemistry is

Appendix V
Critical Scientific Literacy Rubric
Critical Inquiry Lab Artifacts

The scoring rubric for the three inquiry labs was the same and was developed from the "Inquiry Student Scoring Rubric" (n.d.), the rubric used in the work of Oliveras et al. (2013), and the literature and theoretical framework grounding the description of critical scientific literacy used in this study.

Category	Scoring Rubric
1. Formulation of hypothesis	0 – They do not include a hypothesis 1 – They formulate a hypothesis that is not testable nor answers the question 2 – They formulate a hypothesis that may not answer the question, and is supported by opinions and misconceptions 3 – They formulate a coherent, testable hypothesis that potentially answers the question, includes an independent and dependent variable, and is partially supported by prior knowledge 4 – They formulate a coherent, testable hypothesis that potentially answers the question, includes an independent and dependent variable, and is completely supported by prior knowledge
2. Development of procedure	0 – They do not include a procedure 1 – They design a scientific investigation unrelated to the hypothesis, that does not include logical steps, is not sequential, does not consider constants, and does not contain repeated trials 2 – The relationship between the hypothesis and the scientific investigation lacks clarity, and the procedure is missing steps or contains steps that are out of order, does not properly identify variables and constants, and lacks sufficient trials to test the hypothesis 3 – The relationship between the hypothesis and the scientific investigation is clear, and the procedure only has minor inaccuracies in logic and/or sequence of steps, only has minor inaccuracies in identifying variables and constants they do not significantly affect the results, and contains repeated trials 4 – The relationship between the hypothesis and the scientific investigation is clear, and the procedure contains steps that are logical and in sequence, a clear identification of variables and constants, and contains repeated trials that are sufficient to validate results within reason.
3. Data collection and analysis	0 – They do not collect or analyze data 1 – They select inappropriate equipment and techniques, do not employ safety when using lab equipment, ineffectively use technology and mathematical concepts, and have significant errors or gaps in collected data 2 – They incorrectly use equipment and techniques, ineffectively use technology and mathematical concepts, and have errors present in collected data 3 – They select and safely uses lab equipment, generally use appropriate technology and mathematical concepts, have only minor inaccuracies and some subjectivity in data collection, and have only some inconsistencies

	present in recording data 4 – They select and safely use lab equipment, effectively use appropriate technology and mathematical concepts and collect and analyze data in a systematic, accurate, and objective manner
4. Writing the conclusion	0 – They do not write a conclusion 1 – Their explanations/models are not based on analysis of data or accurate science. They ignore data which refutes the hypothesis. They do not make connections between results and hypothesis, and do no provide evidence for possible revision and alternative explanations 2 – Their explanations/models are based on flawed analysis of data and misconceptions of science. They only formulate limited revisions 3 – Their explanations/models partially reflect evidence from investigation and are based on accurate science. They use results to verify or refute the hypothesis, and they formulate possible revisions 4 – Their explanations/models reflect evidence from investigation and are based on accurate science. They use results to verify or refute hypothesis, and formulate possible revisions and alternative explanations
5. Communicating conclusions and connecting arguments to societal issues	0 – They do not communicate their arguments or connect them to societal issues 1 – Their arguments and responses to critical comments and issues are missing, very unclear, and/or do not connect their investigations to societal issues. They do not demonstrate a metacognitive awareness of their own position in society and how they might affect others. They do not consider both the positives and negatives of science on society. They do not consider diverse knowledge bases or perspectives. 2 – Their arguments and responses to critical comments and issues are unclear, and/or do not connect their investigations to societal issues. They demonstrate a very limited metacognitive awareness of their own position in society and how they might affect others. They do not consider both the positives and negatives of science on society. They do not consider diverse knowledge bases or perspectives. 3 – Their arguments and responses to critical comments and issues are clear, and/or do connect their investigations to societal issues. They demonstrate a degree of metacognitive awareness of their own position in society and how they might affect others. They consider either the positives or the negatives of science on society, but not both. They begin to consider diverse knowledge bases or perspectives. 4 – Their arguments and responses to critical comments and issues are clear, and/or do connect their investigations to societal issues. They demonstrate a high degree of metacognitive awareness of their own position in society and how they might affect others. They consider both the positives and the negatives of science on society. They consider diverse knowledge bases or perspectives.

Appendix W
Critical Scientific Literacy Rubric
Critical Science Writing Artifact

Rubric slightly modified from the rubric created by Oliveras et al. (2013).

Category	Scoring Rubric
1. Identification of the main ideas of the text	0 – They cite non-relevant information or do not reproduce the information 1 – They only identify one of the key ideas or concepts 2 – They mention more than one key idea or concept 3 – They express in their own words the most important information. They identify some of the key ideas and concepts used in a way showing understanding. They make connections between ideas 4 – They express in their own words the most important information in a way showing understanding. They identify all the key ideas and concepts used in a way showing understanding
2. Identification of the writer's purpose	0 – They cite irrelevant information 1 – The information they express cannot be inferred from the text 2 – They assume that news stories are only used to inform in a neutral and unbiased manner 3 – They identify the writer's purpose but in a not very precise way because they do not express themselves well or because they are not specific enough 4 – They communicate the purpose that they believe the writer has well. They realize that the writer has other intentions besides providing information (creating controversy...)
3. Identification of the writer's assumptions and discussing how they might benefit or oppress certain groups of people	0 – They do not answer or cite irrelevant information or they do not identify the writer's viewpoint 1 – They make unreasonable assumptions based on evidence and do not identify the writer's viewpoint or justify the point of view expressed 2 – They cite sentences word for word from the text without inferring the writer's viewpoint 3 – They make reasonable assumptions, identifying the writer's viewpoint, and the people it benefits ***or*** hurts, but they do not justify it 4 – They make reasonable assumptions, identify the writer's viewpoint, the people it benefits, ***and*** the people it hurts or oppresses, and they justify it based on the text
4. Formulation of a scientific question that the writer answers	0 – They pose questions that are not very coherent 1 – They pose the question without being specific 2 – They ask questions which are not answered in the text 3 – They formulate reasoned important questions from a science standpoint, only analyzing one of the variables 4 – They formulate reasoned important questions from a science standpoint, analyzing all of the variables to be taken into consideration
5. Identification of data and evidence given in the text	0 – They validate the information due to their confidence in the newspaper (they do not judge the credibility of the source) or because

	they think that the writer is informed 1 – They cite information in the text with basic or imprecise reasoning or draw conclusions based on irrelevant information in the text or do not mention whether it is evidence or not 2 – They mention whether the text provides evidence or not, or whether the information it provides is scientifically valid without giving further explanation or giving very basic arguments or without looking for an argument to validate the information in the text 3 – They draw reasoned conclusions based on the information provided in the text (facts, data, evidence, ...), without identifying the type of source (fact, opinion, scientific source, ...) 4 – They distinguish between facts, scientific arguments and opinion in the text. They draw conclusions taking into account the information available and using sensible reasoning they demonstrate the ability to analyze and evaluate the information objectively
6. Arguing conclusions based on evidence and discussing how they might benefit or oppress certain groups of people	0 – They cite irrelevant arguments 1 – They reach conclusions based on daily knowledge without activating scientific knowledge 2 – They activate their knowledge of science and demonstrate the ability to argue agreement and disagreement, disagreement, although they do not challenge their knowledge using information in the text 3 – They challenge the information in the text using their scientific knowledge and show reasonable agreement and disagreement without giving explicit grounds. They also identify groups of people that benefit from ***or*** are hurt by their conclusions. 4 – They challenge the information in the text with their scientific knowledge citing at least two other reliable sources, showing an ability to argue agreements and disagreements in a reasoned manner. They also identify groups of people that benefit from ***and*** groups of people that are hurt by or oppressed by their conclusions

Appendix X
Critical Scientific Literacy Rubric
Organic Functional Group Model

Rubric created from the work of Lehrer and Schauble (2006) and Calabrese Barton et al. (2008).

Category	Scoring Rubric
1. Model Accuracy	0 – Model is completely incorrect. 1 – Model contains the correct elements only. 2 – Model in some way demonstrates the correct types of bonds between the elements. 3 – Model in some way demonstrates a two-dimensional spacing or orientation of atoms (similar to if they made a model of structural formula). 4 – Model demonstrates relative elemental size and in some way demonstrates proper three-dimensional orientation of atoms in space.
2. Model Construction	0 – Model is poorly constructed. 1 – Model is constructed but uses materials that are not well chosen. 2 – Model is carefully constructed with materials but does not showcase student's creativity. 3 – The model is carefully constructed with materials that showcase student's creativity and are appropriate. 4 – Model is carefully and creatively constructed. In addition, the construction showcases the student's outside the classroom interests.
3. Supplemental Model Explanation	0 – Supplemental explanation is not included. 1 – Functional group organic notation is demonstrated. 2 – Functional group organic notation is demonstrated and verbally defined. 3 – Functional group organic notation is demonstrated and defined, and some of the common substances that contain the functional group are noted. 4 – Functional group organic notation is demonstrated and defined, some common substances are noted, and a complex organic compound containing the functional group is used to highlight the group.
4. Model Elaboration and Revision	0 – They do not answer peer questions. 1 – They answer peer questions superficially, without critical reflection. 2 – They thoughtfully answer peer questions. 3 – They thoughtfully answer peer questions and include some idea for model revision. 4 – They thoughtfully answer all three peer questions and include an elaborated or thoughtfully considered revision to their model.

Appendix Y

Chemical Reactions Unit Posttest

Balancing Reactions – 3 points each.

1. $H_2O \rightarrow H_2 + O_2$
2. $N_2 + H_2 \rightarrow NH_3$
3. $Al + Cl_2 \rightarrow AlCl_3$

Reaction Types – 4 points each.
Write balanced formula equations for the following reactions. Identify the type of reaction.

4. Solid potassium chloride yields solid potassium and chlorine gas.
   Type of Reaction: ________________________
5. Solid magnesium plus nitrogen gas yields solid magnesium nitride.
   Type of Reaction: ________________________
6. Ethane gas (C_2H_6) plus oxygen gas yields carbon dioxide gas and water vapor.
   Type of Reaction: ________________________

Predicting Products – 4 points each.
Predict the products and balance the following reactions. Indicate if a reaction does not occur. Identify the type of reaction

7. $Cu_{(s)} + NaSO_{4\,(aq)} \rightarrow$
   Type of Reaction: ________________________
8. $Mg(NO_3)_{2\,(aq)} + Li_2CO_{3\,(aq)} \rightarrow$
   Type of Reaction: ________________________

Oxidation & Reduction – 5 Points each.
Identify the oxidation numbers of all the elements in the reactants and the products and identify the element that gets oxidized and the element that gets reduced.

9. $2BeSO_{4\,(s)} \rightarrow 2Be_{(s)} + O_{2\,(g)} + 2SO_{3\,(g)}$
10. $2Co_{(s)} + Pb(NO_3)_{4\,(aq)} \rightarrow 2Co(NO_3)_{2\,(aq)} + Pb_{(s)}$

11. Predict the products and balance the following formula equation. (4 points)
    $Mg + FeBr_3 \rightarrow$

12. Write the complete ionic equation for the reaction in number 11. Make sure it is balanced. Identify the oxidation number of each element. Identify the element that is reduced and the element that is oxidized. (4 points)

13. Write the balanced reduction and oxidation half-reactions for the reaction in number 11. (4 points)
14. Use the half-reactions in number 13 to write the net ionic equation for the reaction in number 11. (2 points)

Appendix Z
Kinetics Unit Pretest

Directions:
Circle the best answer for all multiple-choice. For short answer, write in complete sentences and be concise. You may use a diagram to assist your explanation, but a diagram alone will not suffice.

1. In order to have an effective collision, the particles involved must

a. collide
b. have the proper orientation
c. have enough energy
d. all of the above

2. Which of the following burns the fastest (ie has the fastest reaction rate), if each sample has the same total mass?

a. a large chunk of salt
b. small grains of salt
c. powdered salt (very, very small pieces)
d. they all burn at the same rate

3. Decreasing the concentration of the reactant particles ____________ the rate of reaction because ____________.

a. increases; more particles collide with more force.
b. decreases; fewer particles collide less often.
c. increases; more particles increase collision frequency.
d. decreases; fewer particles collide with less force.

4. Catalysts speed up the rate of reaction by

a. providing an alternate path to overcome the activation energy.
b. increasing the overall activation energy of the reaction.
c. decreasing the number of collisions of the molecules.
d. all of the above.

5. If the particles in a reaction have enough energy to overcome the activation energy, at the moment of collision they form

a. an intermediate.
b. an activated complex.
c. a concentrated complex.
d. a theory.

6. State how temperature affects reaction rate. Explain this effect with at least two reasons.

Appendix AA
Kinetics Unit Posttest

Directions:
Circle the best answer for all multiple-choice. For short answer, write in complete sentences and be concise. You may use a diagram to assist your explanation, but a diagram alone will not suffice.

1. In order to have an effective collision, the particles involved must have

    a. a minimum energy
    b. proper orientation
    c. both a and b
    d. either a or b (not necessarily both)

2. Which of the following burns the fastest (ie has the fastest reaction rate), if each sample has the same total mass?

    a. a large lump of coal
    b. small pieces of coal
    c. powdered coal (very small pieces)
    d. they all burn at the same rate

3. Increasing the concentration of the reactant particles ____________ the rate of reaction because ____________.

    a. increases; more particles collide with more force.
    b. decreases; fewer particles collide more often.
    c. increases; more particles increase collision frequency.
    d. decreases; fewer particles collide with less force.

4. Catalysts speed up the rate of reaction by

    a. providing an alternate path to overcome the activation energy.
    b. increasing the overall activation energy of the reaction.
    c. inhibiting the orientation of the collisions of the molecules.
    d. none of the above.

5. If the particles in a reaction have enough energy to overcome the activation energy, at the moment of collision they form

    a. an intermediate.
    b. an activated complex.
    c. a concentration.
    d. a theory.

6. State how temperature affects reaction rate. Explain this effect with at least two reasons.

Appendix BB
Organic Unit Pretest

Please circle the best answer.

1. A saturated straight-chain hydrocarbon with seven carbons is

a. hexane. b. heptane.
c. octane. d. hexane.

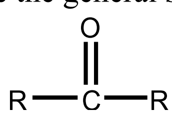
2. An organic compound that contains only carbon and hydrogen atoms and a single triple bond is classified as an

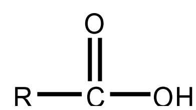
a. alkane. b. alkyne.
c. alkene. d. arene.

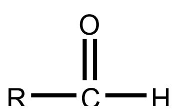
3. Which of these are characteristics of all alkenes?
I. unsaturated
II. carbon – carbon double bond
III. carbon – carbon triple bond

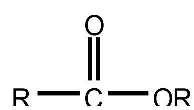
a. I only b. I and II
c. I and III d. I, II, and III

4. Aldehydes have the general structure

a. 

b. 

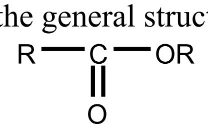
c. 

d. 

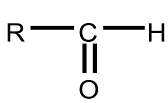
5. This formula $CH_3CH_2OCH_2CH_3$ represents

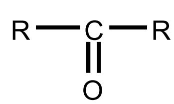
a. an ether. b. a ketone.
c. an aldehyde. d. a halocarbon.

6. Ketones have the general structure

a. 

b. 

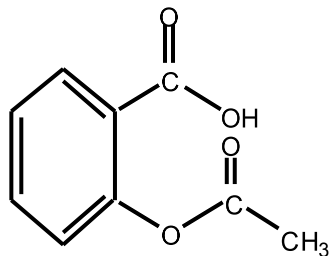
c. 

d. 

7. Hydrogen bonding *cannot* occur between which of the following pairs of molecules?

a. water–alcohol
b. water–amine
c. water–carboxylic acid
d. water–alkane

8. Identify the functional groups present in aspirin (acetylsalicylic acid).



a. amino, halogen
b. ester, carboxyl
c. ester, hydroxyl
d. aldehyde, ketone

9. Which of the following is true about alcohols?

a. All alcohols are soluble in water in all proportions.
b. Alcohols boil at lower temperatures than alkanes containing comparable numbers of atoms.
c. Alcohols are capable of intermolecular hydrogen bonding.
d. all of the above

10. Which of the following is true about esters?

a. They cause the aromas in many fruits.
b. Their functional group contains a halogen.
c. They do NOT have a carbon double bonded to an oxygen.
d. all of the above

Appendix CC
Organic Posttest

Please circle the best answer.

1. A saturated straight-chain hydrocarbon with six carbons is

a. hexane. b. heptane.
c. octane. d. hexane.

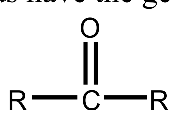
2. An organic compound that contains only carbon and hydrogen atoms and a single double bond is classified as an

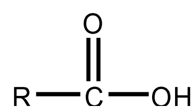
a. alkane. b. alkyne.
c. alkene. d. arene.

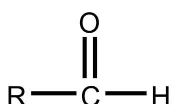
3. Which of these are characteristics of all alkynes?
I. unsaturated
II. carbon – carbon double bond
III. carbon – carbon triple bond

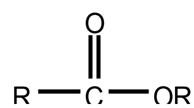
a. I only b. I and II
c. I and III d. I, II, and III

4. Carboxylic acids have the general structure

a. 

b. 

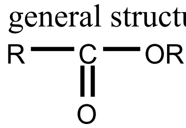
c. 

d. 

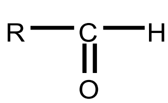
5. The formula CH_3CH_2OH represents

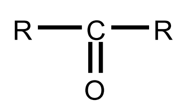
a. an ether. b. an alcohol.
c. an aldehyde. d. a halocarbon.

6. Ethers have the general structure

a. 

b. 

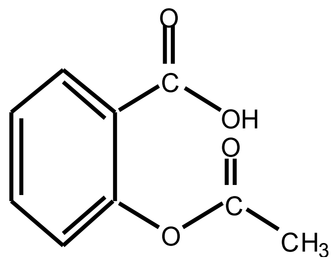
c. 

d. 

7. Hydrogen bonding can occur between which of the following pairs of molecules?

a. water–alcohol
b. water–alkyne
c. water–alkene
d. water–alkane

8. Identify the functional groups present in aspirin (acetylsalicylic acid).



a. amino, halogen
b. ester, carboxyl
c. ester, hydroxyl
d. aldehyde, ketone

9. By definition all fatty acids contain?

a. carboxyl groups.
b. amino groups.
c. ester groups.
d. none of the above

10. Which of the following is true about amines?

a. They cause the aromas in many fruits.
b. They are the chemicals in caffeine.
c. They always contain a carbon double bonded to an oxygen.
d. none of the above

Appendix DD
Acid/Base Pretest

Matching

Match each term in Column B with the correct description in Column A. Write the letter of the correct term on the line.

Column A	Column B
________ **1.** acid dissociation constant	**a.** acidic solution
________ **2.** $[H^+]$ greater than $[OH^-]$	**b.** conjugate acid–base pair
________ **3.** The cations or anions of a dissociated salt remove hydrogen ions from or donate hydrogen ions to water.	**c.** amphoteric **d.** basic solution **e.** K_w
________ **4.** point of neutralization of the titration	**f.** end point **g.** neutral solution
________ **5.** H_3O^+	**h.** hydronium ion
________ **6.** $[OH^-]$ and $[H^+] = 1 \times 10^{-7}$	**i.** K_a
________ **7.** $[OH^-]$ greater than $[H^+]$	**j.** salt hydrolysis
________ **8.** ion-product constant for water	
________ **9.** describes a substance that can act as both an acid and a base	
________ **10.** two substances that are related by the loss or gain of a single hydrogen ion	

Multiple Choice

Choose the best answer and write its letter on the line.

________ **11.** A solution in which the hydroxide-ion concentration is $1 \times 10^{-5} M$ is

a. acidic. **c.** neutral.
b. basic. **d.** none of the above

________ **12.** The products of the self-ionization of water are

a. $H_3O_7^+$ and H_2O. **c.** OH^+ and H^-.
b. HO^- and OH^+. **d.** OH^- and H^+.

________ **13.** Which of these solutions is most basic?

a. $[H^+] = 1 \times 10^{-11}$ **c.** $[H^+] = 1 \times 10^{-2}$
b. $[OH^-] = 1 \times 10^{-4}$ **d.** $[OH^-] = 1 \times 10^{-13}$

________ **14.** What is the pH of a solution in which the $[H^+] = 1 \times 10^{-12}$?

a. –1.0 **c.** 2.0
b. –2.0 **d.** 12.0

________ **15.** What is the pH of a 0.01*M* hydrochloric acid solution?

a. 10^{-2} **c.** 2.0
b. 12.0 **d.** 10^{-12}

________ **16.** In the reaction $NH_4^+ + H_2O \rightleftharpoons NH_3 + H_3O^+$, water is acting as a(n)

a. Arrhenius acid. **c.** Brønsted-Lowry acid.
b. Brønsted-Lowry base. **d.** Arrhenius base.

________ **17.** A solution with a pH of 5.0

a. is basic.
b. has a hydrogen-ion concentration of 5.0*M.*
c. is neutral.
d. has a hydroxide-ion concentration of $1 \times 10^{-9} M$.

________ **18.** With solutions of strong acids and strong bases, the word *strong* refers to

a. molality. **c.** solubility.
b. molarity. **d.** degree of ionization.

________ **19.** The hydrolysis of water by the salt of a weak base and a strong acid should produce a solution that is

a. weakly basic. **c.** strongly basic.
b. neutral. **d.** acidic.

________ **20.** Which of these is an Arrhenius base?

a. KOH **c.** $H_2PO_4^-$
b. NH_3 **d.** $HC_2H_3O_2$

Problems

21. What is the $[OH^-]$ of a 0.0025 M HNO_3 solution?

22. What is the molarity of a NaOH solution, if 25.0 mL of it is titrated to the end point by 20.0 mL of 0.175 M HCl? Start with the neutralization reaction equation.

23. At equilibrium a solution of lactic acid ($HC_3H_5O_3$) has a $[HC_3H_5O_3]$ of 0.750 M and $[C_3H_5O_3^-]$ of 0.025 M. If the K_a of lactic acid is 8.32×10^{-4}, answer the following questions.

a) Write the ionization equation for lactic acid in water.
b) Write the K_a expression for the equation in part a.
c) Solve for $[H_3O+]$
d) Solve for the pH.

Appendix EE
Acid/Base Unit Posttest

Matching

Match each term in Column B with the correct description in Column A. Write the letter of the correct term on the line.

Column A	Column B
________ **1.** $[H^+]$ greater than $[OH^-]$	**a.** the ion-product constant for water
________ **2.** a compound that produces hydroxide ions when dissolved in water	**b.** acidic solution
	c. acid
________ **3.** the particle formed when a weak base gains a hydrogen ion	**d.** conjugate acid
	e. neutralization reaction
________ **4.** 1.0×10^{-14}	**f.** basic solution
________ **5.** $[OH^-]$ greater than $[H^+]$	**g.** base
________ **6.** a compound that produces hydrogen ions when dissolved in water	**h.** diprotic acid
	i. amphoteric
________ **7.** H_2SO_4	**j.** conjugate acid–base pair
________ **8.** when the number of moles of hydrogen ions equals the number of moles of hydroxide ions in titration	**k.** equivalence point
________ **9.** describes a substance that can act as both an acid and a base	
________ **10.** two substances that are related by the loss or gain of a single hydrogen ion	

Multiple Choice

Choose the best answer and write its letter on the line.

_______ **11.** Which of the following is true about acids?

a. Acids give foods a bitter taste.
b. Aqueous solutions of acids conduct electricity.
c. Acids have a pH value greater than 7.
d. all of the above

_______ **12.** The products of the neutralization reaction between HNO_3(*aq*) and $Ca(OH)_2$(*aq*) are

a. $CaNO_3 + H_2O$.
b. $Ca(NO_3)_2 + H_2O$.
c. $CaNO_3 + 2H_2O$.
d. $Ca(NO_3)_2 + 2H_2O$.

_______ **13.** A solution in which the $[H^+]$ is 1.0×10^{-4} mol/L is said to be

a. acidic.
b. basic.
c. neutral.
d. none of the above

_______ **14.** What is the pH of the solution in question 13?

a. 1.00
b. 4.00
c. 10.00
d. 14.00

_______ **15.** Among the following, which solution is the most acidic?

a. $[H^+] = 1 \times 10^{-5}$ mol/L
b. pH = 3
c. $[OH^-] = 1 \times 10^{-7}$ mol/L
d. pH = 10

_______ **16.** The monoprotic acid from among the following is

a. H_2CO_3.
b. H_2SO_4.
c. H_3PO_4.
d. HCl.

_______ **17.** In the reaction: HCl(*g*) + NH_3(*aq*) → NH_4^+(*aq*) + Cl^- (*aq*), HCl(*g*) is acting as a(n):

a. Brønsted-Lowry acid.
b. Brønsted-Lowry base.
c. Lewis acid.
d. Lewis base.

_______ **18.** The conjugate acid in the reaction described in question 17 is

a. HCl(*g*).
b. NH_3(*aq*).
c. NH_4^+ (*aq*).
d. Cl^-(*aq*).

_______ **19.** Among the following K_a values, which represents the strongest acid?

a. $K_a = 1.2 \times 10^{-3}$
b. $K_a = 3.4 \times 10^{-5}$
c. $K_a = 8.7 \times 10^{-8}$
d. $K_a = 5.8 \times 10^{-10}$

_______ **20.** In the reaction $NH_4^+ + H_2O \rightleftharpoons NH_3 + H_3O^+$, water is acting as a(n)

a. Arrhenius acid.
b. Brønsted-Lowry base.
c. Brønsted-Lowry acid.
d. Arrhenius base.

Problems

21. What is the $[OH^-]$ of a 0.0025 M HNO_3 solution?

22. What is the molarity of a NaOH solution, if 25.0 mL of it is titrated to the end point by 20.0 mL of 0.175 M HCl? Start with the neutralization reaction equation.

23. At equilibrium a solution of lactic acid ($HC_3H_5O_3$) has a $[HC_3H_5O_3]$ of 0.750 M and $[C_3H_5O_3^-]$ of 0.025 M. If the K_a of lactic acid is 8.32×10^{-4}, answer the following questions.

a) Write the ionization equation for lactic acid in water.
b) Write the K_a expression for the equation in part a.
c) Solve for $[H_3O+]$
d) Solve for the pH.

Appendix FF
Cumulative Final Exam

PART I: MULTIPLE CHOICE

Make sure you place your answer in the proper blank on the answer sheet. Each Question is worth 1pt.

1. A sample of unknown composition was tested in the laboratory. The sample could ***not*** be broken down by physical **or** chemical means. On the basis of these results, the unknown sample was most likely

   (A) a compound.
   (B) an element.
   (C) a mixture.
   (D) a solution.
   (E) none of the above.

Questions 2-4 refer to the following answers:

   (A) H_2SO_4
   (B) $HC_2H_3O_2$
   (C) KOH
   (D) a salt
   (E) an indicator

2. Is a strong base

3. Forms from the reaction between an acid and a base

4. Is a strong acid.

---

5. Which of the following is a **nonpolar** *molecule*?

   (A) H_2
   (B) H_2O
   (C) KI
   (D) HF
   (E) $CaBr_2$

6. As the wavelength of a wave increases the ______ decreases.

   (A) frequency

(B) amplitude
(C) speed
(D) velocity
(E) none of the above

7. Catalysts decrease the activation energy during chemical reactions. What effect does this have on the overall reaction?

(A) Increases the temperature
(B) Increases the concentrations of the reactants
(C) Increases the rate of the reaction
(D) Decreases the energy of the products
(E) Decreases the temperature

8. Atoms of carbon-12 and carbon-14 are isotopes because

(A) they have the same mass.
(B) they have the same number of protons, but different masses.
(C) they have different numbers of protons.
(D) they have different numbers of electrons.

Questions 9-11 refer to the following answers:

(A) F^{1-}
(B) S
(C) K^{+1}
(D) Be
(E) Ti

9. Has the electron configuration [Ne] $3s^2 3p^4$.

10. Has electrons in the d sublevel.

11. Has the same electron configuration as Argon.

Questions 12-15 refer to the following answers:

(A) polar molecule
(B) ionic compound
(C) nonpolar molecule
(D) metallic element

(E) noble gas

12. Methane (CH_4)

13. Krypton

14. Calcium hydroxide

15. Magnesium

Questions 16-20 refer to the following answers:

(A) cathode ray tube
(B) gold foil
(C) graduated cylinder
(D) calorimeter
(E) indicator

16. Device used to measure volume of a liquid.

17. Apparatus used in the discovery of electrons.

18. Used in Rutherford's experiment.

19. Device used to measure the energy (**enthalpy**) of a substance or reaction.

20. Substance that changes color depending on the pH of the solution.

Questions 21-24 refer to the following answers:

(A) boiling point elevation
(B) entropy
(C) solubility product constant (Ksp)
(D) condensation
(E) sublimation

21. This equilibrium value determines how much of a substance dissolves in water at 25°C.

22. Measure of *disorder* in the universe.

23. Change from a solid directly into a gas.

24. Change a gas into a liquid

25. What is the molarity of a solution of HCl if 31ml is required to neutralize 40ml of a 1M NaOH solution?

(A) 0.3 M
(B) 1.3 M
(C) 2.3 M
(D) 3.3 M
(E) 4.3 M

26. The **molarity** of a solution refers to the number of moles of the solute in
a. a mole of solvent.
b. a mole of solution.
c. one kg of the solvent.
d. one liter of the solution.

27. The correct name for Na_3P is

(A) tri sodium potasside.
(B) tri sodium phophide.
(C) tri sodium phosphate.
(D) sodium phosphide.
(E) sodium phosphate.

28. What mass of KCl will dissolve in 250g of water at 20ºC if 34.0g of the solute dissolves in 100g of water at that temperature?

(A) 34.0g
(B) 68.0g
(C) 85.0g
(D) 17.0g
(E) Cannot be determined with the given information.

29. Which type of radiation is identical in mass and charge to a helium nucleus?

(A) alpha
(B) beta
(C) gamma
(D) positron
(E) epsilon

30. An increase in temperature increases the rate of a chemical reaction because the

(A) activation energy increases.
(B) activation energy decreases.

(C) number of molecular collisions increases.
(D) number of molecular collisions decreases.

31. Real gases approach ideal gas behavior at

(A) low temperature and low pressure
(B) high temperature and high pressure
(C) low temperature and high pressure
(D) high temperature and low pressure
(E) cannot be predicted

32. Which of the following pairs exhibits the most similar chemical properties?

(A) Mg and S
(B) Ca and Br
(C) Mg and Ca
(D) S and Cl
(E) Ca and Na

33. If the total enthalpy of the reactants is less than that of the products, the reaction *must* be

(A) exothermic
(B) endothermic
(C) spontaneous
(D) non spontaneous
(E) none of the above.

34. A reaction that is both exothermic and has an increase in entropy is

(A) always spontaneous.
(B) never spontaneous.
(C) spontaneous at high temperatures.
(D) spontaneous at low temperatures.
(E) cannot exist in nature.

35. Which of the following pH values corresponds to the <u>lowest</u> concentration of hydrogen ions ($[H^+]$) ?

(A) 2
(B) 3
(C) 4
(D) 5
(E) 6

36. According to Graham's Law, which of the following gases will diffuse most rapidly at room temperature?

(A) CH_4
(B) SO_2
(C) NO_2
(D) C_2H_4
(E) H_2

37. Which applies to the following reaction?

$AgNO_3(aq) + NaCl(aq) \rightarrow AgCl(s) + NaNO_3(aq)$

(A) Ag is reduced.
(B) Ag is oxidized.
(C) Na is reduced.
(D) Na is oxidized.
(E) none of the above.

38. After you balance the equation below, the coefficients of the KOH and H_2SO_4 are

__KOH(aq) + __$H_2SO_4(aq) \leftrightarrows$ __$K_2SO_4(aq)$ + __$H_2O(l)$

(A) 1 mole KOH: 1mole H_2SO_4
(B) 1 mole KOH: 2 moles H_2SO_4
(C) 1 mole KOH: 3 moles H_2SO_4
(D) 2 moles KOH: 2 moles H_2SO_4
(E) 2 moles KOH: 1 mole H_2SO_4

39. Which of these compounds has the largest percent by mass of nitrogen?

(A) N_2O
(B) NO
(C) NO_2
(D) N_2O_3
(E) N_2O_4

40. $CS_2(l) + 3O_2(g) \rightarrow CO_2(g) + 2SO_2(g)$

According to the equation for the reaction represented above, what volume of $SO_2(g)$ is produced (at STP) if 0.5 mole of CS_2 is consumed?

(A) 2.0L
(B) 22.4L
(C) 44.8L
(D) 1.0L
(E) None of the above

41. How will the equilibrium of the following reaction be affected if the temperature is decreased?

$N_2(g) + 3H_2(g) \leftrightarrows 2\ NH_3(g) + 30kJ$
(ΔH = -30kJ/mole for the reaction)

(A) It will be shifted to the right
(B) It will be shifted to the left
(C) It will be unaffected
(D) The effect on the equilibrium cannot be determined without more information
(E) None of the above.

42. What is the oxidation number of *chromium* in potassium dichromate, $K_2Cr_2O_7$?
(A) +1
(B) +2
(C) +6
(D) +12
(E) -2

43. How many moles of oxygen are needed to form 6 moles of aluminum oxide, as shown in the balanced equation below?

$4Al(s) + 3O_2(g) \rightarrow 2Al_2O_3(s)$

(A) 1
(B) 2
(C) 3
(D) 6
(E) 9

44. Nuclear power plants are currently fueled by:

(A) alpha decay.
(B) beta decay.
(C) fission reactions.
(D) fusion reactions.
(E) all of the above.

45. Which of the following can be expected to <u>**decrease**</u> the amount of water produced in a closed container according to the reaction below?

$2\ H_{2(g)} + O_{2(g)} \leftrightarrows 2\ H_2O_{(g)} + \text{energy}$
(ΔH is a negative value.)

(A) Removing some hydrogen gas.
(B) Decreasing the temperature.
(C) Removing some water from the system.
(D) Adding additional oxygen to the system.
(E) Increasing the pressure.

46. What are the products of the following double replacement reaction?

$BaCl_2$ + Na_2SO_4 → ???

(A) $BaNa_2$(aq) + Cl_2SO_4
(B) $BaSO_4$(s) + NaCl
(C) $NaCl_2$(aq) + Ba_2SO_4
(D) Cl_2(g) + Na_2(s) + $BaSO_4$(s)
(E) No reaction

47. In nuclear decay, what is balanced on each side?

(A) only atomic number
(B) only mass number
(C) both mass number and atomic number
(D) number of gamma rays
(E) none of the above

48. For a sample of a gas held under constant pressure conditions, as the Kelvin temperature is doubled the volume of the gas sample will

(A) will double.
(B) will decrease by half.
(C) will be unchanged
(D) will increase four fold
(E) not enough information to determine.

49. Which best represents the valence electron configuration for the element germanium (atomic number =32)?

(A) s^2p^6
(B) s^2p^2
(C) s^2
(D) s^4p^1
(E) s^2p^4

50. __K(s) + __O_2(g) → ???

When the equation for the synthesis reaction represented above is completed and balanced by the use of lowest whole-number coefficients, the coefficient for K is

(A) 1.
(B) 2.
(C) 3.
(D) 4.

(E) 6.

51. Given the reaction below, which compound is a salt?

$Al(OH)_3 + HCl \rightarrow AlCl_3 + H_2O$

(A) H_2O
(B) $Al(OH)_3$
(C) HCl
(D) $AlCl_3$
(E) none of the above

52. Which particle is represented by X in the following nuclear equation?

${}^{32}_{15}P \rightarrow {}^{32}_{16}S + X$

(A) ${}^{4}_{2}He$
(B) ${}^{1}_{0}n$
(C) ${}^{2}_{1}H$
(D) ${}^{0}_{-1}e$
(E) gamma ray

53. What <u>mass</u> of KCl is needed to prepare 1.00L of 0.200M solution? (Molar Mass of KCl =74.6g)

(A) 7.46g
(B) 14.9g
(C) 22.4g
(D) 29.8g
(E) 74.6g

54. Which of the following combinations of particles represents an atom of net charge of +2 and of mass number 40 ?

(A) 23 neutrons, 20 protons, 22 electrons
(B) 20 neutrons, 20 protons, 18 electrons
(C) 17 neutrons, 23 protons, 23 electrons
(D) 22 neutrons, 18 protons, 20 electrons
(E) 20 neutrons, 20 protons, 20 electrons

55. What is the correct name for the acid, H_2S?

(A) sulfuric acid
(B) hydrosulfuric acid
(C) sulfurous acid
(D) hydrosulfurous acid

(E) phosphoric acid

56. The half-life of Technetium-99 is 6.00 hours. What fraction of a sample of Technetium-99 remains after 24 hours?

(A) 1/2
(B) 1/4
(C) 1/8
(D) 1/16
(E) 1/32

57. Which substance is ***oxidized*** in the reaction below?

$2Al + Cr_2O_3 \rightarrow Al_2O_3 + 2Cr$

(A) Al
(B) Cr
(C) O
(D) both Cr and O
(E) no oxidation occurs

58. Which equation shows an increase in ***entropy***?

(A) $CO_2(g) \rightarrow CO_2(s)$
(B) $CO_2(l) \rightarrow CO_2(g)$
(C) $CH_3OH(l) \rightarrow CH_3OH(s)$
(D) $CH_3OH(g) \rightarrow CH_3OH(l)$
(E) none of the above

59. Which of the following could be both a molecular formula <u>and</u> an empirical formula?

(A) CH_4
(B) C_2H_2
(C) C_3H_9
(D) C_6H_6
(E) C_3H_6

60. Which change of phase is ***endothermic***?

(A) liquid to solid
(B) liquid to gas
(C) gas to solid
(D) gas to liquid
(E) none of the above

61. Most of the elements in the Periodic Table of the Elements are

(A) nonmetals
(B) metals
(C) ions
(D) metalloids
(E) molecules

62. The geometrical shape of CO_2, a carbon dioxide molecule, is best described as
(A) linear
(B) trigonal
(C) planar
(D) square
(E) tetrahedral

63. On the basis of the acid ionization constants given below, it can be determined that which of the following is the strongest acid?

(A) $HCN \leftrightarrows H^+ + CN^-$	4.0×10^{-10}
(B) $HNO_2 \leftrightarrows NO_2^- + H^+$	4.6×10^{-4}
(C) $HF \leftrightarrows H^+ + F^-$	6.7×10^{-4}
(D) $H_3PO_4 \leftrightarrows H^+ + H_2PO_4^-$	7.1×10^{-3}
(E) $H_2CO_3 \leftrightarrows H^+ + HCO_3^-$	4.4×10^{-7}

64. When a substance goes from liquid to a gas at the *surface* of the liquid over a range of temperatures, this is called

(A) fusion
(B) condensation
(C) evaporation
(D) sublimation
(E) crystallization

65. Which element attains the structure of a noble gas when it becomes a **+1** ion?

(A) Ca
(B) F
(C) O
(D) K
(E) Ne

66. A gas has a volume of 1.4L at a temperature of 20 K and a pressure of 1.0kPa. What will be the new volume when the temperature is changed to 40 K and the pressure is changed to 0.50kPa?

(A) 0.35L
(B) 0.75L
(C) 1.4L
(D) 5.6L
(E) 14L

Questions 67-68 pertain to the reaction represented by the following equation:

$$H_2(g) + I_2(g) \leftrightarrows 2\,HI(g) + 150 \text{ kilojoules}$$

$$(\Delta H = -150kJ)$$

67. The equilibrium constant (Keq) for the reaction is given by the expression

(A) $\frac{[2\,HI]}{[H_2][I_2]}$

(B) $\frac{[HI]^2}{[H_2][I_2]}$

(C) $\frac{[H_2][I_2]}{[HI]^2}$

(D) $\frac{[H][I]}{[HI]^2}$

(E) $\frac{[H][I]}{[2HI]}$

68. The above reaction can be described as

(A) an endothermic single replacement reaction.
(B) an exothermic single replacement reaction.
(C) an endothermic synthesis reaction.
(D) an exothermic synthesis reaction.
(E) an exothermic decomposition reaction.

69. $CuO + H_2 \rightarrow H_2O + Cu$

What occurs during the reaction above?

(A) The copper is reduced and its oxidation number changes from +1 to 0.
(B) The copper is oxidized and its oxidation number changes from +2 to 0.
(C) The copper is reduced and its oxidation number changes from +2 to 0.
(D) The copper is oxidized and its oxidation number changes from +1 to 0.
(E) Copper is a spectator in this reaction.

70. The electrons shared in a bond between hydrogen and fluorine are more strongly attracted to the atom of

(A) hydrogen, which has the higher electronegativity.
(B) fluorine, which has the higher electronegativity.
(C) hydrogen, which has the lower electronegativity.
(D) fluorine, which has the lower electronegativity.
(E) Neither atom, because electrons are always shared equally in covalent bonds

PART II: Solve all the problems in the space provided.

1. Write the chemical formulas for the following compounds: (2 points each)

a. tin (II) sulfide
b. dinitrogen pentoxide
c. sodium carbonate

2. Label each compound as a Bronsted-Lowry acid or base and show the conjugate acid/base pairs in the following reactions: (2 points each)

a. $HSO_4^{1-} + H_2O \leftrightarrows SO_4^{2-} + H_3O^+$
b. $NH_4^+ + PO_4^{3-} \leftrightarrows NH_3 + HPO_4^{2-}$

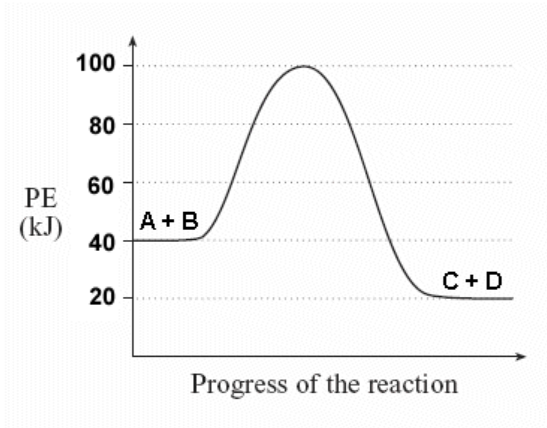
3. Balance the following equations and identify the reaction type: (3 points each)

a. ___P_4O_{10} + ___H_2O $\leftrightarrows$ ___H_3PO_4
Type_______________

b. ___$Pb(NO_3)_2$ + ___ KI $\leftrightarrows$ ___PbI_2 + ___KNO_3
Type_______________

4. In the space below, write the complete, balanced equation for the neutralization reaction between hydrochloric acid and magnesium hydroxide (5 points).

5. Use the following diagram to answer the questions that follow, regarding the hypothetical reaction A + B $\leftrightarrow$ C + D (5 pts.).



a. What is the potential energy of the products?
b. Is the forward reaction exothermic or endothermic? Explain.
c. What would be different about this diagram if a catalyst were added to the system?

6. For the following solubility equilibrium system:

$$AgBr\ (s) \leftrightarrows Ag^{+}(aq) + Br^{-}(aq) + heat$$

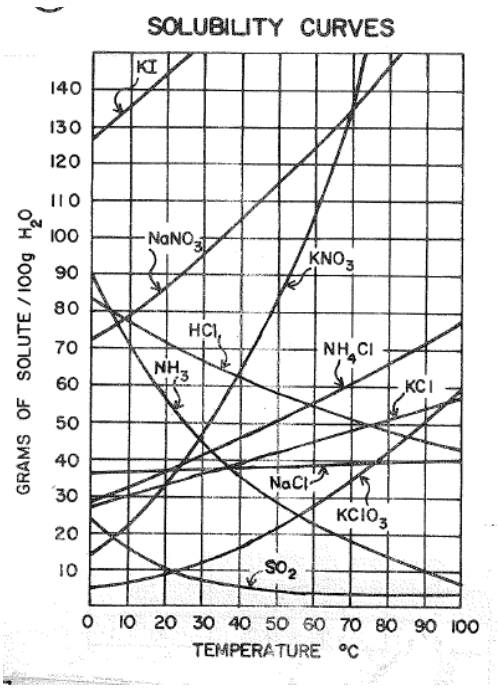
What direction, if any, would the system shift if the following changes were made (1 point each)?

a. NaBr is dissolved in the same container.
b. The temperature of the system is raised.

7. Name the following compounds (2 points each).

a. $Ca(C_2H_3O_2)_2$ b. SO_3

8. Use the provided solubility curve to answer the following questions (2 points each).



a. How many grams of ammonium chloride per 100 g of water constitute a saturated solution at 50 degrees Celsius?
b. Identify two substances whose solubility decreases as the temperature increases.
c. If a solution of potassium nitrate was prepared at 60ºC, and it contained 85g of solute per 100g of water, what type of solution would it be (unsaturated, saturated, or supersaturated)?

PART III: Free Response
Chose one of the following questions and answer all the parts (10 points).

1. A gas laws "thought experiment."

   a. You have just returned from the carnival, and have a helium balloon tied to your finger. You accidentally release the balloon into the atmosphere. It rises until it disappears. But you wonder . . . what happened to the density of the gas **inside** of the balloon as it climbed higher and higher into the atmosphere (assuming that the temperature remained constant). Explain in terms of kinetic theory.

   b. You take your favorite balloon everywhere you go. You live in Alaska and decide to travel to Mexico (much hotter) for spring break. What happens to the density of the gas **inside** of your balloon as you travel from Alaska to Mexico (assume outside pressure is constant)? Explain in terms of kinetic theory.

2. A solubility "thought experiment"

   Imagine you have been working outside and your hands are dirty. Now, it is time to eat and you have to get the dirt off your hands. You go to the sink and want to dissolve the dirt off your hand.

a. Indicate 2 things you will do to make more of the dirt dissolve in the water and WHY those actions will increase the **total solubility**.

b. Indicate 3 things you would do to make the dirt dissolve faster and WHY these actions would increase the **rate** of solubility.

c. Indicate in terms of molecular polarity, why some of the dirt may not come off your hands by using just water.

3. Answer the following questions, which refer to the reaction shown below.

$C_2H_4(g) + H_2(g) \leftrightarrow C_2H_6(g)$ + Heat energy

a. What direction would the equilibrium shift if more hydrogen gas was pumped into the reaction vessel? Explain.

b. What direction would the equilibrium shift if the temperature were decreased? Explain.

c. What direction would the equilibrium shift if the overall pressure were decreased? Explain.

PART IV: Solve the problems in the space provided.
Show all formulas, proper substitutions, factor labels, givens, and math work. Include scientific units and significant figures for all answers. Circle your final answers.

1. What is the **molarity** of a solution that contains 22.0 g of potassium bromide (KBr) in 6.25 L of a water solution? (3pts.)

2. The reaction below is studied at equilibrium, and the following was found: [HCl] =0.0012M; $[O_2]$=0.00038M; $[H_2O]$= 0.058M; and $[Cl_2]$ = 0.058M.

$$4HCl(g) + O_2(g) \leftrightarrow 2H_2O(g) + 2Cl_2(g)$$

a) Write the Keq expression for this reversible reaction. (3 pts.)
b) Determine the value of the equilibrium constant (Keq) for this system. Which reaction is favored at equilibrium? (4 pts)

3. If 222.00 grams of water gains 2.10×10^4 joules of heat, what will be the change in temperature of the water? (The specific heat of water is 4.20 J /g °C). (3pts.)

4. A quantity of gas at a pressure of 350.0 kPa and a temperature of 132.2 K has a volume of 20.00 L. What pressure will the gas exert if the temperature changes to 55.0 K and the volume is increased to 450.0 L? (3pts.)

5. Aluminum hydroxide decomposes to produce water and aluminum oxide according to the reaction below. How many grams of aluminum oxide are produced from 55.0 g of aluminum hydroxide? (5pts.)

$$2\ Al(OH)_3 \leftrightarrows 3\ H_2O + Al_2O_3$$

6. The ΔH of a certain reaction is -135.0 kJ and the ΔS is -0.230 kJ/K.
   a. Calculate ΔG at 900.0 K. (3pts.)
   b. Will this reaction occur spontaneously at 900.0 K? Explain your answer. (2pts.)

7. If you have a 0.001 M HCl solution, (this is a strong acid).
   a. What is the concentration of H^+ in the solution? (1 pt.)
   b. What is the concentration of OH^- in the solution? (2 pts.)
   c. What is the pH of the solution above? (2 pts.)
   d. Is the solution acidic or basic? (1pt.)