Science Education as a Catalyst for Social Change?
Justice-Centered Pedagogy in Secondary Chemistry

BY

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SUMMARY

This dissertation presents the findings of a retrospective case study of an Advanced Placement (AP) chemistry class in a neighborhood high school that was founded as the result of a hunger strike organized to protest the systemic neglect of an urban Mexican American community. Within this context, three research questions guided the investigation of the (1) opportunities and challenges of developing and implementing socially transformative science curriculum, (2) the teaching practices, classroom structures, and routines that supported or impeded the students' development (3) the responses and reflections of students on their experiences through their classwork and as they looked back on the class as college students. Justice-centered science pedagogy is presented as a framework that is built on the traditions of critical pedagogy and culturally relevant pedagogy to theorize teaching that aims to address inequities in science education as one component of oppression caused by white supremacy, capitalism, and patriarchy. This study is teacher research that applies the extended case method to analyze three data sets: interviews with students and other stakeholders, student work artifacts, and the teacher's archival records.

Analysis of these data sets resulted in four major findings related to (1) the design of socially transformative science curriculum, (2) student learning and achievement, (3) students' orientations towards science, and (4) teaching practices that supported justice-centered science pedagogy in the case study class. With respect to first finding, two different approaches to the development of socially transformative science curriculum (Mutegi, 2011) emerged from the data: "problem-posing science education" and "injected relevance." Problem-posing units were organized around socio-scientific issues which I had good reason to believe were relevant to students and their communities. Units with an injected relevance approach were organized

around canonical chemistry concepts with daily lessons or homework problems to provide examples of how theses concepts might matter in students' lives. While there was some back-and-forth between content and context in planning each unit in the class, the data show that problem-posing units are qualitatively different from injected relevance units both in terms of my planning process and in the ways students experienced the curriculum.

The second major finding emerged from an analysis of student work from problem-posing and injected relevance units: students demonstrated academic achievement in ways that are consistent with components of the Next Generation Science Standards (NGSS), the AP Chemistry Course Description, and the Common Core State Standards (CCSS). My analysis of student work and interview transcripts also indicated that working to achieve the three criteria for culturally relevant pedagogy (academic achievement, cultural competence, and critical consciousness) was synergistic, which challenges notions that relevance and rigor must compete for class time or curricular space. The retrospective design of this case study also allowed me to consider students' preparedness for college chemistry courses as an indicator of academic achievement. Four of the five student participants who went on to take college general chemistry courses indicated that they felt very prepared by the case study class and earned A's and B's in college general chemistry.

The third major finding is that students' development as transformative intellectuals is associated with three orientations towards science. I have labeled these orientations (1) tourists in the culture of science, (2) concerned scientists, and (3) science *nepantler@s* (Aguilar-Valdez et al, 2013). These orientations are consistent with the notion of youth as transformative intellectuals because all of the student participants in this study expressed agency and hope with respect to transforming their communities and/or the world. These orientations should not be

interpreted as fixed categories of students nor an exhaustive list of possible orientations. Instead, they describe the way students in this study view the relationship between science and social change as they move through their academic and life trajectories, and are thus subject to change. “Tourists in the culture of science” do not wish to pursue a science career path, but are interested in learning science when it is useful to solving problems in their lives or communities. “Concerned scientists” describe themselves as always having been interested in science and intend to pursue a science career path. Students of this orientation are motivated both by fascination and also by notions of contributing to humankind’s wellbeing and understanding of the universe. Science *nepantler@s* intend to pursue a science career path, even as they are critical of the culture of science for being racist, sexist, and disconnected from the problems of marginalized communities. Students of this final orientation are concerned with changing science and using science to change the world.

The fourth major finding is that two sets of classroom practices, structures, and routines supported the implementation of socially transformative science curricula. The first set of practices, structures, and routines included a start of class ritual and frequent opportunities for students to work together in both structured and organic ways. The second set of teaching practices involved pushing forward with the planned curriculum during a time of district-induced upheaval at the school. The data suggest that rather than being innovative or unique, these two sets of practices, structures, and routines were effective because they aligned the values of the case study class with the values of other communities in which students participated. The final chapter of this dissertation reconstructs theories of culturally relevant and critical pedagogies as they apply to an urban secondary science class and offers implications for science teachers, teacher educators, and educational researchers.

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LIST OF ABBREVIATIONS

AP	Advanced Placement
CCSS	Common Core State Standards
MWI	Medical Waste Incinerator
NGSS	Next Generation Science Standards
SSI	Socio-Scientific Issues
sTc	socio-transformative constructivism

Chapter I: Introduction

In 2001, William Tate issued, "…an open invitation to the science education community to engage in social justice issues and to treat the opportunity to learn science as a civil rights construct" (p. 1016). Tate's invitation was coupled with prophetic warnings about the pitfalls of "raising standards" and "increasing accountability" as methods for engaging in these issues. Now, more than a decade later, science teachers are faced with unprecedented levels of standardization and accountability in their practice. Meanwhile, recent science education research acknowledges that the concept of social justice remains under-theorized in the field (Dimick, 2012; Rivera Maulucci, 2012). More importantly, there is no semblance of equity across lines of race or class in science education (Atwater, Lance, Woodard, & Johnson, 2013; Smith, Nelson, Trygstad, & Banilower, 2013). In other words, the continued lack of equitable opportunities to learn science for African American[1] and Latin@[2] students constitutes an ongoing violation of students' civil rights.

Since educational inequity is built into the politics, economics, and ideology of our society, issues of "social justice" in schools and classrooms are inextricably entangled with broader issues of social inequality (Duncan-Andrade & Morrell, 2008; Noguera, 1996). For example, recent research has linked inequitable school outcomes with environmental racism (Akom, 2011; Mohai, Kweon, Lee, & Ard, 2011). Issues like unequal access to healthy food and

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[1] I use the term African American because this is the term that was used in interviews by the two participants of African descent in this study and the term used, more often than not, in the literature to which this study seeks to contribute.

[2] I use the term Latin@ throughout to emphasize the shared experience of people in the US with mixed Indigenous American, African, and European ancestry who have roots in Latin America, including parts of the US. As in LatCrit scholarship (Cantú and Fránquiz, 2010 as cited in Aguilar-Valdez et al., 2013) I use the @ to trouble using the default masculine form or the "fragmented" o/a.

high incidences of post traumatic stress disorder caused by the violence that is prevalent in urban neighborhoods provide further examples of social injustices that are likely to impact academic performance (Acevedo-Garcia, Osypuk, McArdle, & Williams, 2008; Duncan-Andrade, 2011). Given this context, science educators have suggested that teachers must engage students in challenging social inequality through science curriculum, teaching, and learning that prioritize social transformation (Dos Santos, 2009; Mutegi, 2011; Rodriguez, 1998). However neither standards documents nor the science education literature provide enough in the way of guidance or concrete examples for practitioners who wish to engage their students in socially transformative science education in urban secondary schools.

This teacher research project examines the complexities and contradictions of engaging this type of work at La Lucha High School,[3] an urban public school that serves two low-income working class communities, one that is predominately Mexican American and another that is predominately African American. I apply the extended case method (Burawoy, 1998) to retrospectively study one of my AP chemistry classes. Justice-centered science pedagogy, an emerging theoretical framework built on the traditions of critical and culturally relevant pedagogies, is used to analyze curriculum, classroom practice, and student work alongside interviews with key stakeholders (parents, students, and community members). The following research questions guide this study:

1. What challenges and opportunities are associated with designing and implementing socially transformative science curriculum within the context of an AP chemistry class at an urban neighborhood school serving low-income Latin@ and African American students?

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[3] Pseudonyms are used for the school, community organizations, students, and other participants.

2. What teaching practices, classroom structures and routines support or impede the implementation of socially transformative curriculum within the context of an AP chemistry class at an urban neighborhood school serving low-income Latin@ and African American students?
3. How do students respond to and reflect upon justice-centered science pedagogy as it relates to their preparation and experiences in college courses and community involvement as young adults?

There are several theoretical assumptions and constructs embedded in these questions, which are further elucidated in the next chapter but require brief explication here. These questions assume that the various components of a teachers' work are interconnected and inseparable in practice, but questions 1 and 2 separate issues of curriculum from teaching practices and classroom routines and structures for analytical purposes. These questions also assume that socially transformative science curriculum supports students to achieve academically while also supporting students to intervene their own lives and communities to make them more just and sustainable (Dos Santos, 2009; Mutegi, 2011). These questions thus assume a distinction between academic achievement and learning. The former is associated with navigating formal educational institutions and the latter can be understood in multiple ways and occurs in all sorts of social contexts. Finally these questions assume that both learning and academic achievement are better understood by examining their development over time rather than by instantaneous measurements.

Historical, Social, and Political Context

Schooling as social reproduction.

US schools have played a central role in maintaining and justifying economic and racial injustice (Bowles & Gintis, 1976/2011; Woodson, 1933/2006). Rather than providing a pathway to equality, in African American and Latin@ communities, US public schools have generally played an impactful role in the process of colonization and the maintenance of oppression (Duncan-Andrade, 2005; Spring, 2003; Watkins, 2001). This has been accomplished both through the inequitable allocation of resources and opportunities and also through the transmission of ideology that reinforces and rationalizes inequality. While the history of this phenomenon is important to understand, the function of US schools as producers of social inequality is not an historical relic. Currently, conversations about the “failure” and “reform” of urban schools, which educate predominately working class African American and Latin@ students, are commonplace in both the academic literature and popular media. But a critical perspective reveals that “Urban schools are not broken; they are doing exactly what they are designed to do” (Duncan-Andrade and Morrell, 2008, p. 1; see also Freire and Macedo, 1987) .

The mechanisms by which public schools have contributed to oppression are neither simple nor uncontested and my goal here is not an exhaustive analysis. However, in order to fully contextualize this study’s efforts to consider how science education can be enacted in the best interest of urban students, a brief analysis of the ways schools, including science classes, reproduce social inequality is appropriate. At the same time, it is important to acknowledge the ways in which, despite the oppressive nature of US schools, educators, parents, communities, and students have maintained a “political understanding of schooling as a permanent terrain of struggle, resistance, and transformation” (Darder, 2002, p. 61). Educators and scholars have insisted that resistance to the historically oppressive function of schools is not only possible, but necessary, and should simultaneously challenge both white supremacy and capitalism as totalizing and hegemonic forces (Stovall, 2006a).

Inequitable resources and opportunities.

The disparate opportunities and resources available to students in US schools along the lines of race and class are evident in funding disparities between highly segregated districts (Kozol, 1992). These disparities are often just as glaring within districts or even within individual schools because of selective enrollment schools and tracking, respectively (Lipman, 2011; Oakes, 1985). Specifically with respect to science education, recent research shows that disparate resources are persistent in US schools (Smith, Nelson, Trygstad, & Banilower, 2013). The analysis of the data from the 2012 National Survey for Science and Mathematics Education (NSSME) conducted by Smith and his colleagues found that students who attend schools with high percentages of African American and Latin@ students and/or students who receive free or reduced lunch tend to have fewer science education resources. Not only are material resources for science instruction (laboratory supplies and instructional materials) more likely to be lacking at these schools, but access to well prepared teachers, advanced courses, and research-based science pedagogy are also scarce compared to schools whose students are wealthier and whiter.

Oppressive curriculum.

While policies have ensured unequal access to resources and opportunities for working class students and students of color, the curriculum (including in science classes) works to transmit ideology that justifies social inequality and discourages dissent (Anyon, 1980; Apple, 2004; Spring, 1972). Several scholars have described how US schools attempt to mold working class students into compliant workers who passively accept their subordinate role in society.

Spring (1972) traces the influence of business leaders and corporations in molding public school policies and curricula to serve their interests. Anyon (1980) famously documented differences in the curriculum between schools that served students from different socioeconomic classes. She found that low-income students were subjected to an overemphasis on rules and obedience at the expense of academics, while students from the wealthiest families were taught to think freely and prepared to assume their inherited roles as society's leaders. Apple (2004) specifically critiques science curriculum for obscuring the role of conflict in scientific communities as part of an effort to emphasize cooperation and compliance while denouncing conflict and dissent. Tobin (2011) uses his experience in Australian and US schools to illustrate how science curriculum is influenced by and reproduces neoliberalism, the dominant ideology of globalization.

Retrofitting scientific racism.

In addition to reproducing existing class structures, the ideology of racial inequality is also reinforced and reproduced through curricula in US schools. Racial oppression is subtly perpetuated through curriculum via two modes of ideological transmission. Eurocentric curricula justify racial inequality and also attempt to negate the cultures of non-dominant groups. In the preface to his germinal book, *The Mis-Education of the Negro*, Carter G. Woodson articulated the first mode of ideological transmission when he wrote, "the philosophy and ethics resulting from our educational system have justified slavery, peonage, segregation, and lynching" (1933/2006, p. xii). The claims of objectivity and neutrality made by Western Science are often extended to science education, supposedly shielding school science from these criticisms about reproducing racial inequality. However, science educators have argued that, "An uncritical teaching and learning of science as currently practiced inevitably engages the teacher and learner in maintaining structural racism" (Gill & Levidow, 1987, p. 3).

Brown and Mutegi (2010) document the ways that science has been influenced by racist ideologies and then used to reinforce notions of white supremacy in support of racist oppression. This cycle has worked to “scientifically” justify oppression from slavery and colonialism through current forms of educational inequality. Brown and Mutegi trace the history of racism in science through various frameworks and methodologies including racial evolutionist perspectives, craniometry, eugenics, and psychometrics. While the methods and theories changed as they were debunked, the racist ideology remained and has been reified in generation after generation of science that aims to establish people of African descent as inferior. Brown and Mutegi refer to this phenomenon as “theoretical retrofitting of scientific racism.”

Rather than being the work of a handful of fringe racist scientists and pseudo-scientists, a critical look at the history of modern science provides numerous examples of Nobel laureates and other renowned scientists, doctors, and educators who espoused the ideology of eugenics or other forms of scientific racism (Takaki, 2000; Vance, 1987; Washington, 2006; Watkins, 2001; Winfield, 2012). Brown and Mutegi argue that science education (and science education research) have tacitly supported the ideologies of scientific racism by framing science as neutral and value-free. These claims of neutrality obscure the impact of scientific racism, thus allowing these myths to continue. Recently, a prominent *New York Times* science reporter has engaged in the latest round of retrofitting scientific racism with the release of his book *A Troublesome Inheritance: Genes, Race and Human History* (Wade, 2014). In this book, Wade attempts to explain present social inequalities on the basis of supposed genetic differences between races. Given this endemic nature of racism in science, science educators must address race and racism directly (Brown & Mutegi, 2010; Gill & Levidow, 1987). Indeed, if students do not learn to deconstruct scientific racism and Eurocentric notions of science in their science classes, it is unlikely that the cycle of "retrofitting" described by Brown and Mutegi will be brought to an end in the near future.

Deculturalization.

Besides justifying racial inequality, the curriculum in US schools also perpetuates racial oppression by attempting to negate non-dominant cultures. Spring (2003) argues that maintaining white supremacy and the dominance of Anglo-American protestant culture was a priority of US public schools from their inception. He describes how this has been achieved through "deculturalization…the educational process of destroying a people's culture and replacing it with a new culture" (p. 3). Spring concisely describes the deculturalization of Native Americans, African Americans, Latin@s, and Asian Americans in US schools. Valenzuela (1999) uses her case study of a large high school in Houston, Texas to investigate the ways in which this deculturalization has a cumulative negative effect on the school performance of Mexican American students over the course of generations. Valenzuela refers to this effect as "subtractive schooling," a process wherein school "divests [Mexican American] youth of important social and cultural resources, leaving them progressively vulnerable to academic failure" (p. 3). The recent outlawing of Mexican American Studies classes in Tucson, Arizona demonstrates that efforts to maintain US schools as institutions of deculturalization through Eurocentric curricula are ongoing (Cammarota & Romero, 2014).

While the terms "deculturalization" or "subtractive schooling" do not often appear in the science education literature, Jegede and Aikenhead (1999) conceive of learning science as requiring all students to cross cultural borders from their home culture into the culture of Western science. For students whose cultures are significantly different from that of Western science, being required to learn Western science often amounts to cultural violence:

> If Western ways of knowing and valuing continue to dominate science teaching for [non-Euro-American] students, then science classrooms continue to be instruments of colonization because Western cultural ways of knowing are transmitted with the expectation that students will reject their indigenous ways of knowing to participate in the classroom's community of science learners. (Aikenhead, 2006, p.108)

This critique of science education aligns closely with Spring's concept of deculturalization. In fact, there is a growing body of research in science education that debunks the notion that science education is "culturally neutral" (Bang, Warren, Rosebery, & Medin, 2013; Brown, 2005, 2006; Brown, Reveles, & Kelly, 2005; Calabrese Barton & Yang, 2000; Emdin, 2010b). Claims of objectivity and neutrality belie the true impact of science education, making it complicit with the tendency of curriculum in US schools to transmit ideology that reinforces and reproduces racial oppression.

The Dilemma of standards.

In several ways the notion of national standards as a lever for equity in science education epitomizes the contradictions created by an educational system that reproduces social inequality through the mechanisms described above. On one hand standards documents provide guidelines that can be used to push against the systematic exclusion of African American and Latin@ students from advanced science courses and towards equitable "opportunities to learn" (Oakes, 1990; Tate, 2001). On the other hand, national standards are a top down solution that limits community control while re-inscribing the hegemony of Western values in the curriculum. In fact, science educators have disagreed about whether a science education can be both locally determined and standards-based at the same time (Aikenhead, Calabrese Barton, & Chinn, 2006).

This contradiction is exacerbated by high stakes tests and school accountability. If science standards are assessed by high stakes standardized exams, then science educators will feel immense pressure to "teach to the test" rather than being responsive to their unique students and contexts. But if science standards are excluded from high stakes accountability measures that focus on literacy and math, science is likely to be marginalized, especially in schools whose test scores are under scrutiny. This marginalization often reaches the point where science instruction all but disappears from elementary schools and receives less than a fair share of limited time and resources in middle and secondary schools (Rivera Maulucci, 2010; Rodriguez, 2010, 2015; Tate, 2001).

Given this complexity with respect to the role of standards in pushing for equity in science education, it is worthwhile to consider the standards themselves, especially in light of the recent widespread adoption of the Next Generation Science Standards (NGSS Lead States, 2013). The previous Science Education Standards (NRC, 1996) were criticized for making issues of race, gender, culture, and class invisible (Rodriguez, 1997). The National Research Council Framework for Science Education (hereafter "the NRC Framework"), the document that guided the development of the NGSS, considered this criticism and was more explicit about its reasons for and approaches to promoting equity in science education. It also acknowledges the importance of building on students' funds of knowledge and valuing their cultural forms of expressing their knowledge. As such, the NRC Framework encourages connections between science curriculum and youth discourses, identity, and interests. Whereas the previous standards document included vignettes that skirted issues of identity and culture, the NGSS materials include teacher case studies that explicitly focus on ethnicity, culture, language, and socioeconomic status (Rodriguez, 1997, 2015). Still the NRC Framework and the NGSS did not retrospectively consider the successes and failures of the previous standards to make a meaningful impact in science classrooms, nor did they truly prioritize issues of equity (Rodriguez, 2015). They also failed to take a strong political stance against accountability measures in No Child Left Behind and other policies that undermine the sorts of meaningful science learning opportunities they advocate (Rodriguez, 2015).

The NRC Framework that guided the development of the NGSS also falls short of acknowledging the root causes of inequity in science education or dealing with closely connected issues of inequality that impact the teaching and learning of science. While noting that African American and Latin@ students have disparate "opportunities to learn," the NRC Framework still relies heavily on "achievement gap" language to describe the outcomes created by these inequities. Gloria Ladson-Billings (2006) suggests that educational researchers abandon their focus on the "achievement gap," and shift towards an examination of the "education debt" owed to African American, Latina@, and Native American students. Referring to the "achievement gap," incorrectly implies that African American, Latina@, and Native American students are "failing to achieve" at levels comparable to their white and Asian counterparts. In contrast, the "education debt" acknowledges that centuries of inadequate schooling is one component of the ongoing systematic dispossession and disenfranchisement of African American, Latin@, and Native American communities.

While the NRC Framework's focus on "inclusive" science instruction marks significant progress from previous standards documents, it falls short of envisioning science education that addresses the injustices associated with exclusion. For example, the NRC Framework states as its overarching goal:

> to ensure that by the end of 12th grade, all students have some appreciation of the beauty and wonder of science; possess sufficient knowledge of science and engineering to engage in public discussions on related issues; are careful consumers of scientific and technological information related to their everyday lives; are able to continue to learn about science outside school; and have the skills to enter careers of their choice, including (but not limited to) careers in science, engineering, and technology (NRC, 2012, p. 1).

At first glance, it may be hard to disagree with these goals. However, by focusing only on the "appreciation of the beauty and wonder of science," this goal implies no opportunities for students to critique the culture of science. As discussed in the previous section, the culture of science has not only been exclusionary, but has also justified racial inequality through scientific racism and frequently permitted unethical practices. For students to truly be "careful consumers of scientific and technological information," they must have tools and opportunities to critique, not just appreciate, science.

Furthermore, the NRC Framework's shortcomings with respect to the roots of inequity in science education extend to the NGSS as they are silent with respect to other pertinent issues of inequality. For example, the NGSS devote considerable attention to human impacts on earth systems and global climate change (and rightfully so). But, nowhere in these standards is there any mention of the way these impacts are distributed unequally. The unequal distribution of the impacts of environmental hazards across race and class is well documented (Bullard, Mohai, Saha, & Wright, 2007; UCC, 1987). Students who live in neighborhoods heavily impacted by environmental racism are unlikely to become "careful consumers of scientific and technological information, related to their lives" if this pertinent information is left out of the standards and thus excluded from the curriculum. Moreover we are unlikely to achieve the equity sought by the standards if we do not address larger issues like environmental racism, which has been connected to disparate educational outcomes (Akom, 2011; Mohai et al., 2011).

Given the analysis of US schools as reproducers of social inequality presented above, it should come as no surprise that national science education standards fail to deal with the root causes or widespread ramifications of social inequality in meaningful ways. Since the NGSS were developed with the support of 26 “Lead States,” they essentially constitute national standards. National science education standards imply a national science education agenda, the likes of which was articulated by President Obama (2011) in a recent state of a union address. In this address, Obama organized his remarks around the refrain “win the future,” a term that implies making the shifts necessary to ensure continued dominance, economically and militarily, in a globalized world. STEM education was one of the key components of the plan that President Obama outlined in this address. He lamented that the, “quality of our math and science education lags behind many other nations.” He also credited an increased emphasis on math and science education for the recent increase in the economic competitiveness of China and India. These themes are echoed in numerous recent reports on the role of math and science education in the US (e.g. Augustine et al., 2010; Augustine & Mote, 2012; Hess, Kelly, & Meeks, 2011). Indeed a tagline on the NGSS website indicates alignment with the “learn to earn” philosophy of Obama’s speech: “Next Generation Science Standards for Today’s Students and Tomorrow’s Workforce” (NGSS Lead States, 2013).

This focus on the preparation of students for careers in science related fields constitutes what Aikenhead (2006) calls the “pipeline approach.” The pipeline approach refers to prioritizing the preparation of science professionals (including scientists, engineers, and doctors) at the expense of other possible goals. Aikenhead documents that, historically, this has been the prevalent purpose for science education in Europe, the US, and Canada. He traces the origins of the pipeline approach to a secondary school curriculum developed according to the goals of the British Association for the Advancement of Science in 1867. He argues that since that time, challenges to the pipeline approach have emerged from various cultures and traditions around the world. Aikenhead develops a comprehensive case for an alternative to the pipeline approach in which students learn science for application in their "everyday life," a "humanistic" approach. As part of this case, Aikenhead cites a litany of studies that document the "major failures of the traditional science curriculum." Aikenhead's review of these studies extends beyond issues of inequity and social injustice to point out that even students from dominant sociocultural backgrounds are unlikely to experience meaningful or effective science learning in traditional pipeline-oriented Western science classrooms. He also notes that, "researchers have only recently begun to assess humanistic approaches to school science designed to ameliorate the underrepresentation of conventionally marginalized students" (p. 27).

To its credit, the NRC Framework that guided the development of the NGSS repeatedly emphasizes the importance of both "pipeline" and "humanistic" approaches to science education. The framework provides justifications for improved science education that include both career preparation and the utility of everyday science knowledge for those who do not pursue a STEM career. But a humanistic framework is insufficient to ensure humanistic standards. Aikenhead (2006, p. 52) documents how the previous NRC standards fell short even though the documents that guided their creation had a humanistic perspective. Whether the NGSS are able to support a shift in the historical priorities of US science education towards a humanistic approach has yet to be seen. In the meantime, we must question whether the creation of national standards supports or handcuffs local communities in making their own decisions about the goals of science education (Aikenhead, Calabrese Barton, Chinn, 2006). Because as Aikenhead (2006, p. 111) asserts about teaching in marginalized communities, "The purpose of science education should be established by the school's community and not by Eurocentric science educators."

While standards are supposed to provide teachers with guidance about what content is important, science teachers are often pulled in multiple directions by various standards and other considerations. In a journal entry dated July 22, 2012, I wrote the following:

> Entering into my tenth year teaching, nothing continues to perplex me more than the various and multiple demands on science curriculum. For example: science concepts, math skills, literacy skills, science college readiness standards, skills particular to Advanced Placement Chemistry, science literacy versus preparing experts, culturally relevant connections, social justice contexts, nature/philosophy/culture of science and critiques of it, including feminism.

Science teachers, especially in urban settings, are often called upon to teach math and literacy skills defined by the CCSS in addition to multiple sets of content standards currently in use as the NGSS are phased in. The potential of these pressures to negatively impact the professional development of science teachers has been documented (Rodriguez, 2010). Whether science standards like the NGSS provide clarity or prevent more meaningful community-driven ways of engaging with students is one of the issues that will be explored in this study.

Significance of the Problem

In her recent review of "Social Justice Research in Science Education," Rivera Maulucci (2012, p. 587) warns against research that "does not convey an adequate understanding of the researchers' agendas or the ways their positional identities frame how they perceive and work to address social justice issues." Not only does this lack of transparency prevent readers from fully understanding the work, but more importantly, it may signal a lack of accountability to the participants and the community. Smith (1999) documents the long history of harm caused to indigenous communities by outside researchers, both well-intentioned and ill-intentioned alike, who worked against the best interests of the community. Along similar lines, Martin (2007) questions the intentions and qualifications of some teachers of African American children who have a missionary mentality or minimal knowledge of the cultural context in which they work. As this study is concerned with science education that addresses the values, strengths, needs, concerns, and aspirations of students and their communities, I must be transparent about my motivations for being involved in this work or else risk betraying its very purpose. Since I am not from the either of the neighborhoods served by La Lucha High School, being accountable to the community means being honest about my reasons for being there, as a teacher and as a researcher. My reasons for teaching and conducting research in urban schools generally and at La Lucha High School in particular are motivated by the way I understand social change to occur. I believe that genuine progressive social change occurs only through collective grassroots efforts led by the people most affected by injustice. I believe that these efforts can be inspired and informed by education that subverts the traditionally oppressive function of schooling described above. These beliefs are rooted in my personal experiences, identity, and understanding of social theory.

Personal significance and positionality.

My hyphenated surname often inspires people to ask, "Where is your family from?" When I respond "Chicago," they usually follow up in a way that indicates that they were really asking about my ethnicity. If I say that most of my great-grandparents were Irish immigrants to the US, it usually becomes clear that it is specifically Morales and not Doyle that sparked their curiosity. The truth is that I have trouble connecting my surname with a specific ethnicity. My uncles who have tried to trace family records through the Catholic Church and census documents have found that our Morales ancestors were in Louisiana as far back as their searches could dig. Family pictures of my great-grandfather, Manuel Morales, have led to speculation that our ancestors were from somewhere in the Caribbean or Central America. But in Louisiana in the early 20th century, my grandfather likely identified as Creole (Jolivétte, 2007). As a child, I simply understood we had the name Morales because we were "Spanish," or on school forms "Hispanic." Like most Latin@ ethnicities, Louisiana Creoles are multiracial people with hybrid cultural traditions that came about during Spanish (and French, and British, and US) colonization and enslavement of Indigenous Americans and Africans. Jolivétte (2007) argues that the government should recognize Louisiana Creole as a unique ethnicity. In my experience growing up in Illinois, and having never met my late grandfather, I found that being named Daniel Morales-Doyle marked me as "Hispanic" or "part-Hispanic."

The historical and socially constructed nature of race and ethnicity does not imply that racism is solely ideological nor is it a relic of history (Bonilla-Silva, 2001). In the US these social constructs are deeply rooted in the enslavement, genocide, torture, and displacement of Africans and Indigenous Americans that characterized the settler colonialism of Europeans on this continent. The fact that race and ethnicity are socially constructed make them no less real as a half-millennium of hegemonic white supremacy and Anglo cultural imperialism fundamentally structure the social, political, and even physical world we seek to understand. But the fact that race and ethnicity are socially constructed means that these constructions change in nuanced ways across time and space, even as the fundamental premises of white supremacy and Anglo cultural imperialism remain intact (Bonilla-Silva, 2014). My identity is not simply inherited from my Creole grandfather or Irish American grandparents who lived in different contexts, but is related to the ways inherited ethnic markers (like my surname and phenotype) are interpreted in my context and thus shape my life.

In my own experience as a student, my surname elicited some of the questions, stereotyping, and microaggressions that Latin@ students are used to experiencing in schools (D. Solorzano, Ceja, & Yosso, 2000). For example, a middle school science teacher concerned about my performance in her class accused me of belonging to a street gang. I was not sure how to interpret this accusation until the same teacher later explicitly attributed my younger brother's consistent tardiness to him being "Hispanic." I have had numerous other experiences like these, but, for the most part, my physical appearance and familiarity with the dominant culture have resulted in significant white privilege, especially in school settings. For example, in contrast with the occasional microaggressions like those perpetrated by my middle school science teacher, the following incident was more typical in my experience. After being disciplined alongside an African American classmate for being disruptive in our middle school reading class, the teacher pulled me aside after class to apologize for scolding me. She insisted that my classmate was solely responsible for the disruption, despite my admission that we were equally to blame.

Both of these anecdotes are illustrative of larger patterns in my experience in and out of schools. The contrast between these two sorts of personal experiences has been foundational in the way I understand race and ethnicity in education and white supremacy and cultural imperialism in schools. It has also caused internal conflict about the way I position and identify myself. If I identify as Latino, as people often perceive me, I feel like a fraud. I continue to struggle to learn Spanish and I am ignorant of specific ancestral connections with a particular

Latin American ethnicity or nationality. If I identify simply as white, I feel like I am copping out. With the surname Morales and other familial traits stereotypically associated with Latin@s, when I minimize my Latino identity, I have a hard time convincing some people that I am not simply trying to pass as Anglo. Race and ethnicity are socially constructed, but that does not mean I can simply choose my own identity. Whenever I encounter a government form, I cringe at the prospect of checking "white (not of Hispanic origin)" and erasing my grandfather and other Morales ancestors from family history. I also cringe at checking "Hispanic" and benefitting from affirmative action policies that are intended to counterbalance the benefits accorded by the white privilege that I experience (Corlett, 2007). On census forms, checking "Hispanic" as an ethnicity and "white" as race seems roughly accurate for my identity even as I understand that this is not the case for the vast majority of Latin@s (Vargas, 2015). Thus, even this choice is indicative of my white privilege.

In my life as well as my work as a teacher and researcher, I hope to work against the historical forces that led Irish immigrants and phenotypically lighter Latin@s and Creoles to seek or embrace whiteness in the US (Ignatiev, 1995; Jolivétte, 2007; Muñoz, 1989). Whether brought forth by internalized oppression or economic necessity, becoming white exchanged potential solidarity with African and Indigenous struggles against colonization and slavery for complicity with their oppressors. In an era of "racism without racists" or color-blind racism, Bonilla-Silva (2014) predicts that this historical practice will continue as racial formations and discourse in the US begin to mirror those of Latin America. Phenotype remains a salient social marker in Latin America, but even as most people acknowledge their multiracial heritage, racism is a taboo subject (Bonilla-Silva, 2014). In this sort of Latin American racial context, I would be considered white. But in the strange and unique present context of the US, it has been important for me to understand myself as both Latino and white. Specifically in the context of La Lucha High School, it is important to proudly embrace my ambiguous Latino heritage, while I also acknowledge that I experience white privilege that most of my students do not.

Educational and environmental justice.

The way I experienced my conflicted Latino and white identities in schools certainly played a role in my decision to work as a teacher and researcher in urban schools. My decision to work at La Lucha High School in particular was motivated by a set of childhood experiences that formed my beliefs about the relationships between education and social justice. When I was in second grade, a story circulated around my elementary school about how a piece of plaster fell from a crumbling classroom ceiling and struck a sixth grader in the head. To this day, I do not know if that story is true, but I do know that the dilapidated state of the old wing of the building prompted the district to make plans to close the school that year. The school served a large percentage of the students of color in the district and was home to the city's only multicultural education program. Students at Martin Luther King Elementary School came from the surrounding African-American community, a nearby trailer park inhabited by low-income white residents and refugees of violence in Cambodia, and from family housing at the University of Illinois, which was occupied mostly by international graduate students. My brothers and I, who lived in a small bungalow in the school's neighborhood, would have been among the students bussed to various schools in other parts of town were the school to be shut down. My parents, a community organizer and a preschool teacher, were active participants in a community struggle to keep the school open. As a seven-year-old, I canvassed the neighborhood with my parents, asking neighbors to sign a save-our-school (SOS) petition. Ultimately, our community's efforts resulted in a new wing to replace the dilapidated section of the school, but the struggle was about more than securing resources; it was about a community fighting to determine the destiny of its children. This was a formative experience for me.

Another formative experience came roughly a decade later. Late one cold winter night when I was a sophomore in high school, my father and I were returning home in the family car when he abruptly pulled over two blocks from home. He grabbed a video camera that was stashed between the front seats and pointed it out his window to capture billows of smoke pouring from a hospital building across the street. The building was not on fire; he was filming one of two medical waste incinerators (MWI) in the city. Both of these MWIs were located in our working class neighborhood where a slight majority of residents were African American. My father and several other neighborhood activists and residents had recently become aware of the potential harm caused by these facilities. He was documenting this late night emission to refute the hospital's claims that the incinerator was operated infrequently and only at certain scheduled times. This documentation was part of a larger community effort to force the closure of these MWIs. I remember conversations with my father where I tried to apply my knowledge from high school chemistry class to understand the impact of the incinerators on our neighborhood and health. My father gave me readings that explained how burning polyvinyl chloride (PVC) could produce polychlorinated dibenzo dioxins (PCDD or dioxins for short), a class of highly toxic and carcinogenic substances emitted by the incinerators. Besides the fear caused by the emission of dioxins, we also suspected that the incinerators were to blame for my younger brother's asthma.

This was my first exposure to the concept of environmental racism and also the first time that I remember my favorite high school class, chemistry, being relevant in my life and in my community. But despite my interest in the chemistry, I did not really participate in this struggle. I remember reluctantly attending the protest march, which became a victory celebration when the hospitals agreed to shut down the MWIs. As I write almost 20 years later, one of my sharpest memories from that morning is that when I arrived to the starting point of the march at the park across the street from our house, a revered local activist gave me a hard time about the new Air Jordan shoes I was wearing. I bought the shoes with the money and employee discount that I earned working for minimum wage at a local sporting goods store on the weekends and after school. As this respected organizer criticized the ethics and wisdom of my fashion choice, my dad nodded in agreement, having given me the same lecture countless times. I include this seemingly trivial memory to avoid romanticizing community struggle or my role in it. Win or lose, community struggles and their participants are usually wrought with contradictions. As a marginal participant in this particular effort, I was certainly no exception. While the examples of community victory that I provide here are important for my own sense of hope and philosophy about how social change occurs, our community also suffered many losses along the way. Even when community struggles are successful, forces like environmental racism or divestment of educational resources cause real damage and leave real scars on communities and people.

While I participated in some activist and organizing efforts as a high school student, these efforts did not get nearly the amount of attention that I gave to buying fashionable clothes or daydreaming of a career that would allow me to drive luxury cars. Despite my feminist and pacifist upbringing, as a teenager, I uncritically consumed violent and misogynistic media and generally was not a very nice person. Occasionally I would get kicked out of my high school classes for questioning the Eurocentric curriculum. More frequently, I would be disciplined for sleeping in class or being disruptive just for the sake of it. Still, I earned good grades and had a group of close friends and family who somehow put up with all of these character flaws. The contradictions of the racist, sexist, capitalist society in which we live manifest in our lives, habits, thoughts, identities, and even in our efforts to change that society. These contradictions can be especially sharp for (and within) young people who rail against the hypocrisies of this society and resist the adults who have become complacent therein. After all, constructing a cohesive identity is difficult amidst these contradictions and “we subsume these memories and their interpretations under the fashioning of a trajectory that we (as well as others) can construe as being one person” (Wenger, 1998, p. 88). Now as an adult who has tried to commit my personal and professional life to economic, educational, environmental justice, it would be easy to recount the story of the struggle against the MWI without this caveat. In fact, the current trajectory of my life has everything to do with why these memories are salient to me. However, it is important for me to be honest as I remind myself and inform readers that my life has not been a straight path. If I had followed my intended path towards a lucrative career in chemical engineering, maybe I would not remember that protest march turned celebration at all. Or maybe I would lament my small role in increasing environmental regulations or resentfully remember the way my father and his friend connected my consumerism with the exploitation of sweatshop labor. I do not mean to imply that we outgrow these teenage contradictions, only that it is possible to name them and either accept them or work to change ourselves. It is important for me to consider these personal contradictions as I examine the trajectories, memories, meanings, and work of my students who were the approximately the same age as I was when I reluctantly marched to celebrate the closing of the MWI in my childhood neighborhood. Being aware of my own contradictions is part of what allows me to see beyond the contradictions that trouble the young people I teach. It is part of what makes me hopeful, optimistic, and able to recognize beauty amidst ugly sets of circumstances that we often face in under-resourced schools.

Local significance.

Eight years after the MWIs were shut down, I was working as a high school science teacher in Chicago, when I heard about a local high school campus that was started as the result of a 19-day hunger strike waged by 14 community members. Members of a working class Mexican American community were protesting the negligence of their community by the Chicago Board of Education and the severe overcrowding at the only high school in the neighborhood. The story deeply resonated with me; this is the school where I wanted to teach. I was fortunate enough to be one of the first two science teachers at one of the four small schools on the campus and to teach there for seven years. When I was hired, the founding principal told me that the community had explicitly charged this small school with carrying on the values and traditions of the hunger strike, which are understood as the values of "social justice." These values were articulated during the design process of the school, which was a collaborative effort between professional educators and community members (Stovall, 2006b). This articulation of values took the form of four core beliefs: (1) truth and transparency, (2) struggle and sacrifice, (3) ownership and agency, and (4) collective and community power. For me, these core beliefs echoed the lessons I learned by watching my parents and community struggle against educational and environmental injustice. Social justice is only achieved by a collective and informed struggle of those people most harmed by the status quo to determine their own future. This struggle is waged against those who have created or perpetuated unjust circumstances for their own benefit.

In the years since the school opened, our three-person science department has wrestled with how to enact the school's four core beliefs in science classrooms. We have had dozens of meetings with representatives from community organizations, including an organization dedicated to fighting for environmental justice. We have listened to parents and students about their concerns and aspirations. But we have never had the capacity to develop a formal mechanism by which to take them into consideration. Nor have we had the opportunity to document our work in a way that holds us accountable to the community or allows other science educators to learn from our mistakes and successes. I will never forget the student who boldly told me on the first day of my first class at La Lucha High School, "I'm sick of all this social justice shit!" So even as we have taken "the present, existential, concrete situation, reflecting the aspirations of the people" in the community seriously (Freire, 1970/2001, p. 75), those efforts are not always viewed by the young people as reflecting their point of view.

This study is, in part, an attempt to do better in that respect. It is an attempt to analyze our informal attempts to be responsive to the community, so that we can move forward with a deeper understanding of student, parent, and community priorities for *their* science education. As a teacher, I have the responsibility and opportunity to improve my practice, inform the work of my department, and pursue the lofty ideals set forth by the community. As a researcher, I have the responsibility and opportunity to address the noted under-theorization and inadequate definition of "social justice" in the science education literature (Rivera Maulucci, 2012). This study aims to grapple with the complexities and contradictions of science pedagogy that prioritizes educational, social, and environmental justice above other possible goals.

Overview of Chapters

The next chapter presents justice-centered science pedagogy as a theoretical framework that is built from the traditions of critical pedagogy and culturally relevant pedagogy and well suited to guide this study. A review of recent science education literature informs this framework and also demonstrates the need to further explore the applicability of critical and culturally relevant pedagogies in science education. The third chapter describes the methods for this study as teacher research that applies the extended case method retrospectively to study an Advanced Placement chemistry class that I taught at La Lucha High School. An embedded single case study design, which considers curricular units as embedded cases, is used to organize data that include student work artifacts, interviews with students and other stakeholders, and my own archival records. Chapter III also provides descriptions of the case, the context, and the participants who include nine students and three other stakeholders. Chapter IV begins with a modification of the embedded case design that emerged from the initial data analysis. Then I provide an in-depth analysis of data from the soil project, one of the embedded cases that is particularly relevant to justice-centered science pedagogy. Chapter V focuses on a second embedded case, the aspirin unit. Together chapters IV and V describe examples of "problem-posing science education," which takes a Freirean approach to curriculum development in an attempt to braid together Ladson-Billings (1995) three criteria for culturally relevant pedagogy: academic achievement, cultural competence, and critical consciousness. Chapter VI introduces the concept of "injected relevance" through an analysis of the data from two more traditional chemistry units: stoichiometry and chemical equilibrium. Chapter VI also introduces three orientations to science exhibited by students in this study that have implications for how they experienced the curriculum and how they view the relationship between science and social change, including their role in both. Chapter VII departs from the curricular focus to examine teaching practices, classroom structures, and routines that emerged from the data as important components of justice-centered science pedagogy in this particular context. In the final chapter, I reconstruct the framework that is presented in Chapter II in order to identify the implications of this study for science teachers, teacher educators, and educational researchers. I also draw from my findings to make suggestions for the science department at La Lucha High School.

Chapter II: Justice-Centered Science Pedagogy

Beginning with an analysis of schools as reproducers of racial oppression and social inequality is important to provide historical context for this study. However, it is important to move "beyond structural determinism" not only to recognize that people within schools and communities have agency to resist this function of schools, but also that schools can be places of possibility, resistance, and transformation even within this troubling context (Duncan-Andrade & Morrell, 2008, p. 10). In a recent book chapter, Akom, Scott, and Shah (2013) introduce a theory of youth resistance called "structural resistance and agency" (SRA). Their theory highlights the possibilities that can be created by embracing youth resistance to racist school structures alongside the opportunities that STEM education presents for sustainable development within a context of eco-apartheid (environmental racism). Akom, Scott, and Shah identify culturally and community responsive STEM pedagogy as an important component of such efforts. Unfortunately the science education literature does not adequately define the criteria or possibilities for this sort of pedagogy in secondary science classrooms. There is a need for more concrete examples and empirical analyses of secondary science teaching that grapples with issues of social justice. Justice-centered science pedagogy is presented as a theoretical framework that builds on the related traditions of critical and culturally relevant pedagogy along with applicable work in science education to consider the potential roles of science education in broader struggles for social justice.

Science education as a catalyst for social change?

Once a politically charged term, "social justice" has become common in educational research and in the mission statements of various educational institutions. Unfortunately this increase in use may be the result of a decrease in potency. “Social justice” is too often used without being defined or adequately theorized, which can render it virtually meaningless (Stovall & Morales-Doyle, 2010). Nowhere is this truer than in the science education literature where social justice now appears more frequently, but is still rarely dealt with in a substantive manner (Rivera Maulucci, 2012). In an era where neoliberalism co-opts previously radical terms like social justice, science educators must be clear about our use of this term, which requires theorizing underlying “constructs like freedom, democracy, and autonomy” (Tobin, 2011, p. 140).

La Lucha High School, the context for this study, defines social justice according to four core beliefs, which emerged from the design process that followed the hunger strike that founded the school. These core beliefs (truth and transparency, struggle and sacrifice, ownership and agency, and collective and community power) speak to underlying constructs of social justice. For example, ownership and agency is described as follows:

> We will take responsibility as agents and catalysts of change to expose the truth about the functions of power, work (unite) to interrupt their operations, and operate as producers of power to meet the needs of the community

The “catalyst for change” metaphor that is used in this description and in the title of this manuscript is common among educators and others involved in efforts to organize for a more just society. My background in chemistry compels me to refine and elaborate this metaphor in a way that extends its usefulness in theorizing social justice in science education while also maintaining fidelity with respect to the chemical function of a catalyst. In its common usage, “catalyst for change” refers to somebody who activates or speeds up a process for social change.

A chemical catalyst does indeed speed up a reaction by lowering the activation energy required. But the metaphor can be extended to consider that a catalyst operates in this way by providing an alternate mechanism by which the reaction occurs. This alternate mechanism or pathway also allows the reaction to proceed under less harsh conditions and provides for greater selectivity in reactions with multiple possible products.

Rather than conceiving of people as catalysts for change, Justice-Centered Science Pedagogy builds on the traditions of culturally relevant and critical pedagogies to suggest that an alternate approach to science education may provide a mechanism that lowers the activation energy required for social transformation. This alternate approach to science education must support the development of critical consciousness in order to facilitate social change under less harsh conditions. Justice-centered pedagogy defines critical consciousness as understandings that seek to dismantle white supremacy, capitalism, and patriarchy as totalizing hegemonic forces (Stovall, 2006a). In a school science setting, this includes disrupting Eurocentric and androcentric curricula (Brown and Mutegi, 2010) and the assumption that the primary role of science education is the development of the STEM workforce (Obama, 2011).

In order to fit the criteria of the extended catalyst metaphor, science education as a catalyst for social change must also support greater selectivity with respect to the products or outcomes of this social change. This selectivity is conceived of as supporting communities that have been disenfranchised and dispossessed by oppressive forces to construct a more just and sustainable future. Justice-centered science pedagogy works in opposition to traditional schooling and requires providing rich educational opportunities for students from marginalized communities who wish to pursue STEM pathways and also for those students who do not. In a world wrought with complex socio-scientific issues (SSI) and ever-changing technology, communities that have been historically disenfranchised and dispossessed will have little say in their own future (or our collective future) without scientifically literate community members *and* homegrown experts. The former are necessary for democratic decision-making and mobilizing people power when the community is faced with an SSI. The latter must understand the strengths and struggles of the community in order to leverage their technical expertise in service of public and environmental health or sustainable development. Science education as catalyst for social change must support students, regardless of the individual path they choose, to achieve academically. But it must also support students in maintaining or developing cultural competence in order to remain grounded members of their communities as they struggle alongside their families and neighbors to construct a more just and sustainable future. This implies learning that includes, but goes beyond, proficiency with respect to various learning standards. To develop critical consciousness, students must have opportunities to critique and produce (not just consume or appreciate) scientific knowledge.

Justice-centered science pedagogy thus combines and builds on previous work that applies the criteria for culturally relevant pedagogy to science education with work that suggests a Freirean approach to science curriculum and a transformative view of teaching and learning (Dos Santos, 2009; Mensah, 2011; Mutegi, 2011; Rodriguez, 1998). Relying on the dictionary definition of pedagogy as “the art, science, or profession of teaching” (Merriam-Webster.com, 2015), justice-centered science pedagogy encompasses curriculum, teaching practices, and classroom structures. In order to enact science education as a catalyst for social change “we must create curricula with community members that speak to local political, social, and economic conditions, while developing critical academic skills that equip youth to create change.” (Pulido, Cortez, Aviles de Bradley, Miglietta, & Stovall, 2013, p. 85). Through structured engagement

(Yang, 2009) with this sort of curricula, teachers and youth develop as transformative intellectuals (Morrell, 2008; Romero, 2014). Justice-centered science pedagogy borrows the term transformative intellectuals from critical pedagogues who have extended Gramsci's (1971/2014) concept of the organic intellectual, a thinker who remains grounded in the culture and interests of his or her social class. A transformative intellectual in justice-centered science pedagogy builds on community strengths and leverages scientific knowledge to struggle against injustice while also constructing new possibilities for just and sustainable communities. The remainder of this chapter draws on the traditions of culturally relevant and critical pedagogies as they apply to recent science education literature to flesh out justice-centered science pedagogy. The focus of this framework is on teaching rather than learning, still as Freire (1998) asserts, "there is no teaching without learning" or in other words "to teach is not *to transfer knowledge* but to create the possibilities for the construction or production of knowledge" (p. 29-30, emphasis in original). My analysis here applies socio-transformative constructivism (sTc) as a theory of science teaching and learning that is well aligned with justice-centered science pedagogy to consider whether such opportunities were created (Rodriguez, 1998).

Two related transformative pedagogies

Culturally relevant pedagogy and critical pedagogy are related traditions that emphasize teaching as a means to disrupt the historical function of schools as producers of social inequality. In this section, I draw from both classic and recent literature in these traditions to define their tenets, including their significant overlap and instances where their emphases are different. Both culturally relevant and critical pedagogies share a commitment to working with students, their families, and their communities to develop a critique of the status quo in order to inform and create social change. While issues of culture, social consciousness, and social change are usually associated with social studies or literacy education, recent trends in the science education literature indicate that science educators can no longer be silent on these topics. For example, there has been increased emphasis in science education on affirming and building upon the strengths and cultures of students (Brown, 2005; Calabrese Barton & Tan, 2009; Elmesky & Tobin, 2005), which is a central tenet of both of these pedagogical traditions. Culturally relevant and critical pedagogies reject deficit notions of students and also mechanistic approaches to teaching. Instead, teachers in these traditions view students and their cultures and communities as beautiful and powerful. In both traditions, teaching is driven by principles of love and caring and informed by critical reflection and dialogue, notions that have also received more attention in recent science education literature (Emdin, 2010a; Parsons, 2005; Tobin & Roth, 2005).

Three criteria for culturally relevant pedagogy.

Gloria Ladson-Billings (1994, 1995) coined the term, "culturally relevant pedagogy," to describe the work of effective teachers of African American students. It is rooted in what Theresa Perry (2003) describes as the "indigenous African American philosophy in education" (p. 12). This philosophy is inextricably connected with the African American struggle for freedom. Culturally relevant pedagogy is aligned with the idea of "education for liberation" (Payne & Sills Strickland, 2008) that is echoed in the work of numerous African American scholars (DuBois, 2001; Morrell, 2008; Woodson, 1933/2006). In this study, I rely on Ladson-Billings' concise definition of culturally relevant pedagogy as "rest[ing] on three criteria or propositions: (a) students must experience academic success; (b) students must develop and/or maintain cultural competence; and (c) students must develop a critical consciousness through which they challenge the status quo of the current social order" (1995, p. 160). The third criterion, critical consciousness, sets culturally relevant pedagogy apart from other frameworks that consider the role of culture in learning. In this way, Ladson-Billings (1995, 1997) points out that culturally relevant pedagogy has much in common with critical pedagogy, which most scholars trace to Paulo Freire. She notes that Freire's literacy work in northeast Brazil was not unlike the work done in African American freedom schools in the segregated South. In his prolific work, Freire emphasizes *conscientização* (best translated as conscientization), which aligns well with Ladson-Billings' third criterion.

The praxis of critical pedagogy.

In his writing, Freire (1970/2001) stresses praxis, "the action and reflection of men and women upon their world in order to transform it" (p. 79). By focusing on praxis, Freire conceives of social transformation as the ultimate goal of education. This stands in opposition to approaches that focus on schooling as a way to transmit a canon of accepted knowledge or as the narrow development of technical skills associated with economic development (Freire & Macedo, 1987; McLaren, 1988). Freire's problem-posing education begins with "generative themes," which are identified by a process whereby educators and students "co-investigate" reality. Generative themes thus represent central issues that emerge from the material conditions and immediate concerns of the students and are the point of departure for curriculum development in critical pedagogy (Freire, 1970/2001; O'Cadiz, Wong, & Torres, 1998).

Problem-posing education is different from "problem-based learning," which was developed by medical educators and has been extended to other school contexts, including secondary science education (Barrows, 1986; Hung, Jonasssen, & Liu, 2008). Both problem-posing education and problem-based learning situate content and skills within authentic "real world problems." But problem-posing education differs from problem-based learning in that it is explicitly critical and political. In problem-posing education, the problems are not merely technical in nature nor can they be understood or addressed apart from understanding and addressing issues of oppression, domination, and exploitation. In a problem-posing approach, educators use the generative themes to organize curriculum that “re-presents” these themes to students as problems for students and teachers to address together. Addressing these problems requires both learning and taking some sort of action. Reflecting on these actions is also essential in the praxis of critical pedagogy.

Both culturally relevant and critical pedagogies emphasize the importance of educators developing deep understandings of local contexts and community priorities. In the opening chapter of her germinal book on culturally relevant pedagogy, *The Dreamkeepers,* Ladson-Billings (1994) writes about her own positive experience in schools where most of the teachers and most of the students were African American. She fondly remembers the familiarity of her teachers, most of who lived in her community. “Most importantly, the teachers knew our families and had a sense of their dreams and aspirations for us” (p. 7). Ladson-Billings identifies an understanding of families’ goals for their children as the most important aspect of the familiarity that existed between community and teachers. Freire also emphasized the importance of the relationships between schools and communities in his work. For Freire, parent and community voice are crucial in determining the destiny of their schools, while schools are also central to marginalized communities’ efforts to develop and transform (Darder, 2002; Freire, 1993). My commitment to understanding the priorities of students, parents, and community members emerges from these pedagogical traditions. Similar commitments can be found in recent science education literature (Aikenhead et al., 2006; Bang, Medin, Washinawatok, & Chapman, 2010).

Political clarity about multiple forms of oppression.

Despite being locally grounded and context specific, critical pedagogy also emphasizes developing an understanding of the larger historical, social, and political contexts that shape local realities (Cammarota, 2011; Kincheloe, Slattery, & Steinberg, 2000). Similarly, Ladson-Billings (1995) notes that she developed the culturally relevant pedagogy framework, in part, to address the lack of larger contextual considerations in previous theories that linked learning and culture. Teachers must develop deep understandings of these larger contexts in order to avoid inadvertently reinforcing the values, beliefs, and expectations of the dominant culture and class (Darder, 2002). Critical pedagogues often refer to this as political clarity, which is the ability to see the interconnections between the injustices we encounter or observe in everyday life and the larger political forces from which they arise (Freire, 1998; Gutstein, 2012; Macedo, 1993). Freire stresses that political clarity cannot be achieved only by studying political theory, but also cannot be developed through a superficial interpretation of everyday occurrences. It must be developed through praxis (Freire & Macedo, 1987).

Critical pedagogy in general and Freire's work in particular has been criticized for lacking political clarity with respect to issues of race and gender (Haymes, 2002; hooks, 1994; Ladson-Billings, 1997). In fact, Ladson-Billings identifies culturally relevant pedagogy as filling a gap with respect to the role of race in the work of scholars who identify themselves as students of Freire (Ladson-Billings, 1994, p. 16-17). In her feminist critique of Freire's work, bell hooks (1994, p. 49) emphasizes that Freire's blind spots should not prevent us from learning from his insights. In that spirit, justice-centered science pedagogy leans heavily on Freire's work while also following other critical pedagogues who emphasize the centrality of race and racism and gender and sexism alongside the economic exploitation of capitalism in structuring society and schools (Cammarota & Romero, 2014; hooks, 1994; Parker & Stovall, 2004; Stovall, 2006a). Even in the foreword to Freire's (1998) *Pedagogy of Freedom*, Macedo writes about the importance of political clarity as it pertains to understanding white supremacy. Political clarity with respect to white supremacy and patriarchy is especially important for science educators given that science and scientists often claim neutrality and objectivity even as their work is used to justify racism and sexism (Brown & Mutegi, 2010; Gill & Levidow, 1987; Harding, 2006).

Pedagogies of hope.

For both culturally relevant and critical pedagogies, understanding oppression and injustice is necessary but insufficient. Misguided critics of these traditions (like those who have opposed ethnic studies in Tucson, Arizona) suggest that teaching about oppression leads students towards feelings of resentment and hatred (Cammarota & Romero, 2014). In contrast, the most visible proponents of these traditions have always emphasized the way good teaching inspires hope for students and teachers alike (Freire, 2006; Ladson-Billings, 1994). In this tradition, Duncan-Andrade (2009) distinguishes between the "critical" hope inspired by critical pedagogy from false hope peddled by dominant narratives of schooling. Critical hope has three components: material hope, Socratic hope, and audacious hope. All three of these components of critical hope emphasize teachers acting in solidarity with their students to address the forces which cause unjust human suffering in marginalized communities.

Pedagogies of access, dissent and liberation.

Justice-centered science pedagogy draws heavily from both culturally relevant pedagogy and critical pedagogy because of their varied emphases. In the section that follows, my analysis of the concept of cultural relevance as it appears in the science education literature highlights the exclusion of the criteria of critical consciousness from this work. By focusing on the praxis of social transformation, critical pedagogy prevents the tendency in science education to exclude this concept by placing conscientization at the center of the educative process. Conversely, while critical pedagogues clearly value content teaching and skill development, their emphasis on social transformation has led to their work been frequently misunderstood as rejecting these aspects of traditional schooling (Darder, 2002). By explicitly foregrounding academic achievement, culturally relevant pedagogy avoids such misinterpretation and highlights the importance of equipping students to navigate mainstream institutions.

As a science educator, I have learned a great deal from educators with other content area backgrounds who have examined their practice using the tenets of both critical and culturally relevant pedagogies. For example Ernest Morrell's (2008) work draws on both traditions to articulate "pedagogies of access, dissent, and liberation," which provide students with skills and opportunities to access dominant institutions while also developing the ability to critique and ultimately transform those institutions. Together Duncan-Andrade and Morrell (2008) have articulated a grounded theory of practice by examining their own efforts to enact the tenets of critical pedagogy in English classrooms and extracurricular settings in urban California contexts. They summarize the work of critical pedagogues who have built on Freire's work, but also of others who are not usually associated with critical pedagogy, to conclude that: "Although differences exist in their analysis, these critical thinkers are united in their belief that any genuine pedagogical practice demands a commitment to social transformation in solidarity within subordinated and marginalized groups" (p. 23). For Duncan-Andrade and Morrell, this solidarity necessarily requires that their students achieve academically and develop their social identities in a way that is consistent with Ladson-Billings' first two criteria for culturally relevant pedagogy.

Eric Gutstein's (2006) work in mathematics education draws heavily from both traditions and thus emphasizes achievement, developing positive social identities, and critical consciousness through two sets of pedagogical goals, one focused on social justice and the other on mathematics. Gutstein differentiates between community, classical, and critical knowledge to describe the knowledge that resides in students' communities, the knowledge valued by content standards, and the knowledge needed to critique unjust social conditions, respectively. By valuing all three equally and striving to build on community knowledge to develop classical and critical knowledge, Gutstein captures the tenets of both culturally relevant and critical pedagogies. Gutstein's (2012) practitioner research project in a yearlong secondary school mathematics for social justice course explores the possibilities and problems associated with using generative themes as a starting point for this pedagogical process. This work emphasizes the complexities and interconnections with respect to race, gender, and class that arise from this approach to teaching.

My searches of the literature did not find analogous studies of experienced educators enacting critical and culturally relevant pedagogies in science education. This study extends the work of critical pedagogues cited above into an urban US secondary science classroom. As such, it provides a much-needed concrete example to the literature that applies the tenets of critical pedagogy to theorize about science education in service of social transformation. Still the contributions of this study are not simply to provide a science analog to Duncan-Andrade and Morrell's work in English education or Gutstein's work in mathematics education. By focusing on curriculum, teaching practices, and student responses and reflections from a retrospective point of view, this case study contributes to larger bodies of research dealing with critical and culturally relevant pedagogies by linking students' orientations and experiences in college with their experiences with justice-centered pedagogy in high school. It also extends the rich body of literature on the role of culture in science education by examining culturally relevant pedagogy through all three of Ladson-Billings original criteria. In order to further situate these contributions, the remainder of this chapter examines related bodies of literature in science education to make the case that justice-centered science pedagogy addresses the under-exploration of culturally relevant pedagogy and critical pedagogy in our field.

What is “cultural relevance” in science education?

The extension of the catalyst for change metaphor that I used to introduce justice-centered science pedagogy draws on the three criteria for culturally relevant pedagogy originally proposed by Gloria Ladson-Billings (1995): academic success, cultural competence, and critical consciousness. Felicia Moore Mensah (2011) recently re-articulated Ladson-Billings’ original case for culturally relevant pedagogy specifically in the realm of science education. Her study of pre-service teachers’ development of a science unit about environmental racism in a New York City elementary school stands out as one of the few science education studies to address these three criteria together. Other recent literature implies that the role of culturally relevant pedagogy in science education is still unclear. In two recent responses to studies that were published in the Journal of Cultural Studies of Science Education, culturally relevant pedagogy was suggested as potentially more insightful than those frameworks employed by the original studies. Both of these studies involved experienced science educators teaching high school classes with African American students. In his response to the critical physics agency framework developed by Basu and Calabrese Barton (2009), Bryan Brown (2009) suggested that culturally relevant pedagogy may have worked to explain some of the phenomena that are described in the original study. Brown thus questions the need for developing a new framework to describe teaching that could be well understood through culturally relevant pedagogy. Similarly, in response to Yerrick and Johnson's (2011) article ‘‘Negotiating White Science in Rural Black America: A Case for Navigating the Landscape of Teacher Knowledge Domains," Bettez and her colleagues (2011) suggest that the authors did not sufficiently employ the critical race theory lens which helped to frame the study. They argue that culturally relevant pedagogy would have been a better fit for analyzing Yerrick's teaching. Rather than belaboring the particulars of these two debates, I am concerned that they serve, along with the relative lack of studies of culturally relevant pedagogy in science education, to suggest that we have not fully explored the usefulness of this framework in our field.

Aikenhead (2006) provides more evidence of this uncertainty. He claims "cultural relevance precipitates a long-standing [curriculum] policy dilemma for science educators" (p. 47), but he does not reference Ladson-Billings' culturally relevant pedagogy. Instead he argues that the idea of "cultural relevance" should be understood primarily in terms the goals of the science curriculum with respect to students' culture and the culture of Western science. He argues that for most students, from any cultural background, the worldviews of Western science are not congruent with their own worldviews. He advocates that science class should "enculturate" these students into their local, national, and global communities while learning to "deal effectively with hegemonic Western science and technology" (p. 112). Aikenhead's notion that science class should help students to operate in these cultural contexts is consistent with Ladson-Billings' assertion that "teachers with culturally relevant practices help students make connections between their community, national, and global identities" (1994, p. 49). In this way, Aikenhead's notion of cultural relevance is aligned with Ladson-Billings' criterion of maintaining cultural competence. Both scholars prioritize developing the ability of students to participate in the communities from which they come while also considering the relationship between their community and larger national and global contexts. But by including the development of critical consciousness as a criterion for culturally relevant pedagogy, Ladson-Billings' culturally relevant pedagogy pushes the notion of cultural relevance further than Aikenhead. Ladson-Billings' (1995) insists, "Students must develop a broader sociopolitical consciousness that allows them to critique the cultural norms, values, mores, and institutions that produce and maintain social inequities" (p. 162). Justice-centered science pedagogy attempts to clarify the meaning of cultural relevance in science education by extending Aikenhead's conception to include all three of Ladson-Billings' criteria.

Youth popular culture and science education.

Whereas most of the literature that examines culture in science education deals with the culture of Western science vis-a-vis the ethnic culture of students' families, some scholars have identified hip-hop culture as central to the lives and experiences of many urban youth (Elmesky, 2011; Emdin, 2010b; Varelas, Becker, Luster, & Wenzel, 2002). Christopher Emdin's work deserves attention for considering hip-hop culture holistically, not just as rap music, or even as a set of practices or activities, but also a set of shared understandings. Emdin (2010a) describes hip-hop culture as a productive response to urban marginalization and oppression. This holistic and critical view of hip-hop culture allows Emdin to consider the ways that the culture of hip-hop is marginalized by the culture of school science and also how these two cultures can align to support student learning. He attributes the widespread student disengagement in science class in two seemingly different New York City high schools to a lack of attention and respect for students' shared affiliation with hip-hop culture.

Extending the concept of culture in education to include youth popular culture generally and hip-hop culture specifically has been advocated in both critical and culturally relevant pedagogies (Duncan-Andrade, 2004; Ladson-Billings, 1995; Stovall, 2006c). Emdin's work is supported by these authors who validate hip-hop as an expression rooted in resistance to marginalization and oppression. They also agree that hip-hop culture is worthy of intellectual examination and can be an excellent bridge to more canonical content. However, unlike these scholars from other disciplinary backgrounds, Emdin's work is more aligned with Aikenhead's view of cultural relevance in that he does not emphasize an explicit intention to cultivate critical consciousness. A more critical approach would aim to capitalize on the "resistant capital" inherent in hip-hop culture to create opportunities for students to learn science while also mobilizing what they learn to challenge oppression (Akom et al., 2013; Yosso, 2005). Still by emphasizing that youth culture and worldviews are often different (and sometimes more critical) than those of their parents or community elders, Emdin highlights the importance of youth voice in considerations of culture in science education. He identifies "co-generative dialogues" as a concrete strategy to bring youth voice into science classrooms. Co-generative dialogues are conversations where students and teachers participate as equals in conversations about improving instruction (Tobin & Roth, 2005). As such, co-generative dialogues are a teaching practice that are well-aligned with justice-centered science pedagogy to affirm the importance of youth voice as a component of culturally relevant pedagogy in secondary science classrooms.

Developing scientific literacy and expertise in marginalized communities.

Ladson-Billings' criterion of academic achievement is complicated in science education by the long-standing tension between "pipeline" and "humanistic" approaches discussed in Chapter I. In other words, when considering academic achievement in science, do we prioritize the development of scientific literacy and success in academic institutions in general or do we privilege achievement within the STEM pipeline in particular? Justice-centered science pedagogy affirms that academic achievement must include both of these forms of access, but also rails against uncritical forms of scientific literacy and assimilationist forms of access to the STEM pipeline (Calabrese Barton, 2003; Roth & Calabrese Barton, 2004). Aikenhead (2006) argues that because the pipeline approach has attempted to enculturate all students into specific scientific disciplines, it causes students to experience school science as forced cultural assimilation. For Aboriginal students in his Canadian context, Aikenhead characterizes this as a colonizing approach to science education. This argument can be extended to African Americans and Latin@s in US settings for science educators who understand the circumstances of these groups as characterized by colonization (Martínez & Antrop-González, 2013; Mutegi, 2011). As an alternative, Aikenhead (2006, p. 112) advocates "culturally responsive enculturation" into specific science disciplines for only the small percentage of students from any community for whom a Western science worldview resonates with their own. He quotes from O'Loughlin to elaborate that this means that students learn to "master and critique scientific ways of knowing without, in the process, sacrificing their own personally and culturally constructed ways of knowing" (O'Loughlin as cited in Aikenhead, 2006, p. 112).

Roth and Lee (2004) use their experience co-teaching seventh grade science classes through a focus on issues in the local watershed to develop a collectivist conception of scientific literacy that includes three propositions: (1) scientific literacy is a property of a collective group of people rather than of individuals (2) scientific knowledge should be just one of many considerations in community decision-making processes, and (3) students should learn scientific literacy by participating in their communities. Roth and Lee's conceptualization of scientific literacy aligns with some of the principles of culturally relevant and critical pedagogies. Consistent with the tenets of critical pedagogy, the curriculum is derived from the immediate concerns of the community and students are encouraged to engage in praxis by learning, taking action, and reflecting on their actions. By valuing the activities and knowledge of adults in the community, including the First Nations leaders in the particular context of this study, this model is also likely to encourage cultural competence and thus fulfill one of the components of culturally relevant pedagogy.

The notion that scientific literacy is a collective rather than an individual property is well suited for developing the capacity of communities to use science in their own interests, as documented in Corburn's (2005) work which is discussed below. However, within school systems that place great value on individual assessments and individual notions of achievement, this model could lead to problematic outcomes. What is troubling about this notion in Roth and Lee's article is their observation that "particularly girls and indigenous students felt disenfranchised by [data analyses and activities that focused on mathematical representations]" (p. 272). They thus allow several students to opt out of these activities in favor of generating film, narratives, photographs, and interviews. Roth and Lee (p. 279) defend this choice by arguing that to force these students to participate in the activities as originally planned would have been "cognitive imperialism" or education that forces students to assimilate by thinking like a Western scientist. Certainly, teachers could unintentionally enact a colonizing pedagogy in this scenario. Also, allowing students to choose the means by which they demonstrate their knowledge can be a very effective teaching practice. However there is a tension here between critiquing the androcentric and Eurocentric nature of Western science and simply reifying racist and sexist stereotypes of women and First Nations students as averse to mathematical reasoning.

Furthermore, in most North American school contexts, this aspect of Roth and Lee's pedagogy would be likely to leave some students – namely female and non-white students, given their analysis – underprepared for academic achievement. As problematic as these school contexts may be, it is an injustice to sidestep our responsibility as teachers to prepare students to navigate institutions that are extremely impactful in their lives. Delpit (2006) has criticized progressive educators for having low expectations for "other people's children." She argues that well-meaning approaches that encourage students to "find their voice" and focus on process over product ultimately disserve students of color in a school system that judges them by the extent to which their intellectual products (school assignments) adhere to a well-defined set of rules and norms. She emphasizes the development of skills, not in isolation or to the detriment of critical thinking, but within meaningful contexts that also develop students' capacity for critical analysis. By denying Indigenous and female students opportunities to develop the skills required to access to the "culture of power" (Delpit, 2006), it is questionable whether the teaching practices described by Roth and Lee avoid or reinforce the colonial relationship between Western science and marginalized students.

Megan Bang and her colleagues (Bang & Medin, 2010; Bang et al., 2010; Bang et al., 2013) take a different approach to negotiating the disconnect between Western and Native American ways of knowing. Bang and her colleagues found the discord that their Native American students experienced in learning science was the result of a lack of connections built between the different contexts where they learn science (e.g. school and community) rather than a complete disagreement between these different ways of understanding nature. Bang, Medin, Washinawatok, and Chapman (2010) describe a "community-based design" (CBD) process whereby Native American community members and tribal elders worked with mostly Native

American science educators to design and teach a culture-based science curriculum. Their article details how they formed an equitable partnership between the Menominee tribe of Wisconsin, the American Indian Center (AIC) of Chicago, Northwestern University, and the science education research organization TERC to enact participatory action research (PAR) that included CBD. The CBD teams focused on the places in the curriculum where there was either noticeable discord or harmony between Native ways of knowing and Western science to make the most of "third spaces," or opportunities for cultural hybridity that support student learning (Bhabha, 1994; Gutiérrez, Baquedano-López, & Turner, 1997). Ultimately, through this project, community members were able to shift from surface-level science-culture connections to using culture as a starting point around which to organize science curriculum. "The curricula were relationally-driven, place-based, and problem-based, involving locally meaningful interventions focused on ecosystems" (Bang et al., 2010, p. 575). Students saw increased standardized test performance and began to have a more complex view of science. Finally, participation in this project inspired various Native American participants on the CBD and PAR teams to seek further formal education. They pursued additional degrees with the explicit goals of contributing to tribal sovereignty and self-determination. Thus, by emphasizing community self-determination and seeking coherence between home and school conceptions of science, this program encouraged students to navigate potentially problematic educational settings in order to contribute to tribal sovereignty.

Rather than viewing Western science learning standards and place-based education as irreconcilable, Bang and colleagues found ways to make meaningful connections between the two. Their results clearly speak to the first two criteria for culturally relevant pedagogy: academic achievement and cultural competence. While the development of critical consciousness was not an explicit goal of this project as reported in these articles, since pursuing tribal sovereignty is part of a legacy of hundreds of years of resistance to colonial oppression, this project arguably addresses all three criteria for culturally relevant pedagogy and more directly confronts the cognitive imperialism that Roth and Lee sought to avoid.

In claiming that "decolonization is not a metaphor," Tuck and Yang (2012, 2014) push educators who seek to resist the colonizing function of US schools to consider whether their practices are aligned with repairing the actual harms caused by settler colonialism in their local contexts. Tuck and Yang note that decolonization cannot be generalized because it is always local, but still should focus on the concrete abolition of all forms of slavery and the restoration of Indigenous land rights. Bang and colleagues document how their work facilitates Indigenous peoples' control of over their own land-based resources, including the American Indian Center's use of urban land to cultivate medicinal plants and increasing the control that the Menominee tribe of Wisconsin exercises over their forestry industry. In this way, Bang and her colleagues provide examples of science education that concretely contributes to decolonization.

The work of Bang and her colleagues is unique in my searches of the literature in the way that it prioritizes the autonomy and culture of the community in science education. But this work fits a larger trend in the literature in applying the concept of third space (Bhabha, 1994; Gutiérrez et al., 1997) to describe the hybridity that occurs when students mix their home cultures with the dominant culture of school (see for example Calabrese Barton, Tan, & Rivet, 2008 and Moje et al., 2004). One of the implications for teaching practice to emerge from this work is that science teachers should encourage students to engage in hybridity. However, it is worth noting that Richardson Bruna (2009) has criticized the application of third space in much of the science education literature as having become teacher-centered and losing touch with the radical politics that Homi Bhabha (1994) originally intended in the concept.

Learning science as border crossing.

Jegede and Aikenhead (1999) introduce a different metaphor for hybridity in science education in borrowing the concept of learning as border crossing from critical pedagogue Giroux (1992). They conceive of learning science as requiring all students to cross cultural borders from their home culture into the culture of Western science. For students whose cultures are significantly different from that of Western science, being required to learn Western science often amounts to cultural violence. To minimize this violence, Jegede and Aikenhead suggest that teachers engage in a “cross-cultural” science education, acting as “culture brokers,” who guide students between their familiar culture and the culture of Western science. When science is taught in this manner, Jegede and Aikenhead suggest that it allows students to engage in “collateral learning.” Collateral learning describes a process by which students either compartmentalize their newly acquired Western science knowledge, avoiding conflict with previously held beliefs, or they find resolutions to conflicts between new and previously held frameworks.

Jean Aguilar-Valdez and her colleagues (2013) also use the analogy of border crossing as they draw on the work of Chicana feminist Gloria Anzaldúa to conceptualize cultural border crossings and hybridity for Latin@ students learning science. These scholars argue that Anzaldúa’s frameworks are especially useful for understanding the experiences of Latin@ students because they are based in the idea that Chicanas’ lives are characterized by the hybridity inherent in reconciling the indigenous, Spanish, and Anglo aspects of their identities and culture. For many Latin@s, it would be appropriate and important to add African to this list of hybrid identities and culture. For Latin@s, hybridity is not something that just happens in the science classroom. Aguilar-Valdez and her colleagues use several examples from their research with Latin@ students in different settings to describe the role of a successful science teacher of Latin@ students as a *nepantler@.*

A *nepantler@* science teacher is one who guides students through the *nepantla*, a Nahautl word for "in between space," and towards a reconciliation of the various aspects of their identity (indigenous, Spanish, and newly introduced Western-science). In some ways, this concept is similar to Jegede and Aikenhead's (1999) science teacher as culture broker, but Aguilar-Valdez and her colleagues describe it as a radical role. A *nepantler@* science teacher relies heavily on her or his own experience, including the pain she or he has felt in *nepantla,* and "holds back nothing to help her/his students in nepantla" (p. 831). The ultimate goal for a nepantler@ science teacher is that students travel the "path to *conocimiento,*" which is a journey towards knowledge that is never complete and implies much more than learning science. Aguilar-Valdez and her colleagues stress that this is a transformative approach and that *mestiz@ consciousness* is a form of critical consciousness that allows Latin@s to be whole rather than being fragmented by colonizing forces. In this way, their work is more aligned with critical and culturally relevant pedagogies than much of the science education literature that focuses on hybridity.

Socially transformative science learning.

The development of critical consciousness in Aguilar-Valdez and colleagues' work and in culturally relevant pedagogy implies questioning hegemony and challenging authority. If science education is to serve as a catalyst for social change, this process of conscientization must be part of students' learning in science class. Rodriguez' (1998, 2002) sociotransformative constructivism (sTc) provides a theoretical basis for understanding this sort of critical science learning that extends beyond the understanding of canonical concepts of the development of technical skills. Rodriguez extends the social constructivist approach that has become common in science education research by explicitly considering issues of power and inequality to articulate a framework for "sociotransformative constructivism." Sociotransformative constructivism (sTc) consists of four elements: the dialogic conversation, authentic activity, metacognition, and reflexivity. Through these four elements, Rodriguez emphasizes aspects of learning which encourage two concepts that are central in critical pedagogy: praxis and critical consciousness.

In sTc, students and teachers alike must reflect on issues of power, values, identity, and the sociocultural relevance of their learning. For example, the sTc concept of the dialogic conversation draws on the work of Bakhtin (1981) to emphasize that true dialogue requires more than simply understanding the literal meaning of language. Sociotransformative constructivism requires students and teachers to think about how the positionality and context of the speaker are important as people make meaning together. The sTc concept of authentic activity pushes science educators, in particular, to move beyond "hands-on, minds-on" activities to also consider the sociocultural relevance of these activities and their learning. Metacognition in Rodriguez' framework also pushes beyond typical descriptions of "thinking about thinking" to encourage teachers and learners to ask critical questions about learning that consider issues of power. For example, students should be encouraged to think about why they are learning science in a particular way and what agency they have with respect to their own learning. Finally, the sTc notion of reflexivity engages students and teachers in a critique of the production of scientific knowledge. In this way, sTc posits that science education must consider the impact of cultural and economic issues on the enterprise of science if it is to be socially transformative. For example, an sTc approach questions whose ideas matter in science, who gets positioned as a scientist, and how issues like funding and ideology impact scientific research. Rodriguez and his colleagues have applied sTc to understand the learning of pre-service or novice teachers and elementary school science learners. This study extends the application of sTc to a secondary science context as a way to understand how justice-centered science pedagogy supports students' development of critical consciousness and the maintenance of cultural competence.

A summary of the catalyst metaphor and its limits.

If science education is to act as a catalyst for social change, it must meet the three criteria for culturally relevant pedagogy, which have particular nuances in science classes. The criterion of academic achievement requires both the development of critical forms of scientific literacy and the preparation of science experts. By addressing both pipeline and humanistic concerns, science education can contribute to the ability of disenfranchised communities to determine a more just and sustainable future. The criterion of cultural competence reminds us that this ability will be negated if academic achievement is defined or accomplished by assimilation to the culture of Western science. Conceptions of culture that include students' ethnic cultures and youth popular cultures are important to enacting justice centered science pedagogy. As an approach that problematizes the culture of Western science, justice-centered science pedagogy supports students' maintenance of cultural competence and encourages students to question and critique the production of knowledge in Western science while also using it as a tool to understand and change unjust social relations.

A catalyst is distinguished from chemical reactants because it ultimately remains unchanged upon the completion of the process it facilitates. Herein lies the limit of the metaphor of science education as a catalyst for social change. Unlike a catalyst, "education is…constantly remade in the praxis" (Freire, 1970/2001, p. 84). The tenets of critical pedagogy require its practices to be reinvented in local contexts, as Freire (1978) repeatedly stressed in his letters to the leaders of the anti-colonial revolution in Guinea-Bissau. So while a catalyst is unchanged by the process it facilitates, our approaches to education should change and evolve across time and space.

Locally Responsive Science Education

Science education that is reinvented in local contexts has been described as "place-based science education" (Aikenhead, Calabrese Barton, & Chinn, 2006). Place-based science education values local ways of knowing and equips students to address local socio-scientific issues (SSI). Unfortunately, Aikenhead's (2006) review of the literature found that " *Most often canonical science content is not directly useable in science-related everyday situations*" (p. 29, emphasis in original). This reality creates tension for teachers between being responsive to the community and being accountable to standards.

This tension is amplified in many urban communities where there are numerous SSI related to the impacts of environmental racism, while at the same time schools are under immense pressure to demonstrate student proficiency with respect to learning standards. In order to inform my own navigation of this tension, I have looked to literature that deals with the interactions between local knowledge and official, professional, or expert scientific knowledge. Corburn (2005) uses several case studies in urban communities of color to document how community members mobilized their knowledge to fight for environmental justice. Corburn avoids romanticizing local knowledge. Instead he argues that rather than rejecting or replacing professional knowledge, local knowledge challenges experts to reconsider their framing of problems or their interpretation of data based on the insights of people living with the impacts of environmental racism. By seeking to develop scientific literacy and also provide access to STEM pathways, justice-centered science pedagogy seeks to build on the forms of local knowledge that Corburn studies while also increasing the representation of members from marginalized urban communities among scientific experts.

Local knowledge.

Valuing local knowledge in the way that Corburn describes is well aligned with the tenets of critical pedagogy. One of Freire's contemporaries in Latin America, Colombian scholar Orlando Fals-Borda wrote extensively about participatory action research (PAR) as an approach to enhancing local knowledge and applying it to solve problems facing oppressed communities. Fals-Borda and Mora-Osejo (2003, p. 104) argue that the creation of "endogenous paradigms rooted in our own realities" is crucial for progress in addressing the threats to survival faced by oppressed people. They argue that societies in the global South should reject Eurocentric views of science in favor of integrating understandings of Euroamerican science with local ways of knowing. For Fals-Borda and Mora-Osejo, Euroamerican frameworks alone are too closed to ancient wisdom and to the intricacies of local contexts and complexities to solve problems faced by societies in the global South.

Corburn's work demonstrates that frameworks that value local knowledge alongside Western science can also be applied to address the issues of environmental racism faced by oppressed communities within the United States. Akom's work reinforces this approach, while also extending it in two important ways. Akom (2011b) enriches previous work on PAR by inserting explicit consideration of structural racialization and African centered approaches to research to define a framework for Black Emancipatory Action Research (BEAR). Akom (2011a) also makes the connections between educational inequity and eco-apartheid explicit.

Finally, with the SRA framework that opened this chapter, Akom and colleagues (2013) suggest an approach to understanding youth resistance that aims to address these interconnected challenges together.

While the literature above is focused on the importance of local knowledge in solving problems related to environmental racism, education, and community development, it does not necessarily speak to the relationship between this work and school science curriculum. In a forum in the second issue of the journal *Cultural Studies of Science Education,* Aikenhead, Calabrese Barton, and Chinn (2006) disagreed about whether it is possible or desirable for science teachers to reconcile the top-down colonizing nature of science standards with a commitment to local knowledge and place-based science education. Tobin (2011) and Carter (2008) also express doubts as to whether national learning standards in science can be reconciled with teaching science in a way that resists neoliberalism as the hegemonic ideology of globalization. Critical pedagogue and literacy educator, Camangian (2011) insists that reconciling social justice education and standards-based curriculum is possible "so long as we practice the intellectual, cultural, and political creativity to connect our teaching with our students needs" (p. 459). Justice-centered science pedagogy looks to critical pedagogy to inspire and inform the creativity that Camangian describes.

Critical pedagogy in science education

Dimick (2012) proposes a framework informed by critical pedagogy that conceives of "teaching science for social justice" as consisting of three components of student empowerment: social, academic, and political. The social empowerment component in Dimick's framework relates to student voice and relationships in the classroom and thus echoes other visions for social justice in science education that emphasize the role of power in interpersonal relations between teacher and students and between groups of students (Calabrese Barton, 2003; Emdin, 2011). Dimick's academic empowerment echoes Ladson-Billings' (1995) insistence on academic achievement and Gutstein's (2006) conceptions of classical knowledge. Dimick's definition of political empowerment consists of students examining "structures and forces that establish and maintain power inequities" in curricular, classroom, school, and out of school contexts (p. 995). In some ways this component is not unlike Ladson-Billings' (1995) criteria of critical consciousness or Freire's (1970/2001) *conscientização*, but the extent to which this political empowerment engages an analysis of larger forces like white supremacy, capitalism, or patriarchy is unclear.

Dimick applies her student empowerment framework to analyze the practice of a fifth-year white male environmental science teacher in an urban charter school with 24 African American students in 11th and 12th grades. The teacher engages students in a project to address severe pollution issues in Green River, which is located in the school's community that Dimick identifies as "extremely impoverished and racially segregated" (p. 999). Dimick notes that students achieved some measure of social and political empowerment as they had significant voice and decision-making power in designing their own class projects. However, she also notes that these components of her framework were not fully realized as the students who were most vocal prior to this project continued to exercise the most power during the project and none of the student-led projects was actually completed. More importantly, the project fell short of achieving academic empowerment as the teacher and students alike acknowledged that virtually no science content learning occurred while working on these incomplete projects.

Dimick's study deserves credit for laying out a framework that defines what it means to "teach science for social justice" in an urban US school setting and for considering political, social, and academic components that are rarely brought together in meaningful ways in the science education literature. However, the fact that the study was unable to document significant academic empowerment highlights the need for science educators concerned with social justice to clarify the relationship between struggles for social justice and science content learning and also to document effective curricula and teaching practices that support both. Dimick explains the shortcomings of the class project on pollution in the Green River in terms of the lack of scaffolding and support for skills that students needed to complete their projects. This was related to the teacher's difficulty in determining how to move between activities that were teacher-centered and highly structured and those that were student-driven.

My reading of Dimick's study suggests that science educators also need to consider more deeply how we know what issues matter to students, their families, and their community and how to integrate those issues with the science content we are charged with teaching. Dimick writes that the teacher "recogniz[ed] the significance of the Green River to the students and the community" (p. 999), but does not mention how the teacher came to this recognition nor does she provide evidence that the river was in fact significant to students or the community. The polluted Green River may very well have been significant to the students and the community, but reflecting on how teachers come to understand this significance is an important part of negotiating the power relationships between teachers, students, and community members that Dimick identifies as important.

Also, Dimick's framework as it is applied here suggests a lack of political clarity with respect to the root causes of injustice and also the role of science or science education in addressing those causes. Dimick writes that the teacher "tried to help the students develop critical literacy in science by demonstrating the complicated nature of environmental justice" (p.

999). But this concept seems absent in the way the teacher and students spoke about their projects. In her analysis, Dimick highlights the difference between students who understood the problem of river pollution as one of individual responsibility versus collective action, which is an important tension in issues of environmental and social justice. But in discussing the reflections of the student who focused on collective action, she interprets this student's identification of the need for a new sewer system as recognizing the "root causes" of the pollution in the river. This discussion shows a lack of political clarity. Identifying the root causes of pollution would require asking why has the sewer system not been improved. Given that Dimick identifies this part of the city as "extremely impoverished and racially segregated," an environmental justice point of view would consider whether racist public policies or discriminatory practices are the root causes of this environmental problem. The absence of this line of questioning in the analysis may be traced to the fact while Dimick's description of political empowerment mentions "larger forces," she does not explicitly name forces like white supremacy or capitalism. Without naming the forces responsible for social injustices, it is difficult to construct an understanding of how scientific knowledge may be useful in ameliorating those injustices. The teacher's reflections included by Dimick allude to this difficulty as he lamented the fact that he did not "set up a framework for them to sort of use that science information or make sense or sort out the problems in the river and come up with solutions" (p. 1007). The honesty of the teacher's reflections about his practice is commendable. His reflections also point out a persistent gap in science educators' efforts to make connections between science learning and struggles for social justice.

Science education to change the world.

The context of this study is similar in some ways to the context Dimick describes, an urban US school in a segregated low-income community that faces issues associated with environmental injustice. Expanding my literature review to consider work in international contexts provides some examples of work that is more specific in naming some of the larger economic and ideological forces responsible for social inequality. Hodson (2011), Carter (2008), and Dos Santos (2009) are among a handful of scholars who have recently begun to consider the impacts of globalization and neoliberalism on science education (Bazzul, 2012; Bencze, 2008; Tobin, 2011). Hodson (2011) criticizes science education that uses examples from everyday life to motivate traditional science learning as having an underlying goal of social reproduction. He posits that if the ultimate objective is the transmission of conceptual and procedural knowledge (canonical science content), then students are implicitly learning to be compliant and accept their roles in the unjust social hierarchy. This point of view is supported by Apple's (2004) criticism of mainstream science education as falsely portraying science as conflict-free and tacitly communicating to students that conflict is always negative. Hodson also argues that this approach results in scientific literacy that primarily serves to enhance demand for consumer technologies.

Meanwhile, Carter (2008) identifies the uncritical consumption of technology as one of the consequences of the ways that globalization and its dominant ideology, neoliberalism, are changing science. She explains how increasingly, scientific knowledge is treated as a commodity and funders of science prioritize economic growth above all other possible purposes for science. So more than ever, innovations are held in secret as intellectual property. Scientists learn less from each other while public interaction with science is limited to blind trust and uncritical consumption of information and technology. Carter (2008) argues that we must address the influence of neoliberalism as we consider, science education "to what end?"

Her analysis leads Carter to conclude that in industrialized countries, the pre-professional preparation of future scientists is becoming less important as these jobs are increasingly outsourced to countries with lower wages. Given her analysis, Carter and her colleagues teach towards the goals of educating citizens who can grapple with how science is produced and who benefits or is harmed by that production. Carter values the skills and flexibility learned through a problem-based learning (PBL) approach as apposed to organizing curriculum around what she views as lengthy and increasingly obsolete conceptual standards. While the NGSS give significant attention to "science and engineering practices," "cross-cutting concepts," and "disciplinary core ideas," their breadth still leaves them vulnerable to Carter's critique of standards that resemble long lists of canonical concepts. For example, the NGSS standard titled "matter and its interactions" includes eight statements that capture practices and crosscutting concepts, but also require significant and highly specific canonical chemistry content understandings.

In contrast, Carter argues that PBL prepares students both for engagement with "real science-based problems…in their local community" and for the limited opportunities in science industry. As previously mentioned, a PBL approach does not necessarily grapple with issues of oppression and inequality. In this way, Hodson's approach is more aligned with the problem-posing education of critical pedagogy than is Carter's. Hodson's "curriculum for social activism" focuses on teaching about socio-scientific issues (SSI). He advocates science "education that is geared towards social critique and social transformation," so that students, "are prepared to be informed, critical, and active citizens who expect (and demand) to be full participants in the decision-making processes within local, regional, national, and international communities" (p. 10).

SSI as generative themes.

Brazilian science educator Dos Santos (2009) provides a framework for Freirean scientific literacy that he describes as a radical extension of the humanistic approach articulated by Aikenhead (2006). He emphasizes that the primary distinction is that a Freirean approach is overtly political and focuses on understanding and working to eradicate social domination and inequality. Dos Santos acknowledges that there are commonalities between a Freirean approach and those articulated by US science educators like Angela Calabrese Barton, Kenneth Tobin, and even some Science Technology and Society (STS) curricula. Zeidler, Sadler, Simmons, and Howes (2005) previously argued that sociocientific issues education represents a more sophisticated framework for dealing with the moral component of science education than an STS approach. By connecting SSI education with critical pedagogy, Dos Santos theorizes science education that is capable of contributing to struggles against oppression. The contribution of my study is to reify and reconstruct this theoretical application of critical pedagogy to science education through the analysis of a concrete example.

For Dos Santos, SSI are analogous to “generative words” in his reinvention of Freire’s literacy work in the context of science education. For Freire, generative words emerge from a study of the vocabulary used by his students before they achieve literacy and are used in the initial stages of reading instruction (Freire, 1974/2013). In positioning scientific literacy as analogous to “reading the word” in Freire’s work, I interpret that Dos Santos’ equation of generative words with SSI is based on an assumption that students are pre-literate with respect to scientific literacy. Thus, in his reinvention of Freire’s work for science education, SSI are the first examples used to engage students with “reading the (scientific) word.” Given the contested nature of the definition of scientific literacy (DeBoer, 2000; Roth & Calabrese Barton, 2004;

Roth & Lee, 2004), my reinvention of Dos Santos' (and by extension Freire's) work in a US science education context positions SSI as analogous to generative *themes* (rather than words). In this way, I position carefully selected SSI as similar to the use of generative themes, which Gutstein (2012) defines simply as "key social contradictions in people's lives" (p. 26). Thus in order to serve as a generative theme, an SSI would have to capture key social contradictions in students' lives as they intersect with natural or technological phenomena, the understanding of which require scientific knowledge.

This interpretation of SSI as potential generative themes is consistent with the crux of Dos Santos' framework given four caveats he articulates in comparing his approach with others that teach science through an examination of SSI. First, Dos Santos asserts that SSI must be relevant to students' lives in particular, not just to society in general. Secondly, the questions that students are encouraged to ask must focus on the social domination and inequality that relates to or results from the SSI. For Dos Santos, studying science through the critical examination of SSI is set within the context of ever-increasing economic inequality between rich and poor individuals and between rich and poor nations. Third, the process by which students and teachers engage with SSI must be dialogic. While teachers must make their point of view clear, they must also encourage students to come to their own understandings and stances. Through dialogue, both teachers and students will develop deeper understanding of the SSI, including science content knowledge. Finally, the ultimate goal must be to use these newly developed understandings to take action against the issues of oppression embedded in SSI.

Anti-racist science education.

While Dos Santos, Carter, and Hodson are more explicit than Dimick's framework about the root causes of ever-increasing social inequality, they are vulnerable to the same critiques as

Freire’s work as giving insufficient attention to race or gender. Even as Dos Santos acknowledges these criticisms of Freire’s work, he does not address them as they relate to science education or to his emphasis on examining the difference between economically rich and poor people and economically rich and poor nations. In the edited volume *Anti-Racist Science Teaching*, Gill and Levidow (1987) show how science education has traditionally operated in the interests of maintaining structural racism. This point of view is supported by Brown and Mutegi (2010) who document the ways that science has been influenced by racist ideologies and then used to reinforce notions of white supremacy in support of racist oppression. Brown and Mutegi document how the “theoretical retrofitting of scientific racism,” has worked to “scientifically” justify oppression from slavery and colonialism through current forms of educational inequality. It is within this context that Mutegi (2011) posits, “the prevailing curricular approach in science education is not likely to meet the social needs of African Americans.” He summarizes the social condition of African Americans, and people of African descent around the world, as “pervasively deficient” by which he simply means that African Americans “have more of those things that are bad and less of those things that are good… across nearly every area of human activity” (p. 304). He attributes this social condition to the colonization of African peoples, which he characterizes as shifting in form, but ongoing. For Mutegi, this colonization is characterized by the fact that people of African descent experience a lower quality of life as compared with their colonizers and also as compared with their ancestors prior to colonization.

Mutegi considers curriculum reforms that aim to achieve “science for all” as representative of the prevailing curricular approach, which he identifies as a cultural transmission model of curriculum design. He argues that this approach is inadequate and potentially harmful for African American students because the culture transmitted, that of

Western science, has worked to maintain their oppression. As an alternative to the prevailing curricular approach, Mutegi also draws on Freire's work to describe a "socially transformative" curriculum for African American students. Mutegi's socially transformative curriculum for African American students curriculum has five goals: mastery of Western science standards, critical awareness, racial awareness, conscientization, and praxis. In these five goals, the influence of critical pedagogy is apparent. But by explicitly valuing the mastery of Western science standards and the development of racial awareness, Mutegi addresses one of the common misunderstandings (Darder, 2002) and one of the common critiques of critical pedagogy mentioned above (Ladson-Billings, 1997). Also the alignment between critical pedagogy and culturally relevant pedagogy is clear in Mutegi's socially transformative science curriculum. The first goal of content mastery is comparable to the first of Ladson-Billings' criteria of academic achievement, Gutstein's classical knowledge, and Dimick's academic empowerment. Mutegi (2011) describes racial awareness as, "the degree to which African Americans understand themselves as members of a group of people of African descent with whom they share a common ancestry, history, social identification, and social condition" (p. 307). Comparing this description to the way Ladson-Billings describes cultural competence reveals a shared commitment to maintaining and building Black racial and African American ethnic identities alongside academic identities. Still there are subtle differences here. Whereas Ladson-Billings' cultural competence stresses the full integration of African American culture into the curriculum, Mutegi's racial awareness stems from his emphasis on understanding the oppression of the African diaspora. Finally, the alignment of Ladson-Billings' concept of critical consciousness and Freire's conscientization has already been established.

Mutegi illustrates his socio-transformative approach by analyzing an "innovative, reform-based" elementary school science curriculum and suggesting how his approach would modify and extend it to meet the needs of African American students. His analysis articulates five features of a socio-transformative approach for African American students: content, currency, context, critique, and conduct. Mutegi identifies the reform curriculum as fulfilling the first two features of content and currency because it values a mastery of science content and engages students in an analysis of how that content is relevant in real life contexts. He argues that the reform curriculum does not exhibit the features of context, critique, and conduct because it does not make the content specifically relevant to people of African descent, nor does it ask students to consider how the topic at hand contributes to their social oppression. Finally, Mutegi's "conduct" feature refers to students using their content knowledge to intervene in reality to ameliorate the social conditions of people of African descent. Like Dos Santos, Mutegi's work contributes substantially to our theoretical understandings of critical science pedagogies. My study concretizes and nuances socially transformative science curriculum through the analysis of a specific case.

Students and teachers as transformative intellectuals.

The analysis presented in Chapter I posits that the prevailing function of US schools has been to reproduce and justify racial and economic inequality. One of the central mechanisms by which this occurs is the way in which US schools sort students into various positions within the workforce in ways that reproduce class divisions and racial hierarchies (Bowles & Gintis, 1976/2011). This function of schools positions some students (mostly white and from middle class or wealthy families) as intellectuals while it positions others (disproportionately African American, Latin@, Native American, and working class) as manual laborers, or even as criminals (Alexander, 2012). In this school system, teachers are also denied their rightful position as intellectuals as they become gatekeepers responsible for this unethical sorting of students and bank-clerk bureaucrats who transmit the ideology that justifies it (Darder, 2002; Freire, 1970/2001). Given this analysis, justice-centered science pedagogy "turns the traditional purpose of public education on its proverbial head..." (Darder, 2002, p. 57). Indeed as a framework constructed from culturally relevant and critical pedagogy, teachers who take this approach "work in opposition to the system that employs them…In their classrooms, they practice a subversive pedagogy" (Ladson-Billings, 1994, p. 128). Justice-centered pedagogy resists the sorting function of traditional schooling by providing opportunities for young people to critique, produce, and disseminate scientific knowledge. In other words, justice-centered science pedagogy positions all young people as intellectuals capable of thinking in deep ways about science – especially those least likely to be positioned as such in traditional US schools. By enacting justice-centered science pedagogy, teachers can also reclaim their status as intellectuals (Giroux, 1988).

While his language was steeped in sexism, Gramsci argued that all humans are intellectuals who through understanding their own reality and their efforts to live by some moral code, "bring into being new modes of thought"(Gramsci, 1971/2014, p. 9). He thus criticized the fracturing of society into those who have the formal role of an intellectual and those who do not and theorized a difference between "traditional" and "organic" intellectuals. The former uphold the hegemony of the ruling class and the latter represent the class from which they originate. Developing organic intellectuals who represent the interests of the working class was part of Gramsci's vision for how social change could occur.

This Gramscian conception of the organic intellectual has been adopted by critical pedagogues working in US urban schools who conceive of working class students of color as organic intellectuals capable of leading social transformation. For example, in his analysis of a community-based research project with urban youth, Morrell (2008) posits: “Students, through their presentations and written production, revealed their changing identities as transformative intellectuals possessing the confidence and the skills to participate powerfully as researchers and as agents of change” (p. 131). Romero (2014) refers to his Chican@ studies students in Tucson, Arizona as “barriorganic” intellectuals. He echoes Morrell’s interpretation of student identity development as he describes one student’s growth: “the academic identity and proficiency that were nurtured within Blanca helped her develop her critical consciousness and her sense of organic intellectualism, which are evident through her desire to learn more and more as a as a means of advancing her community” (p. 33).

Given the pressing SSI that marginalized communities face, conceiving of students as transformative intellectuals in science disciplines or with scientific literacy becomes a source of hope not only for their communities, but also for all of society. The union of science, technology, capitalism, and colonialism caused or exacerbated modern SSI like climate change, food and water shortages, or drug resistant epidemics. This same unholy union will not provide solutions to these problems that threaten our wellbeing and survival as a species. Instead it would be wise to look to marginalized youth as the group of people most likely to lead the social change required to truly address these problems. Bang et al. (2013) suggest that science education that disrupts the modern manifestations of a legacy of white supremacy can provide “a more transformative science education experience for nondominant youth” (p. 315). They go on to argue that fostering these sorts of transformative science experiences is essential to creating new types of knowledge and viewpoints that will be required to solve the most vexing SSI we face.

Justice-centered science pedagogy is aligned with this belief in marginalized youth to be the transformative thinkers that the world desperately needs.

The literature synthesized in this chapter theorizes socially transformative science education, but does not include sufficient concrete examples to illustrate or test these theories. Critical pedagogy and culturally relevant pedagogy are traditions that rely on praxis. They are theoretical traditions constructed from the work of effective teachers in order to inform subsequent educative action. The contribution of this study is to analyze one teacher’s attempts to enact these traditions in order to theorize, illustrate, and critique science education with the goal of supporting urban youth, as they become transformative intellectuals.

Chapter III: Methods

Inequity in science education across lines of race and class is inextricably related to other forms of educational and social inequality. Recent science education literature has dealt with the complex implications of culture and identity in science classrooms. But there are few examples of science curricula or pedagogies that respond to inequity in science education, not as isolated cases of cultural mismatch, but as one component of systemic deculturalization, dispossession, and disenfranchisement. Critical and culturally relevant pedagogies provide the basis for justice-centered science pedagogy as a framework for developing and analyzing science teaching that supports struggles for environmental and social justice within and beyond the classroom.

Rather than searching for a universal approach to justice-centered science education, this study aims to examine one teacher's attempts to extend radical pedagogical traditions into a secondary chemistry class, specifically an Advanced Placement chemistry class that I taught at La Lucha High School. This examination focuses on the (1) opportunities and challenges of developing and implementing socially transformative science curriculum, (2) the teaching practices, classroom structures, and routines that supported or impeded the students' development as transformative intellectuals (3) the responses and reflections of students on their experiences with justice-centered pedagogy through their classwork and as they looked back on the class as college students.

This chapter outlines my methods, beginning with a description of this study as teacher research that applies the extended case method to conduct a retrospective study of a single class. In the second section, I provide descriptions of the context and the case study class. I also describe the reasons for selecting this particular case and consider some of the advantages and disadvantages that this choice implies. In the third section of the chapter, I describe the data sources, which fall into three categories: interview data, student-submitted artifacts, and my archival data. In this section, I also describe my approach to data analysis, which was organized according to an embedded single-case design and informed by the extended case method. I conclude the chapter with a discussion of trustworthiness by considering practitioner research validity criteria and issues of transferability, analytic generalizability, and reinvention (Anderson & Herr, 1999; Guba & Lincoln, 1982; Guba, 1981; Yin, 2009).

Teacher Research

This study is practitioner research, or more specifically teacher research. At the simplest level, this is a straightforward statement of my dual roles as classroom teacher and educational researcher. Rather than being a choice of convenience or access, selecting this approach was intentional. By utilizing teacher research, I am aligning myself with what has been called the "movement," "tradition," or "stance" of practitioner research (Cochran-Smith & Lytle, 2009). Teacher research is a suitable approach for this study because the tenets of teacher research align with my goals in three important ways. First, as discussed in previous chapters, my questions emerge from both theory and practice to challenge the goals and purposes of schooling. Secondly, this is a case study that looks for confirmations and disconfirmations of theory in a broad set of data, which includes student work, interviews with stakeholders, my personal reflections, and planning documents related to my practice. Finally, the knowledge generated by this study is not objective or universal, but instead is useful locally, is explicitly political, and is intended to contribute to equity and justice in education.

By explicitly working against the historical function of US schools and science education as reproducers of social inequality, this study takes a particular political stance. This approach is well aligned with the principles of both teacher research and critical pedagogy (Anderson &

Herr, 1999; Cochran-Smith & Lytle, 2009; Freire, 1998). Critical pedagogy emphasizes the importance, in any effective teaching practice, of understanding and responding to the local context. Practitioner-researchers from other content area backgrounds have employed case studies in order to understand the complexities of their practice as it relates to this theoretical tradition (Duncan-Andrade & Morrell, 2008; Gutstein, 2006, 2012), but analogous studies have not yet been produced in urban US school science settings. The aim of research in this genre is not universal knowledge or even a reproducible model, but rather context-specific possibilities or lessons-learned that may inform practitioners in other contexts. Several scholars have suggested that this type of knowledge is needed with respect to applying culturally relevant and critical pedagogies to science education (Aikenhead, 2006; Calabrese Barton, 2003; Dimick, 2012; Duncan-Andrade & Morrell, 2008; Hodson, 2011; Morrell, 2008).

My position as a teacher-researcher also means that I have personal knowledge of the school and the students, as well as a vested interest in the success of both. This familiarity implies both strengths and limitations, which are discussed further in the sections on data collection and analysis below. I do not shy away from the fact that I care about the students who are participants of this study. Because my project involves a retrospective look at this class, the opportunities provided to directly impact the educational experiences of the participants are limited. However, it is important for me to highlight that my relationships with the participants are characterized by care and investment rather than disinterest or objectivity. While the student participants have all graduated from high school and I no longer teach at the school, I remain in contact with many of the students and their families.

No research methods can be objective or apolitical. Still in order to avoid being dogmatic or dishonest, any researcher must constantly and critically examine her or his biases, privilege, and ideology. Interpretive research traditions seek “disciplined subjectivity,” or an examination of the incidental or accidental ways that the researcher’s point of view impacts the research (Carr & Kemmis, 1990). But teacher research pushes this notion one step further as the researcher *intentionally* intervenes in reality, thus creating the need for “reflective distance” or “critical subjectivity” (Cochran-Smith & Lytle, 2009; Herr & Anderson, 2005). This implies making one’s own agenda for change explicit while also openly interrogating the ways in which that agenda might distort the perception of reality (Carr & Kemmis, 1990). The extended case method and the criteria for practitioner research validity described below combined with a retrospective design to support my attempt to practice critical subjectivity. Throughout this study, it is my goal to make my own point of view explicit and problematic and to include it as an object of analysis.

Extended case method.

The extended case method is an ethnographic case study methodology characterized by four “extensions” (Burawoy, 1998, 2009): (1) from observer to participant, (2) across space and time, (3) from process to force, and (4) the extension of theory. First, the observer is extended to be a full participant in the research site. In conducting teacher research about curriculum that I planned and taught, this extension is unavoidable. In this way, my particular application of the extended case method is also informed by traditions of critical action research in education (Carr & Kemmis, 1990). In each chapter, I consider the role of my own worldview and actions as important factors in the case study class. Secondly, observations are extended across space and time as “interventions in reality” which create new conditions, and social situations become social processes (Burawoy, 1998). This extension is captured by the retrospective design of this case study, which extends the examination of the class from the origins of the curriculum to the students' reflections looking back on the class as college students. The strengths, limitations, and temporal issues implied by this retrospective design are discussed in the context of data analysis below.

Third, rather than looking for common patterns across multiple cases, in the extended case method, phenomena are extended from the case out to the larger context in order to understand the impact of external forces. Two layers of larger context are important in this study. The first layer is La Lucha High School, which provides a unique historical and community context for this study that has been mentioned in previous chapters and is elaborated below. The second layer is the large urban school system of which La Lucha is a part. This system, as representative of US urban schools in general, is characterized by deep inequity across the lines of race and class and by an obsession with standards and high stakes assessment. These two layers of context exert considerable pressure on the case, which is considered in each chapter as part of the data analysis.

While the reflexive nature of the extended case method has some advantages over positivistic approaches, it also presents limitations. Burawoy (1998) attributes these limitations to the unavoidable effects of power between the researcher and other participants in the case. These effects of power include the possibility (or probability) of domination, silencing, objectification, and normalization. The former two limitations problematize the fact that the researcher is inevitably in a position of power to interpret or present the meanings of participants. The latter two limitations are related to the way dynamic and nuanced realities are often made to fit theories that are more static and flat. I acknowledge these limitations and have done my best to honestly communicate the meanings of other participants in this study and to retain the nuance in the reality I describe. I have sought to meet the criteria for practitioner research validity described below as a means to minimize these limitations. Even so, I acknowledge that my position of privilege and power remains problematic.

The Context: La Lucha High School

La Lucha High School was opened as the result of a 19-day hunger strike waged by 14 community members. This hunger strike was the culmination of years of organizing efforts aimed at addressing neglect and overcrowding in public schools in the predominately low-income Mexican American community of West Ridgevale in Chicago. La Lucha is a small neighborhood public high school (325 - 360 students) that is one of four schools on the campus founded because of the hunger strike. The founders of the school insisted that the campus not be contracted out to charter school operators, but rather be built as a neighborhood public school. This decision means that the campus accepts all students who live within the neighborhood boundaries and that teachers are members of the local teachers union. The school's attendance boundaries include portions of West Ridgevale and East Ridgevale, an adjacent low-income predominately African American community. Students who live within the neighborhood boundaries can rank their choices from among the four schools on campus and the four principals work together to achieve some balance in enrollment across the campus.

The histories of both East and West Ridgevale and the relationships of these communities to each other are complex. Stovall (forthcoming) provides an insightful account of histories as they relate to education policy in particular. Given limited space here, I draw from that account to describe the context in more limited space. Both communities have been subject to similar forms of economic exploitation and governmental neglect, while there is also a rich history of organized community resistance in both neighborhoods. The particular ways in which white supremacy and neoliberalism have shaped the recent histories of the neighborhoods resulted in racial segregation and tensions between the East and West Ridgevale. Deindustrialization, white flight, and predatory lending has left the African American community of East Ridgevale to deal with a declining population, lack of economic opportunity, and decaying infrastructure and housing stock. Meanwhile, the same processes were mitigated slightly in West Ridgevale by forces which sought to integrate Mexican immigrants with Eastern European immigrants in order to preserve business interests in the community. Still, the transition from being a largely European community to a largely Mexican community was accompanied by a decline in city services and the mismanagement of industrial pollution and post-industrial contamination. The racist design and enforcement of immigration policies also adds a layer of marginalization for West Ridgevale residents. Despite "hyper segregation" and "engineered xenophobia" (Stovall, forthcoming) between the two communities, there are several historical examples of grassroots collaboration across the boundary that divides Ridgevale.

All of these forces are at play in considering the demographics and culture of La Lucha High School. Due in large part to a federal consent decree, when the school opened, La Lucha's students were 70% Latin@ (predominately Mexican American) and 30% African American. Students come to La Lucha from highly segregated K-8 elementary schools that are nearly 100% Latin@ or nearly 100% African American. The most integrated of these feeder schools is 84% Latin@ and 15% African American. Since La Lucha opened, a shift in school demographics has been caused by a set of complex factors related to those described above. The expiration of the federal anti-segregation consent decree coincided with the opening of several new charter schools in East Ridgevale and gentrification of some portions of the neighborhood. Meanwhile, hyper segregation and engineered xenophobia often make neighborhood of West Ridgevale an unwelcoming environment for African American students from East Ridgevale, despite the efforts of critically conscious community members to build unity across Ridgevale.

The data for the school year that is the focus of this study indicate a student population that is 89% Latin@ and 10% African American. More than 96% of La Lucha’s students received free or reduced lunch in that school year. The demographic data, including this shift towards more Latin@ and fewer African American students, are very similar for the other three schools on the campus. The district as a whole has seen a drop in the percentage of African American students and an increase in the percentage of Latin@ students (Smith, 2013). This shift is the result of city policies and development efforts that supported the gentrification of several historically Black neighborhoods and the displacement of large segments of Chicago’s African American communities. Meanwhile Chicago continues to be a port of entry for immigrants displaced by the effects of NAFTA and US-induced violence in Mexico and Central America.

I have seen the demographic shifts at La Lucha and in Chicago first hand as I began teaching at the school during the summer immediately following its first year of operation. I lived in East Ridgevale during the first three years that I taught at the school. During my fourth year at the school, I moved to a nearby community that is demographically similar to West Ridgevale. I was one of the first two science teachers at the school and taught there for a total of seven years. During its brief history, I have also seen La Lucha’s status fluctuate several times between “probation” and “good standing” according to the district’s performance policy. This policy is based on high stakes standardized test scores and other quantitative measures including attendance and the percentage of 9th graders who are on track to graduate. For the school year that is the focus of this study, the school received the district’s highest rating according to this policy for the first time.

The community struggle that founded La Lucha High School provides a unique historical context for a study focusing on critical and culturally relevant pedagogies. The mission, vision, and core beliefs of the school, which codify the values of that struggle, echo the tenets of critical and culturally relevant pedagogy in several ways. For example, in addition to asserting that “our students will be prepared for college,” the mission statement of the school includes the statement: “Our students will cherish and preserve their ethnic and cultural identity [and] will serve and determine the future of our community.” Thus the mission statement aligns very well with Ladson-Billings’ (1995) first and second criteria for culturally relevant pedagogy, academic achievement and cultural competence. The second part of this statement also aligns very well with Freire’s focus on oppressed people becoming “subjects of history” or “writers of the world” as it asserts that La Lucha students will determine the future of their own community (Freire, 1970/2001; Freire & Macedo, 1987).

Furthermore, the publicly stated vision of the school positions the teachers as curriculum developers in a way that is aligned with these two radical pedagogies: “Project based and problem based learning that addresses real world issues through the lenses of race, gender, culture, economic equity, peace, justice, and the environment will be the catalyst for developing our curriculum.” Whereas numerous science teachers I encounter lament that their school administration prohibits them from engaging in radical pedagogies, the mission and vision of La Lucha High School explicitly encourage this sort of practice. I do not mean to imply that all teachers at La Lucha embrace their role as curriculum developers or critical pedagogues. Teachers come to the school from various backgrounds and political perspectives themselves and thus have varying levels of commitment and understanding when it comes to these principles.

There are some classrooms at La Lucha that resemble a stereotypical urban classroom and others that embody the ideals set forth by the mission and vision.

The mission and vision of the school are important because they act as guideposts for those of us who try to align our teaching with the school's founding struggle. They can also provide support or justification when district administrators or skeptical colleagues undermine or devalue our practices. This support for this radical pedagogy extends beyond the walls of the school because parents and community members led the struggle that inspired the mission and vision. In fact, I consider employing culturally relevant and critical pedagogies at La Lucha High School as an obligation to the community. The support for culturally relevant and critical pedagogies at La Lucha High School thus provides a revelatory case for investigating the central practices of this approach in a secondary high school classroom.

The Case: AP Chemistry

Student demographics.

The class that I have defined as my case is a recent Advanced Placement (AP) chemistry class at La Lucha High School. There were 29 students in the class (20 juniors and 9 seniors), which demographically mirrored the composition of the school with respect to race and socio-economic status (26 Latin@s, 3 African American students, all from low income households). There was a gender imbalance in the class with 17 female students and 12 male students. Publicly available school data do not include a gender breakdown for students. Table I illustrates the demographic similarities between the class and the school.

Table I: Demographic Comparison of School and Case Class

2012-13 School Year	La Lucha High School (325 students)	AP Chemistry Class (29 students)
African American students	10%	10%
Latin@ students	89%	90%
Students receiving free or reduced lunch	96%	100%[a]
Female students	N/A	59%
Male students	N/A	41%

[a]determined by students who received a fee-waiver for the AP exam, which requires eligibility for free or reduced lunch

Prerequisites and enrollment.

All students in 10th and 11th grade science classes in the previous school year were encouraged through frequent in-class announcements to take AP chemistry if they had an interest in chemistry or a desire to pursue a STEM major. These announcements indicated that "good grades" in previous science classes would be a requirement for enrolling in AP chemistry. But ultimately, all interested students were encouraged to enroll and there were no exclusions from the class based on grades. There was no consideration of standardized test scores in determining the composition of the class. Both of the required 9th and 10th grade science courses (introductory biology and chemistry) were prerequisites for the course, thus limiting the course to 11th and 12th graders. Due to the small size of our department (3 teachers), the course is offered every other year. In years when AP chemistry is not offered, AP biology and physics are offered as upper grades science electives.

The year of the case study class was my seventh year teaching at La Lucha High School and tenth year as a full time secondary science teacher in the district. I taught three sections of

10th grade chemistry in addition to the case study class. Most of the students in the class (25 of 29) took 10th grade chemistry with me in one of the two preceding years. Two others (both 12th grade Latinas) took 10th grade chemistry with a colleague who used the same curricular materials. One of these students is among the participants described below. Another student who participated in the class and in this study (also a 12th grade Latina) transferred to La Lucha to start 11th grade. The final student (an 11th grade Latina) attended a different school on the same campus and was allowed to enroll in this class because La Lucha is the only of the four schools on the campus that offered Advanced Placement chemistry. It is important to note that other science courses at La Lucha, especially the core required courses (biology, chemistry, and environmental science) take a justice-centered approach. The curricula for these classes was developed collaboratively by our three-member department over a number of years to intentionally build students' understanding of both science content and social justice issues and concepts. Students' familiarity with me and with a justice-centered approach is important to consider in terms of how they responded to and reflected upon the case study class.

Summer session.

Enrolled students were required to attend a four-day session during the summer before the class. This session took place in the middle of July from 10AM-2PM everyday. Students were provided with lunch. The summer session curriculum is described in chapters IV and VII. Exceptions and accommodations were made for several students whose summer work, internship, or travel plans conflicted with the sessions. For example, about a third of the class was enrolled in an Upward Bound college preparatory program, which had conflicting summer programming. I worked with the Upward Bound coordinators to ensure that these students were able to attend both programs. There was also a student who missed the entire week due to concurrent enrollment in an out-of-state university science enrichment program. This student completed a series of make-up assignments to account for missing the summer session.

Four students, all of who were 12th graders, completed the summer session and then elected to drop the course once the school year began. They are not included in the demographic description of the course above. Each of them cited a combination of scheduling and time management priorities as their reasons for dropping the course. The class was very time consuming for both students and myself. The class met everyday for two 50-minute sessions at the end of the school day (6th and 8th periods), separated by a 50-minute lunch (7th period) and also required significant homework. This intensive 500-minute per week schedule gave us substantial time to engage with course material, but limited students' ability to enroll in other electives.

AP chemistry curriculum.

The AP chemistry curriculum is highly prescribed by the College Board to simulate a general chemistry course typically offered to first year undergraduates (College Board, 2011) . It is assessed by a standardized exam, which provides students with the opportunity to earn college credit. The exam is scored on a scale from 1-5, with scores of 3, 4, or 5 providing course credits at many post-secondary institutions. AP chemistry is aligned with a "STEM pipeline" approach to teaching science with no apparent considerations for cultural relevance or even connections to everyday life included in the course description (College Board, 2012). Prior to 2013-14, the curriculum was too broad by the College Board's own admission, as evidenced by the recent major revision of the curriculum to narrow its focus (College Board, 2011). The case study course took place before the implementation of this curricular revision. The course description published by the College Board (2012), which guided the development of curriculum for this course, is 40 pages long and includes dozens of itemized concepts that students are expected to understand. This description also includes 11 different types of calculations students are expected to master and 22 recommended laboratory experiments. In addition to this lengthy list of AP chemistry requirements, my planning also considered a draft version of the Next Generation Science Standards (NGSS, Lead States, 2012) and some Common Core State Standards (CCSS) for math and for literacy and writing in science and technical subjects (National Governors Association, 2010). The ways in which these various standards and requirements impacted my curriculum planning are explored in chapters IV, V, and VI.

Opportunities and limitations of the case.

Yin (2009) acknowledges that multiple case studies often provide for richer analytical generalization than single case studies in a way that is analogous to the advantage of multiple over single experiments in laboratory sciences. However, he also provides five rationales for focusing on a single case study. Two of those five rationales are cases that are unique or revelatory. Meanwhile, the extended case method privileges single cases that allow for the four extensions outlined above. In contrasting the grounded theory and extended case method approaches, Tavory and Timmermans (2009, p. 243) describe the extended case method as, "relying on theoretical narratives to delineate the boundaries of an empirical field" and "us[ing] theoretical narratives as a denouement of the case." These two approaches to case study methodology converge to suggest that a single case is especially useful when it represents a unique example as viewed through a particular theoretical lens.

I contend that this AP chemistry class represents this sort of revelatory case for exploring the framework of justice-centered science pedagogy because of the way it highlights the tensions between curriculum that is rigorous and content-driven and also critical and locally responsive.

One of the themes of research that explores critical and culturally relevant pedagogies in urban US contexts is an examination of the relationships between supporting student success in a traditional academic sense while also supporting students from oppressed communities to develop cultural competence and critical consciousness. This interplay is captured by Ladson-Billings' (1995) three criteria for culturally relevant pedagogy, but it is also at the heart of Gutstein's (2006) community, classical, and critical knowledge framework and Morrell's (2008) pedagogies of access, dissent, and liberation. Mutegi (2011) and Dimick (2012) have both introduced frameworks for science education that call for the simultaneous development of academic abilities, sociocultural competencies, and political consciousness.

Advanced Placement courses have become a marker for academic achievement in the college admissions process and also in educational research that documents racial inequities. Access to Advanced Placement courses has been systematically limited for African American and Latin@ students both within and across schools (Solorzano & Ornelas, 2004). This problem has significant implications for the college admissions chances of African American and Latin@ students. Limited access to academically challenging coursework is a problem in science education in particular (Atwater, 2000; Oakes, 1990; Smith et al., 2013; Tate, 2001). The case of an AP course entirely composed of Latin@ and African American youth thus explicitly addresses this notion of access to advanced and challenging coursework. But at the same time, the content-heavy curriculum that is described by the College Board with no local input or attention to culture creates significant challenges with respect to supporting cultural competence and critical consciousness.

La Lucha High School provides a unique context within which to grapple with these challenges. At the start of the case study class, the science department at La Lucha had been working together for more than six years to develop curriculum that responded to the local context in order to support the maintenance of cultural competence and critical consciousness. Outside of regular department meetings, we organized two formal "teaching science for social justice" summer study groups in 2007 and 2008, which also included teachers from other Chicago schools. We also engaged in formal curriculum planning as a department during each summer from 2006 until the year of the case study class. As mentioned above, the vast majority of the students in the case study class had taken two or three previous science courses with curriculum organized around social justice themes. Thus an Advanced Placement chemistry course at La Lucha High School represents a unique and revelatory case within which to investigate justice-centered science pedagogy for its ability to bring into sharp relief the tensions between standards and locally responsive science education (Aikenhead et al., 2006; Yin, 2009). Or in the view of the extended case method, the case study class is well positioned for the reconstruction of theory.

Still there are three major limitations introduced by my choice of this case. First, the highly prescribed and content-driven AP chemistry requirements limited my freedom with respect to developing curriculum. My other courses at La Lucha and those of my colleagues would likely provide more creative and responsive examples of socially transformative curricula within which to examine justice-centered science pedagogy. For example, the use of youth popular culture as a starting point for curriculum development (Duncan-Andrade, 2004) is a principle of curriculum development that I employ in other classes but was not prominent in the case study class. Secondly, the choice of an AP class raises questions and concerns about the composition of the students in the class. It is important that the class was not "tracked" in a traditional sense and it was demographically representative of the school in terms of race and class. But nonetheless, students committed to a 4-day study session in the summer and to two-periods of challenging science curriculum with significant homework during the school year. On one hand, the fact that 29 students accepted this challenge in a school where a typical graduating class is 65-70 students is a testament to school culture and the effectiveness of the core science courses. This is reinforced by the fact that AP biology generally has similar enrollment patterns so that somewhere around 40% of each graduating class takes an AP science course at La Lucha. On the other hand, the group of students in the case study class is likely to have more positive attitudes towards science and school than the student body as a whole. This has implications with respect to student compliance and resistance and student orientations toward science. These issues are explored in chapters VI and VII. The final limitation of this choice of case is related to the context. While the history, mission, and vision of the school provide a unique context within which to examine justice-centered science pedagogy, this context may also limit the "transferability" of this research in the minds of some readers (Guba & Lincoln, 1982). This issue is discussed further in the final section of this chapter.

Data sources

Data sources for this study fall into three major categories: (1) interview data, (2) student artifacts, and (3) my archival records. In this section, I begin with a description of my recruitment process and the participants and then describe each of these three data sets.

Recruitment.

In order to recruit participants for this study, I sent individual emails containing an IRB-approved recruitment script to all 29 students in the case study class and to 4 community members (3 from West Ridgevale and 1 from East Ridgevale) who were involved with the case study class in some way. These emails were sent approximately 15 months after the conclusion of the case study class. At this time, all 29 students had already graduated from high school and most were enrolled in college. I received responses to these emails from ten students and two community members. I was able to interview nine of these students and both community members. Two of these students also recruited the participation of their mothers. Due to my own lack of fluency with Spanish, I was only able to interview one of these mothers, which presents a serious limitation for my data from other stakeholders. The participants ultimately included nine students and three other stakeholders (one parent, and two community members). Student participants were invited to contribute work artifacts from the case study class. All of the nine student participants submitted various artifacts, which are described below.

The participants.

The nine student participants include four Latina women (Marisol, Cristina, Raquel, and Odette[4]), four Latino men (Francisco, Curtis, Gabriel, and Jackson), and one African American woman (Jade). Among these nine participants, five were in 11th grade and four were in 12th grade during the school year being studied. Eight of the nine student participants were enrolled in selective four-year colleges or universities at the time of their initial interview. Cristina was enrolled at a local community college and plans to transfer to a large state university after this year. Table II summarizes the demographic information of student participants.

The two community members who participated in the study, Ms. Juarez and Ms. Avila, are both Latina women who also participated in the hunger strike that founded the school. They are both long-time West Ridgevale residents who are college-educated and work as educators themselves. They also both participated in the case study class in ways that are described in more detail in chapters IV and VI. The parent who participated, Ms. Epps, is Jade’s mother. Ms. Epps

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[4] All names used are pseudonyms

has lived in East Ridgevale for most of her life. She is a military veteran who currently works as an electrician. Besides Jade, Ms. Epps' older daughter also graduated form La Lucha. Ms. Epps frequently volunteered at La Lucha and served one term on the Advisory Local School Council.

Table II: Description of student participants

Pseudonym	Race/ Ethnicity & Gender	Post secondary institution by Carnegie Classification	Declared College Major	Grade level during case study class
Cristina	Latina	Large Two-Year Public College in an Urban Setting	Chemistry	12th
Curtis	Latino	Small Four Year Private College (More Selective)	Sociology	11th
Francisco	Latino	Large Public Research University (More Selective)	Biology	11th
Gabriel	Latino	Large Public Research University in an Urban Setting (Selective)	Undeclared	11th
Jackson	Latino	Large Public Research University (Selective)	Physics	12th
Jade	African-American Woman	Small Four Year Private College (More Selective)	Epidemiology	12th
Marisol	Latina	Large Private Research University (More Selective)	Sociology	12th
Odette	Latina	Small Four Year Private College (More Selective)	Chemistry	11th
Raquel	Latina	Large Public Research University (More Selective)	Undeclared	11th

The composition of the pool of participants presents some strengths and limitations with respect to this study. First, all nine of the student participants were enrolled in college at the time of their initial interview. I do not have specific data about college enrollment for the other 20 students who took the case study class but did not participate in the study. I know from informal contact that most, but not all, of them enrolled in college after graduating from La Lucha. The lack of participants who did not attend college excludes one important set of perspectives from this study. In a study that is concerned with access to higher education as one of the goals of equitable science teaching, this limitation is counterbalanced by the fact that the nine participants are able to compare their experiences in the case study class with their experiences in college classes. Similarly, there is likely an overrepresentation of science majors among participants with two chemistry majors, one physics major, one biology major, and one epidemiology major who has her sights set on medical school. The overrepresentation of science majors and college students among participants may also suggest that these nine participants were among the most academically successful in the class. It is difficult to make a fair comparison between these students and their peers in the class without data for the 20 non-participants. However, it is safe to say based on the artifacts submitted by participants and on my own memory, that the nine participants were all successful in the case study class. While no students failed the case study class, there were others who were less successful than those who chose to participate.

The composition of the group of three stakeholders I interviewed presents similar advantages and limitations. For example, as a member of the Advisory Local School Council and frequent volunteer at the school, Ms. Epps was more engaged and involved with the school than most parents can be. As participants in the hunger strike that founded the school, Ms. Juarez and Ms. Avila are also more engaged than most community members. In a community where average levels of income and formal education are limited by various structural factors (like inequitable educational opportunities and immigration status, among others), the fact that Ms. Juarez and Ms. Avila both hold college degrees and work as educators sets them apart. Even as the uniqueness of these community member and parent participants introduces potential bias, it also provides the valuable perspective of three stakeholders who are especially involved and engaged with La Lucha High School and the communities of East and West Ridgevale.

Interview Data.

I conducted semi-structured interviews with each of the participants. Separate interview protocols for students, parents, and community members are included in the appendix. Student interviews lasted between one and three hours. The duration of stakeholder interviews was between 45 minutes and one hour. Interviews were audio or video recorded and I transcribed each of these recordings. During student interviews, curricular documents or student artifacts were used as heuristic devices as we talked about the different components of the class. For example, I made my curriculum map available to all students so they could look back at the names and descriptions of units to refresh their memory. Five students who submitted binders containing artifacts from the course used these binders during their interviews to look back on their work as we talked about the class. Four or five months after the initial interviews, I contacted each of the 12 participants to conduct member checks and follow-up interviews. I was able to conduct member checks with all nine student participants and also short follow up interviews (1 hour or less) with five of these nine. I was unable to schedule member checks with the other three stakeholders. For member checks, I prepared a short list of clarification questions specific to each participant and another short list of quotes that stood out from their initial interviews. I shared my interpretations of these quotes along with my preliminary findings and asked participants to confirm or critique my interpretations. My methods for analyzing interview data are described as part of the data analysis section below.

Student submitted artifacts.

Each of the student participants contributed artifacts from the case study class for analysis. Francisco, Cristina, Odette, and Raquel contributed their complete course binders, each of which contain approximately 500 pages of their work, notes, and handouts from the course. Curtis contributed a partial compilation of his notes and work from the class, which contains roughly 25% of the documents included in the complete binders. Jade, Marisol, Jackson, and Gabriel contributed lab report portfolios that contain major lab reports from the case study class and some previous classes at La Lucha High School. These portfolios are not equally complete. For example, Gabriel's portfolio only contained the three major lab reports for the case study class while Jade's contained eight lab reports that spanned from 9th through 12th grade. Between the binders and the lab report portfolios, the data include three major lab reports and some related documents for all nine of the student participants. I photocopied and de-identified these artifacts and returned the originals to the participants. Table III contains a summary of the artifacts submitted by students.

Table III: Student Artifact Data

Student Participants	Artifacts Submitted
Cristina, Francisco, Odette, Raquel	Complete Course Binder (includes approximately 500 pages of notes, work, and handouts from the case study class)
Curtis	Partial Course Binder (includes approximately 25% of a complete course binder)
Gabriel, Marisol, Jade, Jackson	Lab Report Portfolio (includes major lab reports from the case study class)

My archival records.

The final data set consists of my curriculum planning documents and my reflective entries in two journals of my practice. The former includes approximately 300 separate files such as the syllabus and curriculum map for the case study course, notes from class, notes from relevant meetings with colleagues and students, nine unit plans, 155 daily presentation files, and dozens of handouts which include assignment descriptions, rubrics, quizzes, and course readings. Two separate journals contain occasional entries (78 in total) dating from my first day at the school in 2006 through the case study class. One of these journals focuses on issues of socially transformative science curriculum while the other contains reflections on events that I perceived as indicative of how La Lucha High School was or was not upholding the mission, vision, and core beliefs of the school. Most of the entries from these journals pre-date the case study class, but provide insight into the development and evolution of the curriculum and teaching practices being examined, which is important in my application of the extended case method.

Data Analysis

Embedded case design and initial content analysis.

The "unique strength" of a case study "is its ability to deal with a full variety of evidence – documents, artifacts, interviews, and observations" (Yin, 2009, p. 11). In order to organize this wide swath of data, I used an embedded case design that positioned my curricular units as embedded cases within the case study class. Table IV shows these nine units, including their sequence and time allotment, as shown in the case study class syllabus and curriculum map. Despite titles indicating traditional chemistry concepts, not all of the units were planned as traditional chemistry units, an issue which became clear during data analysis that is elaborated in the next chapter.

Table IV: Curricular Units from Case Study Class Syllabus

Week(s)	Unit Title
1 – 4	Introduction to Quantitative Analysis (Stoichiometry & Analytical Chemistry)
5 – 7	Gases & Kinetic Molecular Theory (with some liquids and solids content)
8 – 12	Atomic Theory, Structure, and Properties
13 – 16	Chemical Bonding
17 – 19	Thermodynamics & Thermochemistry
20 – 23	Equilibrium
24 – 26	Applications of Equilibrium
27 – 29	Chemical Kinetics
30 – 32	Review for AP Exam
33 – 38	Synthetic Chemistry

I conducted a content-analysis of student interview transcripts (Silverman, 2011) to identify the curricular units, teaching practices, and classroom routines and structures that were most salient for students as they reflected on the case study class. This first phase thus began from a synthesis of my three research questions, which focused on curriculum development, classroom practices, and student outcomes and reflections. I used ATLAS.ti to conduct this content analysis and each subsequent analysis of interview transcripts. Rather than simply counting the number of times that each unit or practice was mentioned, I also constructed a table to keep track of components of the class that students described in superlative ways, like “the hardest topic” or the “most boring lab.” This initial content analysis allowed me to narrow my focus to four curricular units and two sets of teaching practices that are discussed in the following four chapters.

The second phase of data analysis was a time-series analysis of my archival records to reconstruct the origins and planning process for each of the four curricular units that emerged as salient from the initial coding of student interviews. The third phase of data analysis was a second round of coding interview transcripts, using a new ATLAS.ti project. This time I analyzed all twelve of the student and stakeholder interview transcripts by relying on *a priori* codes that were developed from theoretical propositions. This approach to coding is consistent with the extended case method, but contrasts with a grounded theory approach that has been employed by other similar studies (e.g. Duncan-Andrade and Morrell, 2008). As a “reflexive” rather than “positive” approach to social science, the extended case method suggests that our understanding of the world is always filtered or organized by theoretical propositions, even when they are tacit or informal. Thus, Burawoy (1998, 2009) criticizes grounded theory for failing to acknowledge the extent to which implicit theoretical frameworks bias the emergence of themes from data. The extended case method seeks to make the frameworks, which always inform our understandings, explicit and to actively look for disconfirmations of these theories in the data. Of course, one of the limitations of using *a priori* codes is that the researcher may be unable to see themes in the data that fall outside of theoretical frameworks. To mitigate this limitation, I remained open to additional themes and thus expanded my list of codes and iteratively modified my theoretical propositions as a reconstruction of theory that took place throughout the analysis. These iterative coding schemes are included in the appendices.

After this second coding of interview transcripts, I turned my attention to student work artifacts. In this phase of analysis, I narrowed my focus to artifacts that met three conditions (1) they were produced during the four curricular units that the content-analysis of student interview transcripts identified as most salient, (2) a minimum of four of the nine student participants had submitted this particular artifact, and (3) their content was well aligned with the standards identified by the unit plan as a central focus of the unit. These three criteria were chosen to make the number of student artifacts analyzed manageable while also maximizing the richness of this data. I decided to focus on artifacts that were submitted by at least four students because this is the number who had submitted complete binders, so it was likely that I had at least four samples of any major assignment. There were minor exceptions to this criterion. For example, in looking through Curtis' incomplete binder I found a typed end-of-the year reflection that was not present in other binders, but offered insight into his particular experiences in the class. There is a quote from this reflection in Chapter V:because it added to my understanding of his other artifacts. Table V provides a summary of the artifacts selected for detailed analysis, including the number of students who submitted it. Minor exceptions like Curtis' reflection are omitted from the table.

Table V: Student artifacts selected for detailed analysis

Student artifact	**Number of students**
Letters to governor about proposed coal plant	6
Reactions Quiz 1	4
Soil Project Lab Report	9
Aspirin Lab Report	9
Stoichiometry Unit Exam	5
Problem Set 21 on LeChâtelier's principle	4
Problem Set 22 on solubility product constants	4

For each of the assignments in Table V, I made a list of relevant (1) NGSS performance expectations, (2) Common Core State Standards for writing in science and technical subjects, (3) components of the AP chemistry course description, and (4) codes from the second interview transcript analysis. Using Microsoft Excel, I charted evidence relating to these four frameworks for each student and each artifact while I highlighted this evidence on the paper copies of student artifacts. I looked for opportunities across these artifacts to consider the development of a particular concept or idea over time. When such an opportunity arose, I conducted a time-series analysis by comparing and contrasting the artifact through the lens of a particular NGSS, CCSS, chemistry concept, or theoretical construct. The final phase of data analysis consisted of pattern-matching and triangulating data across all three data subsets (interview transcripts, student artifacts, and my archival records).

Figure 1 illustrates my data analysis process. It categorizes much of the interpretative data analysis as relying on theoretical constructs, a technique of the extended case method and other case study methodologies (Burawoy, 1998; Yin, 2009). It also places the initial content analysis and the iterative search for disconfirmations of theory and reconstruction of theory as components of the data analysis process where I intentionally tried to push beyond or think outside of my theoretical framework.

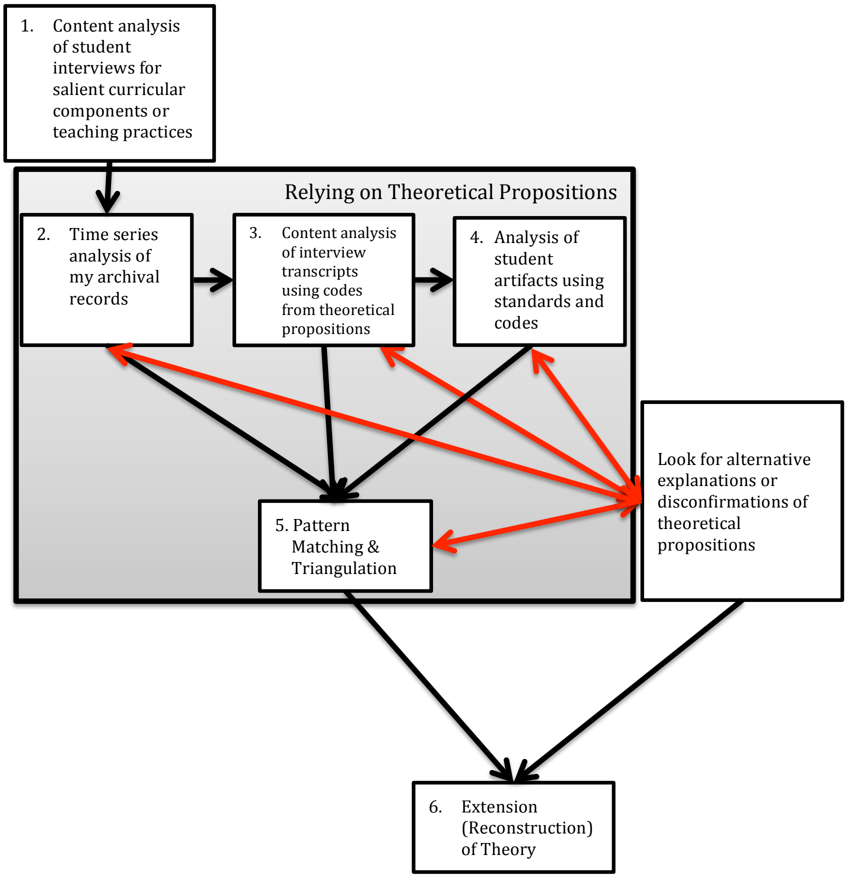


Figure 1: Data Analysis Process

Temporal issues with the retrospective design.

In light of the data sources and data analysis process, the retrospective design of this case study presents strengths and limitations with respect to my research questions. My ability to capture day-to-day teaching practices is severely limited by this retrospective approach. This study is also limited by the memory of the participants and myself. I have tried to counteract this limitation by using student work artifacts and my planning documents as heuristic devices during interviews, but this is no substitute for interview data from the time of the case study class, which unfortunately I do not have.

On the other hand, taking a retrospective approach provides several advantages, especially as they relate to the limitations implied by my own intimacy with the case. For example, ethical concerns about students' participation (or lack thereof) in this research project are lessened by the fact that I no longer have the power or responsibility to assign them a grade. This also provides some relief from the pressure students might feel to give me answers that they think I want to hear (although this is still something I tried to guard against in my introduction during each interview). Another advantage provided by the retrospective design is the opportunity for students to make meaning out of their experiences in the case study class in light of subsequent experiences. For example, during interviews, some students compared and contrasted their experiences in the case study class with their experiences in college science classes. Others traced their current involvement with a particular issue or topic to a particular activity that occurred during the case study class. I was also able to analyze artifacts produced by students during the case study class alongside their reflections as they looked back on assignments during interviews. Making these extensions is consistent with the extended case method and allows me to consider academic achievement as captured by student work artifacts as one part of longer learning trajectories, which are described in Chapter VII.

The retrospective design precludes my ability to make real time adjustments to my pedagogy, which is typically an advantage provided by teacher research. But the time that elapsed between the case study class and this study also provided me with distance that allowed for me to reflect on my practice without the pressure to make immediate curricular decisions or respond to classroom frustrations. Admittedly, as people (both myself and other participants) look back on past experiences, there is a tendency to make those experiences fit within a coherent life narrative that is based on our present circumstances and identities (Linde, 1993 as cited in Wenger, 1998). But in terms of investigating the potential role of science education in supporting struggles for social justice, there is value in the reflective meanings students assign to the case study class while they are engaged in college science classes and in social justice organizations (as most are in one way or another).

Trustworthiness

Qualitative researchers have sometimes adopted the term “validity” from quantitative research, but Guba (1981) famously introduced criteria for “trustworthiness” as a more appropriate way to evaluate the quality of what he referred to as “naturalistic” or social/behavioral research. Traditional researchers, in any field, are accountable to these standards of trustworthiness or validity as judged by their peers, who evaluate the quality of their work and their ethics. As a teacher researcher, I feel accountable to at least three distinct groups of people. Certainly, I want my work to be held in esteem by fellow researchers. But I also must produce knowledge that is useful to my fellow practitioners. Most importantly, I am accountable to students, parents, and community members – not only to those who are involved in this study, but to those who have yet to attend La Lucha High School or enroll in one of my future classes at any institution. Since I have framed the primary problems in education as problems of inequity and injustice, then it is my responsibility to do whatever I can to increase equity and justice. This implies that my work must be of the highest possible quality and that *in addition to* criteria for trustworthiness or validity and ethics upheld by IRBs, I must do whatever I can to improve educational conditions for La Lucha High School and its students.

Given these unique forms of accountability felt by practitioner researchers, some have wondered whether traditional notions of validity or even trustworthiness apply to our work (Cochran-Smith and Lytle, 2009). Given this uncertainty, Anderson and Herr (1999) propose a tentative set of validity criteria for practitioner research that I have applied to maximize the quality of this study. Since the first priority of practitioner research is to improve local educational circumstances and the teacher's practice, the first measure of validity proposed by Anderson and Herr is *outcome validity*. Outcome validity essentially asks whether the research helped to solve the problem it defined while also leading to a new set of questions for further inquiry. Since I no longer teach at the school, I plan to meet with my colleagues in the science department to share my findings and work with them to consider how this study can inform departmental curriculum and teaching practices moving forward. I will also work with my colleagues to develop a new set of locally relevant questions that my findings suggest. These questions could be addressed through my own ongoing research or through practitioner research projects conducted by my colleagues. In Chapter VIII, I also include a section on implications for La Lucha High School in order to address the criterion of outcome validity.

Anderson and Herr's second criterion for quality practitioner research is *process validity*. Process validity is an evaluation of whether the methods used by a practitioner research study facilitate “the ongoing learning of the individual or system” (Anderson & Herr, 1999, p. 16). In other words, process validity distinguishes practitioner research that is deep and reflexive from studies that are superficial in terms of process and epistemology. In order to address process validity, I have triangulated data between multiple participants and between multiple data sets, including my archives, student artifacts, and interview data. I have questioned what counts as evidence and presented what I have evaluated as reasonable evidence for the claims I make in chapters IV - VII. I have looked for evidence that disconfirms my framework or my findings and have tried to include a discussion of this evidence whenever it is applicable.

The third criterion proposed by Anderson and Herr is *democratic validity,* which asks about the extent to which all stakeholders participate in the research and the extent to which any proposed solutions are locally appropriate. In order to maximize democratic validity, in an ideal situation, I would design this study as a participatory action research project that involved students, parents, community members and my colleagues not as participants, but as researchers. However, due to time constraints, lack of funding, and the necessarily individualistic nature of a dissertation, such a design is not feasible in this case. Instead, I have interviewed as many students, parents, and community members as I could, given time limitations and taking care to avoid unethically pressuring people to participate. I have also reached out to all twelve participants in order to conduct member checks and follow-up interviews. I have successfully conducted member checks with nine of the twelve participants. Finally, I plan to present my findings, not only to my colleagues in the science department, but also to the Local School Council (composed of parents, community members, teachers, the principal, and one student) so that this body may consider my findings in their decision-making role at La Lucha High School. These efforts contribute to the democratic validity of this study. Still one of the most problematic components of this study remains the extent to which I, as a person with power and privilege, am positioned to interpret the viewpoints and understandings of students and stakeholders who have relatively less power and privilege.

Anderson and Herr's fourth criterion is *catalytic validity*, which asks whether the study works to reorient and reinvigorate the researcher and the participants towards understanding the world in order to change it. Anderson and Herr recommend keeping a research journal as a way to monitor my own ideas and orientations during the study. Indeed, I have identified my own changing perspective on what justice-centered science education means as a key outcome of this study. I have kept a research journal (in addition to the journals I have included in the data) throughout this study, which contains 46 entries and helps me to keep track of my changing ideas. I present the ways this study has reoriented and reinvigorated some of the participants and myself in the final chapter in order to address the criterion of catalytic validity.

The final criterion proposed by Anderson and Herr for quality practitioner research is *dialogic validity*. They compare this criterion to the process of peer review for more traditional research methods and recommend that practitioner researchers rely on a critical friend to challenge their own thinking and analysis throughout the study. Several advanced doctoral students and I have organized a small writing group to serve as critical friends for each other. This group meets every other week includes one of my colleagues from La Lucha's science department, who has contributed to both the dialogic and democratic validity of my study. The group also includes three science educators who are relatively unfamiliar with La Lucha High School. Two more of these science educators met with our group regularly and I have relied on their feedback along the way to improve the dialogic validity of this study. Besides the feedback from my dissertation committee members, I have also received continuous feedback from a fourth science educator who was born and raised in the West Ridgevale community and has taught secondary science in a nearby school for several years. I have relied on these colleagues to push me to consider alternative interpretations of my data throughout my study.

Reinvention rather than generalizability or transferability

This study brings together teacher research and the extended case method to retrospectively examine justice-centered science pedagogy in an AP chemistry class within a unique context. All of these methodological features present strengths and limitations, which complement each other and the theoretical framework built from culturally relevant and critical pedagogies. Since practitioner research prioritizes the local impact of the knowledge generated, scholars often question whether this knowledge is applicable, in any way, outside of the immediate context in which it was generated. Cochran-Smith and Lytle (2009) assert that it can be, arguing that “practitioner research generates … ‘local knowledge of practice’ that is intended to influence local action but also includes interpretive frameworks and theories of practice that are useful and usable in other contexts.” (Cochran-Smith & Lytle 1999, as cited in Cochran-Smith and Lytle, 2009, p. 95). This position aligns with Yin’s notion of case studies as aiming for “analytical generalization” where the study’s results are “generalizable to theoretical propositions and not to populations or universes” (Yin, 2009, p. 15). Guba and Lincoln (1982) address the issue of generalizability by proposing “transferability” as a more appropriate alternative for the social sciences. For Guba and Lincoln, to what extent the findings of one study can be “transferred” to another depends on how much information is provided about the context in which the initial findings were produced and the context to which they are to be transferred.

This study is delimited in important ways by the case. While it provides a unique opportunity to attempt radical pedagogies, working in a context where the values of “social justice" are explicit in the school's history, mission, and vision may suggest to some that these pedagogies are only possible or applicable in this sort of situation. The context of this study may thus cause readers to question whether it offers any lessons for practitioners in more restrictive or traditional contexts. In other words, some readers may consider justice-centered science pedagogy as only possible in the unique context of La Lucha High School, thus dismissing the applicability of this study in their own contexts. This tendency may be further encouraged by other advantages provided by my context. For example, many urban science teachers do not have the extended contact with students or the resources that I had to teach this course. The mandatory summer session and the double period class provided significantly more instructional time than an average class. Also, while our material resources were still limited compared with affluent public high schools, we did have adequate laboratory space, chemical supplies, and technological equipment for the class.

I close this chapter by discouraging educators in contexts that are more constrictive, repressive, or under-resourced from dismissing the notion that justice-centered science pedagogy can be applied in their contexts. While Ridgevale and La Lucha are unique, all marginalized and oppressed communities have traditions of resistance and transformation, even if they are less pronounced or public than in they are in Ridgevale. Justice-centered science pedagogy seeks to learn from and build on these sorts of local traditions. Furthermore, in a departure from notions of generalizability or transferability, critical pedagogy asserts that transformative educational practices must be reinvented in each new context. By using practitioner research and an extended case study to develop in-depth knowledge, I am limiting (not precluding) the applicability of this knowledge to other situations. It would violate the principles of critical pedagogy to seek a generalizable or objective approach to teaching science. Instead my goal in this study is to provide sufficient context, “thick description,” and disclosure of my own positionality and biases within my analysis so that the concrete examples and reconstruction of theory presented in the next four chapters may inform the reinvention of justice-centered science pedagogy in other contexts.

Chapter IV: The Soil Project

> *So there were times where you connected the unit well with the social justice issue and other times you can tell when you were just strictly trying to teach the [AP] test. You can tell – it was very visible…It was a difficult adjustment at first because it's like this is not really critical…It was more strictly just chemistry-based. I was really comfortable with the way you taught it at first when it was connected it to the real world.*
>
> - Curtis (interview)

My heart sank when Curtis offered this honest critique of the case study class during an interview. Curtis supported his interpretation of the curriculum with the names of concepts, assignments, and units that he had no trouble recalling 18 months after the conclusion of the course. This class was the seventh time that I had taught AP chemistry and in my own mind, I proudly considered it to be the first time I avoided "teach[ing to] the test." I thought I had finally found meaningful ways to contextualize each unit of this rigorous course. Curtis obviously did not experience the whole curriculum that way. Other students interpreted their experiences with the curriculum differently. Odette, for example, offered this reflection when I interviewed her: "It was [the] default to learn something based on an important [sociopolitical] action. It was the norm and that was cool…I definitely would not have considered pursuing a career in science if there hadn't been those connections."

There is a clear contradiction between these quotes from Curtis and Odette, both of which were responses to the same question about how well the course balanced teaching chemistry and grappling with social justice issues. As might be expected, most students' responses fell in between Curtis' interpretation that at times the curriculum resorted to "teach[ing] the test" and Odette's interpretation that learning chemistry through the lens of a social justice issue was the “default” curricular orientation. The difference between the way Curtis, Odette, and other students experienced the curriculum may be partially explained by their different orientations towards science, which are presented and elaborated with supporting evidence in Chapter VI. While Curtis was the only one of the nine students I interviewed to bluntly interpret a substantial portion of the course as “teach[ing] the test,” the examples he used to make his case matched a clear pattern in the data (student interviews, student artifacts, and curricular documents) that led me to modify the embedded case design described in the last chapter.

Through my initial content analysis, I identified four curricular units that students viewed as more salient, memorable, or impactful than others. In my curriculum planning documents (syllabus, curriculum maps, unit plans), I titled these units (1) chemical reactions, (2) introduction to quantitative analysis (stoichiometry and analytical chemistry), (3) equilibrium, and (4) synthetic chemistry. But further examination of the data reveals that two of these unit titles are misleading. In interviews, students consistently identified two of these units as more relevant to their lives than the others, which caused me to return to my notes and curriculum planning documents where I found a distinction that I was surprised I had not noticed earlier. This distinction is illustrated in Figure 2, which illustrates a modification of the embedded case study design introduced in Chapter III and includes the names for the units more commonly used by students in interviews: (1) the soil project, (2) stoichiometry, (3) equilibrium, and (4) the aspirin unit. The soil project and the aspirin unit were developed around SSI that were subsequently aligned to chemistry content. I characterize both of these units as “problem-posing” units because they re-presented generative themes (in the form of SSI) to students as problems to be addressed, in part, through chemistry (Dos Santos, 2009; Freire, 1970/2001). In interviews, students consistently identified problem-posing units as the most relevant portions of the class.

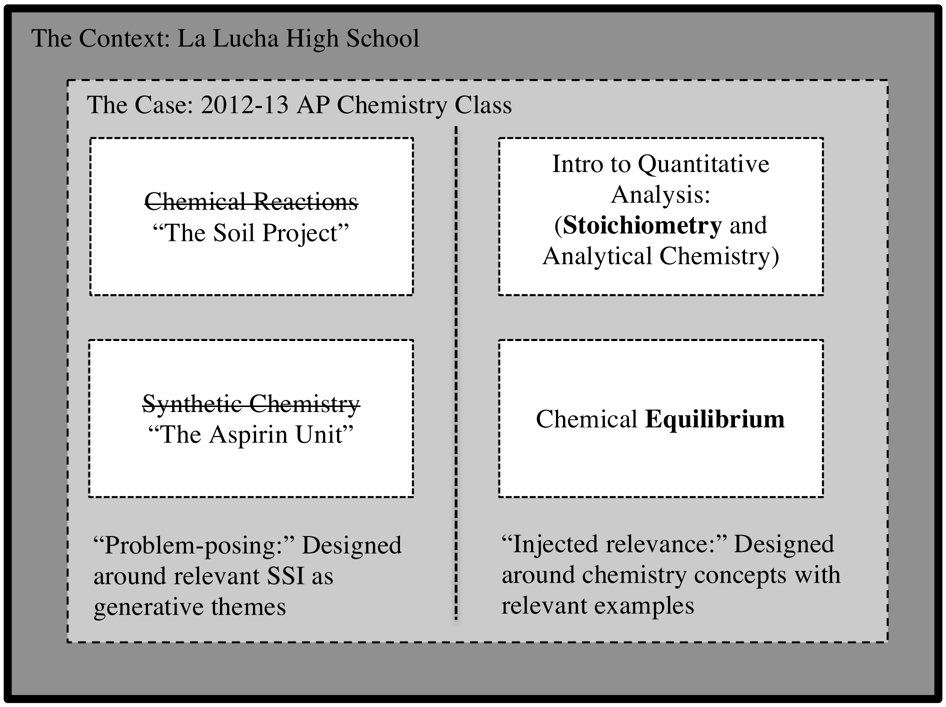


Figure 2: Modified Embedded case study design (Adapted from Yin, 2009, p. 46)

In contrast, the units on stoichiometry and chemical equilibrium were planned beginning with canonical chemistry topics, which I then tried to connect to students' lives. Rather than being organized around a problem, these units were characteristic of what I call an "injected relevance" approach in that they were organized around content with examples that illustrated how this content might matter to students. In addition to the stoichiometry and chemical equilibrium units, the other five curricular units in the case study class can be characterized as examples of an injected relevance approach. This distinction between problem posing units or injected relevance units may seem subtle or semantic to some readers and painfully obvious to others. My distinction between these two approaches is not meant to suggest that there is not some "back and forth" between chemistry concepts and SSI in planning either type of unit. Instead, these categorizations are meant to capture a difference in terms of the central concerns and priorities that guided the planning in each case. Problem-posing and injected relevance units are qualitatively different as indicated by triangulated data from student interviews, student work artifacts, and my archival records.

In each section of this chapter, I analyze interview data, student artifacts, my journal entries, and curriculum planning documents by relying on theoretical propositions, but also by considering disconfirming evidence. I rely on the first two extensions of the extended case method (from observer to participant and across space and time) to analyze my curricular planning in terms of the critical pedagogy concepts of generative themes and political clarity (Burawoy, 2009; Freire, 1970/2001, 1998). The third extension from social process to social structure allows me to consider the ways in which the curriculum supported or impeded students' academic achievement and their development as transformative intellectuals by analyzing their learning through the lenses of the NGSS, CCSS, and socially transformative constructivism (sTc) (Rodriguez, 1998).

My analysis finds that it is possible to identify SSI as generative themes that can serve as the basis for academically challenging problem-posing chemistry units. This process requires teachers to value local knowledge and to have political clarity. In other words, teachers must have an understanding of how larger political, economic, and social forces impact students' lives and communities. The findings also suggest that the NRC framework and the NGSS can be reconciled with this approach to curriculum design, but the specific performance expectations are problematic. Interestingly, the literacy and writing skills developed during the units whose planning began from SSI are well aligned with the Common Core State Standards (CCSS). But ultimately, science teachers are left with the very dilemma with which I started: we are accountable to too many standards, none of which are adequate to support socially transformative curriculum. My analysis also suggests that systematic approaches to identifying

SSI as generative themes are needed. Still, my consideration of student work artifacts, reflections, and trajectories presented in this and the next three chapters suggests that socially transformative science curriculum can support academic achievement while it also supports the maintenance of cultural competence and the development of critical consciousness. Rather than simply competing for class time or curricular space, these three criteria for culturally relevant pedagogy were developed together so that rigor and relevance were mutually supportive rather than mutually exclusive. Providing opportunities for students to be transformative intellectuals who produce, critique, and disseminate (scientific) knowledge was central in this endeavor (Morrell, 2008; Romero, 2014). The fourth extension of the extended case method is the reconstruction of theory. In the final section of this chapter, I reconstruct theory to expand the notion of youth as transformative intellectuals (Morrell, 2008; Romero, 2014) by identifying three orientations towards science from a pattern matching analysis of the data (Yin, 2009).

The SSI: Environmental Racism and Coal Power Plant Pollution

Together with an adjacent neighborhood, West Ridgevale represents the largest concentration of people of Mexican descent outside of Mexico's original (pre-1848) borders. Until August of 2012, these two adjacent communities were also home to Chicago's only two operating coal power plants. One of these plants was located less than a mile from La Lucha High School and was identified as the worst perpetrator of environmental racism among coal power plants in the US for its virtual lack of pollution controls and its location within a densely populated community of color (Patterson et al., 2012). A prolonged community struggle finally won the closure of these two power plants just as the case study class began, after more than a decade of organizing and activism. The soil project was an attempt to use chemistry to begin to investigate the lasting impact of these power plants on the community's physical environment by measuring the concentrations of lead and mercury in neighborhood soil samples. Rather than being a discrete curricular unit, the soil project stretched across much of the case study class.

The impact of the coal power plant as generative theme?

Certainly coal power plant pollution is a local place-based SSI within the context of La Lucha High School. However, the most pertinent question is whether or not it was a *relevant* SSI that resonated with the hearts and minds of the students. A generative theme “must be precisely at the level of the people’s aspirations and dreams, their understanding of reality, and their forms of action and struggle” (Freire & Faundez, 1992, p. 27 as cited in Gutstein, 2012, p. 26). Thus careful consideration of the way students and community members view the issue of pollution from coal power plants is appropriate. According to the extended case method, this implies extending beyond the case and across space and time to analyze the community context. My analysis suggests that environmental racism associated with the coal power plant was indeed a generative theme for community members and students involved with the case study class. The relevance of coal power plant pollution as an SSI is apparent in interviews with community members, students’ recollections of childhood memories and experiences in the case study class, student work artifacts, and my notes and records from classes and meetings during and before the case study class. Still this does not imply that all students were already engaged in thinking about environmental racism generally or the coal power plant specifically, nor does it imply that this issue was equally relevant for all students.

As soon as I was hired to teach at La Lucha, I reached out to a grassroots organization in the neighborhood, Communities Organized Versus Environmental Racism (COVER). I asked COVER organizers to teach me about the issues of environmental justice in the neighborhood.

They were kind enough to bring me up to speed on the six campaigns they were waging at the time. Based on my notes from my first meeting with COVER staff and board members (dated 5/11/2006), shutting down the coal power plant was at or near the top of the organization's list of priorities and campaigns. Later in the spring of 2006, my colleague and I held La Lucha's first science department meeting with the school's founding principal, who was born and raised a few blocks from the school. In that meeting, the principal also suggested that our science classes should include investigating the impact of the coal power plant. While the priorities of one particular community organization or community member do not necessarily reflect the views of the entire community, these meetings provided initial evidence that coal power plant pollution was in fact a relevant theme.

When I interviewed students and stakeholders about challenges facing the community, a lack of economic opportunity was far and away the most commonly raised issue. Still the way students and community members spoke about the coal power plant and the soil project in interviews support assertions that the coal power plant was a relevant issue in the community, even if it was not the primary concern. When I asked Raquel to reflect upon the unit or project during which she learned the most in the case study class, she immediately answered that it was the soil project. Raquel elaborated with a story about how she and her cousins would include the coal power plant in their childhood games. She recounted pretending that the behemoth plant was a giant robot. She and her cousins would compete to see who could run the furthest distance between consecutive flashes of the red aircraft warning lights on top of the smokestacks. They would pretend that the evil robot would capture the competitor who ran the shortest distance between flashes.

I asked Curtis, who grew up within a few blocks of the plant and was one of ten students to be involved with the soil project beyond class time, why he volunteered to collect samples for the soil project after school and on the weekends. Curtis told me that when he was a child, his mother would not allow him and his siblings to play outside when the power plant was emitting particularly large plumes of smoke. He recalled that his cousins would be reluctant to visit his house because they would be stuck inside due to his mother's concern about the impact of the power plant's pollution. Curtis was motivated by a desire to learn whether his mother's concerns were supported by scientific evidence. When I asked Gabriel the same question about his motivation for extracurricular involvement in the project, he explained that he was always curious about the plant when his parents would drive by it on the way to do errands. Gabriel suffers from asthma and he attributed his involvement to wondering whether the coal power plant was partially to blame for his condition. He also expressed a desire to prevent any future cases of asthma from being caused or exacerbated by pollution in the neighborhood. These childhood memories underscore how the coal power plant had some memorable impact on the lives of some students prior to their enrollment at La Lucha. But in my notes from the first meeting with students who volunteered to collect soil samples outside of school (dated 8/17/12), I noted that several students first learned about the plant in my colleague's environmental science class the year before. Jade, who grew up in East Ridgevale, was also one of the ten students who volunteered her time outside of class to work on the soil project. Jade remembered noticing and worrying about the plant when she got off the bus on her way to school and mentioned studying it in environmental science class as impactful for her. Cristina also mentioned that environmental science class at La Lucha was where she first really became aware of the coal power plant.

For community member, Ms. Juarez, "contamination" is a priority issue in the community. She spoke passionately about several other environmental issues in the community that have climbed to the top of her list of priorities with the recent closure of the coal power plant. The other community member I interviewed, Ms. Avila, mentioned that she was "fascinated" by the impact of pollution on the community and stressed the importance of holding local industries accountable for their emissions. So while most participants consider the lack of economic opportunities to be the central concern in the communities the school serves, issues of environmental racism and pollution (including the coal power plant) are still important in the way people understand the myriad of issues the community faces. Odette captured this complexity in our interview when she described her commitment to working for environmental justice and the relative privilege she feels as she studies to become a college-educated chemist:

> I know a lot of families have trouble paying the rent and stuff like that. But I really would like to focus on their environment because I feel like people do have rent paying issues and a bunch of other things that are piling up in their lives, and they don't have time to focus on their health…And so it would be nice to at least provide the community with a clean environment where they are healthy and they don't necessarily have to put their health at the top of the list because they don't have time to. So even with the coal power plant, it was great to have it shut down because now people don't have to – even though there's still a lot of pollution in [the neighborhood], they don't worry about that specifically causing them more asthma attacks…"

In this quote Odette captures the sad irony of environmental racism: those communities who can least afford to spend scarce time and resources on issues of environmental health are the same communities most afflicted with various forms of pollution. In another quote from her interview, Odette says that she feels a “moral” responsibility as a community member to leverage her college education in whatever ways she can to mitigate this contradiction for her family members and neighbors. So while the coal power plant or environmental racism may not have been at the top of the community’s list of concerns, these issues are important to many community members.

The role of the teacher’s political clarity.

The extended case method also requires the extension of the role of the researcher from observer to participant. In the context of studying the soil project, this extension implies considering my role in identifying the environmental racism of coal power plant pollution as a generative theme. Rather than being a neutral observer, my own experiences and point of view led me to contact COVER, which first brought the issue of the coal power plants to my attention. Witnessing my parents and neighbors struggle to close two medical waste incinerators when I was a high school chemistry student myself led me to study environmental racism. I came to understand the empirical evidence and theoretical frameworks that have established the centrality of race and racism in the unequal distribution of the impacts of toxic pollution (Bullard, Doyle, Warren, & Johnson, 2005; UCC, 1987). This deeper understanding of environmental racism informed previous curriculum I had developed while teaching at a predominately African American magnet school. When I shared examples of this earlier curriculum with other politically active teachers at events like the annual Teachers for Social Justice Curriculum Fair in Chicago, several teachers told me about COVER. These interactions are what led me to reach out to COVER as soon as I was hired to teach at La Lucha. I learned from COVER about the local importance of closing the coal power plant, but also about the particular ways an environmental racism framework explained its impact.

Based on what I learned about the coal plants from COVER and some additional research, I wrote a supplement for an environmental science textbook about the environmental racism of Chicago's coal power plants that was rejected for being "too political." In contrast, critical pedagogy acknowledges that all teaching is political and emphasizes that teachers must develop "political clarity" or a complex understanding of the origins and nuances of injustice and oppression (Freire, 1998; Freire & Macedo, 1987; Gutstein, 2012). To ignore issues of environmental racism or to avoid teaching about the power plants is also a political decision, as (Freire, 2006, p. 65) asserts:

> To try to get people to believe that there is such a thing as [a neutral educational practice], and to convince or try to convince the incautious that this is the truth is indisputably a political practice, whereby an effort is made to soften any possible rebelliousness on the part of those to whom injustice is being done. It is as political as the other practice, which does not conceal – in fact, which proclaims – its own political character.

To omit the concept of environmental racism from the curriculum or to hide my own political understandings in order to create the pretense of neutrality would actually make me an accomplice to the companies that profited from operating a virtually unregulated coal power plant in the Ridgevale community for decades. But in making my own position clear, my goal is not to convince students to agree with me, but rather to encourage them to ask critical questions and come to their own understandings. Indeed my analysis below indicates that rather than convincing students to agree with me, the soil project forced students to struggle with uncertainty created by inconclusive and messy data.

My analysis of meeting notes, journal entries, and curriculum maps make it clear that my extended involvement with various formations of politically active teachers and subsequently with COVER were essential to developing my own understandings and professional networks in ways that eventually made the soil project possible. The success of the soil project far out-paced my earlier attempts to enact this sort of curriculum because of the support, resources, and experience I gained through this involvement and these networks. At the heart of the political clarity that facilitated the soil project was understanding the phenomenon that some call eco-apartheid (Akom, 2011a), which led me to COVER, an organization explicitly committed to fighting against environmental racism. I include this analysis not to position myself as somehow more knowledgeable or involved than other teachers, but rather to acknowledge the role of my own worldview in identifying coal power plant pollution and environmental racism as potentially relevant to students at La Lucha. Political clarity was necessary in order for me to hear the community voices that identified this SSI as a generative theme (Freire, 1970/2001, 1998).

Implementation: What we did in (and out of) class

One of my goals on the first day of summer camp was to present the problem of the coal plants to the 20 eleventh graders in the class and to draw out and build upon the knowledge of the 9 twelfth graders who had previously studied the issue in environmental science class. I gave each table of students a small piece of coal, without revealing its identity. In a think, pair, share format, I asked them to consider this material's composition and properties (which were central concepts in the sophomore chemistry class taken by 25 of 29 students). I used our class discussion about composition and properties to pose the two local coal power plants as a problem (Freire, 1970/2001). A few of the seniors shared what they had learned about these plants, including their pending closure. Then I provided a technical explanation connecting the composition and properties of coal to the mechanism the power plants use to convert chemical to electrical energy. After I provided some historical context about the two coal plants, we read an article about the planned construction of a new coal gasification plant in a different Chicago neighborhood, one that was also inhabited by mostly Latin@ and African American residents. Students wrote an initial letter to the governor, who at the time was considering a bill about the proposed coal gasification plant, as a pre-assessment of their scientific knowledge about the combustion of coal, but also to see where they stood with respect to the political issues involved. This is an example of how I tried to weave together the learning of chemistry content with learning about the local SSI that was at the heart of unit.

Over the next week, I modeled the writing and balancing of chemical reactions in the context of introducing students to the various reactions involved in the “lifecycle” of coal as a fossil fuel. This instruction included an introduction to the various impurities in coal that are emitted through the smokestacks, including sulfur, lead, and mercury. Students participated in a “jigsaw” activity where they worked in small groups to plan a brief explanation about how to identify and predict the products for one type of chemical reaction. In reorganized small groups, they taught each other each of six different types of reactions. Interspersed with more modeling and practice of writing and balancing chemical equations, students conducted four laboratory activities that were focused on predicting the products of different types of chemical reactions that we had learned about in the context of coal. At the end of this four-day summer session, students were asked to write a more polished letter to the governor, which they were given the option of sending electronically, through the US postal service, or not at all.

During the previous school year, the director of COVER put me in touch with Professor Hernandez, a chemical engineer who was using his sabbatical from a local community college to investigate the levels of lead and mercury in soil surrounding Chicago's two coal power plants. His hypothesis was that there might be a pattern of increased lead or mercury concentration that would allow him to match the deposition of these heavy metals to power plant emissions. Between the summer camp and the start of the school year, one of my colleagues and I met with Professor Hernandez who had invited La Lucha students to participate in his study. We identified 33 of the 182 randomly generated sites that would be accessible to students who volunteered to participate in soil sampling. At the start of the school year, I introduced students to the project in the context of the unit we started in the summer camp. At that point, ten students (six of whom are also participants in this study) began to meet with me occasionally after school and during lunch to plan the logistics of soil sampling. These students went out on their own in smaller groups of two or three to collect 33 soil samples in triplicate from nearby sites that were randomly determined according to the procedures of Professor Hernandez' larger study. I also participated by collecting a soil sample from one of the randomly selected sites near my home.

While these 10 students collected soil samples and met occasionally to discuss the study and the class, our class moved on with the curriculum to the unit called "Introduction to Quantitative Analysis: Stoichiometry and Analytical Chemistry" and then onto a unit on gases. Just as we began the unit on gases at the end of September, we returned to the soil project as we took a field trip to a prestigious university in a nearby suburb in order to analyze the samples students had been collecting. During a day on campus, we took a campus tour, visited the multicultural, African American, and Latino student affairs offices, and ate lunch in a residence hall cafeteria. These activities were meant to reinforce a class theme of college access and success. But our primary reason for being on campus was to digest and analyze the soil samples that students had collected. Students used the undergraduate instructional laboratories and a procedure written for general chemistry students to grind, sift, and perform a nitric acid digestion of their soil samples. After the nitric acid digestion, students filtered and submitted their now aqueous samples to university researchers, who showed us how they would use an Inductively Coupled Plasma Atomic Emission Spectrometer (ICP-AES) to analyze them. All 29 of the students in the class thus had the opportunity to participate in undergraduate level laboratory work within the context of analyzing the soil samples that some of them had collected to investigate the long-term impact of the coal power plants on their neighborhood.

A few weeks later, we received a spreadsheet containing raw data from the ICP-AES. This spreadsheet contained measurements for lead and for mercury using three different emission wavelengths for each metal and expressing the results in terms of the milligrams of metal in 1.0 mL of the aqueous sample. First in small groups and then as a class, we discussed and decided what conversions and considerations we would need to make in order to make sense of this data. I modeled the use of spreadsheet software to make these calculations and then I shared the data spreadsheet with students. Over the next few days in class, we read and annotated a peer-reviewed journal article written by Nigerian environmental chemists (Wuana & Okieimen, 2011) about the contamination, analysis, and remediation of heavy metals in soil. We also spent some time comparing concentrations of lead and mercury in our samples to state safety and remediation standards. Finally, students were asked to write a lab report based on the results of the experiment. They were given the option of using instructions and rubrics for general chemistry classes at the university we visited or to use the instructions and rubrics for lab reports in all science classes at La Lucha. They were also given the freedom to make decisions about whether to rely on the whole class data set or only the data for the sample they were responsible for preparing in the lab. Students were expected to cite the peer-reviewed study and the state guidelines that we read in class. They were given the option of finding additional scholarly sources. Table VI provides a summary of student artifacts from the soil project, some of which are analyzed in the following sections.

Table VI: Soil Project Student Artifact Summary

Assignment/Artifact	Date Completed	Number of Artifacts Submitted for Study
Initial Letter to Governor	7/16	6
Final Letter to Governor	7/19	6
Soil Study Check-In	10/11	6
Annotations on Peer-Reviewed Journal Article	10/18	4
Soil Study Lab Report Draft	10/29	3
Final Soil Study Lab Report	11/1	9
Abstract and Reflection on Dr. Hernandez' Report	3/5	4

As the curriculum moved forward, we revisited the soil study when we studied electronic excitations and relaxations because this concept is central to the functionality of the ICP-AES used to analyze our soil samples. We also revisited the study when we studied atomic structure and isotopes because Professor Hernandez originally planned an extension of his study to include isotopic fingerprinting as a way to trace lead and mercury in the soil to the coal burned in the plant. Then just after winter break, plans emerged from meetings I had with a handful of students who had collected soil samples and the director of COVER to organize a family science night as a venue where the results of the soil study could be shared. The group of 10 students (with one substitution) who had collected the soil samples had continued to meet for the purposes of discussing the strengths and weaknesses of the course in co-generative dialogues (Emdin, 2010d; Tobin & Roth, 2005). Eight of the ten students who collected soil samples took the lead in preparing a presentation and spreading the word about the science night throughout the school community. Several of these students also participated in planning meetings with COVER organizers and EPA officials who were invited by COVER to participate.

Analysis of student achievement

Student work artifacts from the soil project contain substantial evidence of academic achievement and development. But the simplicity of this statement belies the complexity in the following analysis of student artifacts through the lenses of standards documents and the tensions felt by science teachers as we try to negotiate various curricular priorities. I begin my analysis by using the NGSS and AP chemistry course description to consider the ways in which students did and did not demonstrate understandings and practices valued by traditional science disciplines (especially chemistry) during the soil project. This analysis considers a quiz question and students' final lab reports for the soil project. Through an examination of these work artifacts, I call into question whether NGSS performance expectations support curriculum that engages students in dealing with the complexities and uncertainties that are inevitable in problem-posing education. I supplement this analysis by using Common Core State Standards to examine student writing during the soil project. This analysis demonstrates how a problem-posing unit like that soil project can provide rich opportunities for students to engage in various forms of academic writing, but also suggests that I did not always provide adequate support or scaffolding to make the most of these opportunities.

Analysis of academic achievement through the lens of the NGSS.

Unfortunately work from the soil study provides limited evidence of students demonstrating any of the NGSS performance expectations associated with the disciplinary core ideas of chemistry (HS-PS1: Matter and its Interactions) or those associated with sustainability (HS-ESS3C: Human Impacts on Earth Systems). I am referring here to the specific performance expectations as they are written to weave together disciplinary core ideas, science and engineering practices, and cross-cutting concepts. There was evidence in student work of achievement with respect to individual ideas, concepts, or practices valued by the NGSS or the NRC Framework. There are also NGSS performance expectations related to human impacts on earth systems that arguably apply to the soil project. However, my analysis will focus on the NGSS performance expectation that I targeted in the chemical reactions unit, which became the soil project for simplicity and because the case is a chemistry class. In the 2012 draft of the NGSS that I used for planning, this performance expectation was written as

> HS.PS-CR-e: Construct and communicate explanations using the structure of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties to predict the outcome of simple chemical reactions. (NGSS Lead States, 2012)

In the final version of the NGSS, the wording was changed to the following:

> 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. (NGSS Lead States, 2013)

Regardless of which version is applied, my analysis of student work indicates that students did not meet this performance expectation in their work associated with the soil project. There is evidence of achievement with the various components of this performance expectation (which are deconstructed in Table VII below), but in combinations and with foci that are different from the NGSS. In some cases, if I were to teach the course again now that the NGSS have been finalized and adopted, modifying assignments within the soil project to better align with the NGSS may lead to richer learning opportunities. But overall, the soil project cannot be adapted to align with a specific NGSS performance expectation without losing the focus of the project. I argue below that this is related to the ways this NGSS performance expectation values the simplicity and predictability of chemistry as it is traditionally taught over the complexity and uncertainty that is inevitable in real-world applications of chemistry concepts. Examples from student work illustrate these tensions.

Table VII: Three Strands of NGSS performance expectation HS.PS1-2 (NGSS Lead States, 2013)

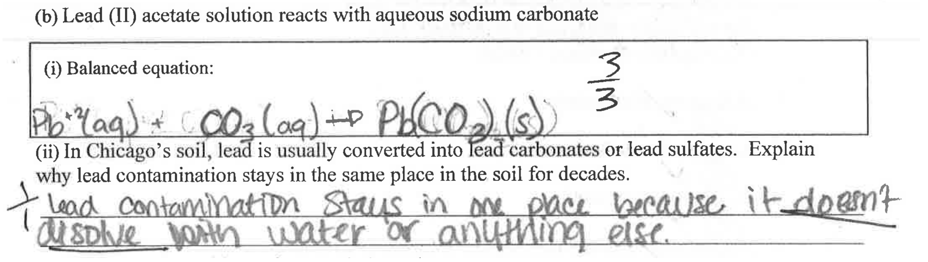
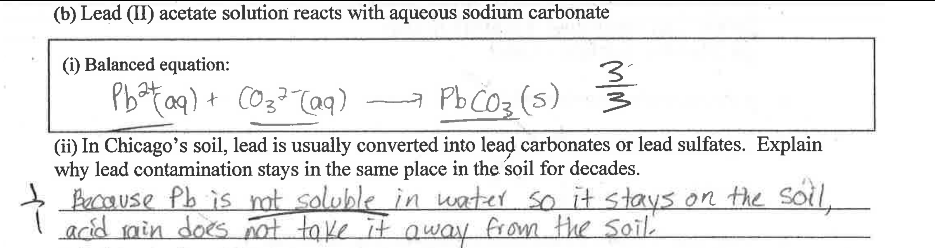
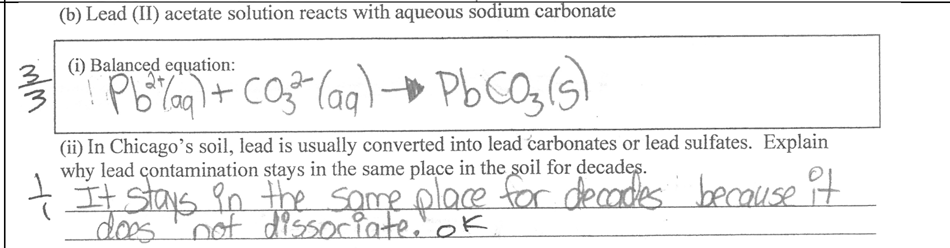
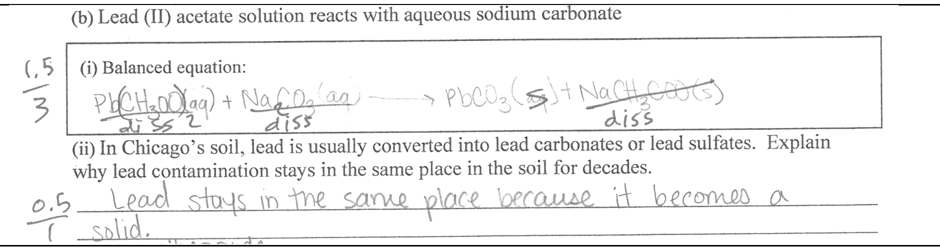
HS.PS1-2: Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties		
Science and Engineering Practice: Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future.	Disciplinary Core Ideas: PS.1A: Structure and Properties of Matter: The periodic table orders elements horizontally by the number of protons in the atom's nucleus and places those with similar chemical properties in columns. The repeating patterns of this table reflect patterns of outer electron states. PS1.B: Chemical Reactions: The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions.	Cross-cutting concept: Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena.

Lead in soil problem on reactions quiz.

The draft performance expectation that I used in my planning asked students "to predict the outcome of simple chemical reactions." This was also an explicit goal of the summer lessons that introduced students to various types of chemical reactions through the SSI of coal power plant pollution and an important skill in the AP chemistry course description. Students had the opportunity to practice predicting various chemical reactions in a daily routine that is further explored in Chapter VII and were also assessed on their ability to predict the products of chemical reactions in monthly quizzes throughout the year. I wrote these six reactions quizzes to align with one type of free response question that was included on each year's AP chemistry exam prior to 2014. These quizzes were included in the binders submitted by Cristina, Curtis, Francisco, Odette, and Raquel, who demonstrated the ability to predict the outcomes of simple (and sometimes not so simple) chemical reactions to varying degrees.

On the first of six reactions quizzes (dated 9/4/12), there was a question that was relevant to the soil project as it dealt with the solubility of lead compounds and asked a follow-up question about soil contamination. This question is more indicative of the “injected relevance” approach described in Chapter VI than the problem-posing approach that is the focus of this chapter, but I include it here because it provides insight into students’ achievement with respect to the targeted NGSS standard. This particular question was included in the binders submitted by Cristina, Curtis, Odette, and Raquel, whose responses are shown in Table VIII below. The second page of Francisco’s reaction quiz, which includes this problem, was missing from my copy of his binder, so I was unable to include his response here. Three out of the four students for whom I have answers for these two problems correctly predicted the product of this reaction between lead (II) acetate and sodium carbonate. While the answers appear to be relatively simple, the problem implicitly requires students to be able to convert the chemical names to symbols while accounting for charges, to understand double replacement reactions, and to know the solubility rules in order to predict the formation of solid lead (II) carbonate. Students also have to know to exclude any “spectator ions” like sodium and acetate that should not appear among the products. While Raquel struggled with a few of these steps, the other three students performed them almost flawlessly, with the only other exception being that Cristina neglected to include a charge on a carbonate ion. All three of these students also correctly (however briefly) used their knowledge of solubility rules to explain why lead compounds persist in Chicago’s soil for decades after the initial contamination has occurred. According to my archival records, the class average on this first reactions quiz was 62%; all four participants who submitted this artifact did better than the class average. But while these students' work may not be a representative sample of the class, the problem and their responses in Table VIII illustrates both how the NGSS might improve this assessment and also the limitations of the NGSS to support a unit like the soil project.

Table VIII: Student responses to Reaction Quiz 1 question about lead

Student	Response	Overall Score on Reaction Quiz 1
Cristina	 (b) Lead (II) acetate solution reacts with aqueous sodium carbonate (i) Balanced equation: $Pb^{+2}(aq) + CO_3(aq) \rightarrow Pb(CO_3)(s)$ $\frac{3}{3}$ (ii) In Chicago's soil, lead is usually converted into lead carbonates or lead sulfates. Explain why lead contamination stays in the same place in the soil for decades. $\frac{1}{1}$ lead contamination Stays in one place because it doesn't disolve with water or anything else.	89%
Curtis	 (b) Lead (II) acetate solution reacts with aqueous sodium carbonate (i) Balanced equation: $Pb^{2+}(aq) + CO_3^{2-}(aq) \longrightarrow PbCO_3(s)$ $\frac{3}{3}$ (ii) In Chicago's soil, lead is usually converted into lead carbonates or lead sulfates. Explain why lead contamination stays in the same place in the soil for decades. $\frac{1}{1}$ Because Pb is not soluble in water so it stays on the soil, acid rain does not take it away from the soil.	89%
Odette	 (b) Lead (II) acetate solution reacts with aqueous sodium carbonate $\frac{3}{3}$ (i) Balanced equation: $Pb^{2+}(aq) + CO_3^{2-}(aq) \rightarrow PbCO_3(s)$ (ii) In Chicago's soil, lead is usually converted into lead carbonates or lead sulfates. Explain why lead contamination stays in the same place in the soil for decades. $\frac{1}{1}$ It stays in the same place for decades because it does not dissociate. ok	82%
Raquel	 (b) Lead (II) acetate solution reacts with aqueous sodium carbonate $\frac{1.5}{3}$ (i) Balanced equation: $Pb(CH_3OO)_2(aq) + Na_2CO_3(aq) \longrightarrow PbCO_3(s) + NaCH_3COO(s)$ diss diss diss (ii) In Chicago's soil, lead is usually converted into lead carbonates or lead sulfates. Explain why lead contamination stays in the same place in the soil for decades. $\frac{0.5}{1}$ Lead stays in the same place because it becomes a solid.	71%

The finalized NGSS performance expectation removes the emphasis on predicting the outcomes of a chemical reaction and instead focuses on students ability to "construct and revise an explanation of the outcome" by relying on some disciplinary core ideas in chemistry. Whereas the quiz question above assesses students' ability to properly manipulate the symbols of chemistry that communicate a tacit understanding of these disciplinary core ideas, asking students to explain these outcomes would encourage students to engage in metacognition and would better assess their understandings. An assessment that asked students to construct and revise explanations about how they predicted the outcomes of a reaction would allow me to know whether a student like Raquel understands some of the underlying concepts but struggles with the symbols of chemistry. It would also provide me with insight as to whether the other students have simply mastered manipulating the symbols without developing deeper understandings. Furthermore, giving students an opportunity to revise their explanations would likely lead to deeper learning of these concepts. Fortunately students were given opportunities to explain their reasoning on problems like this one during a daily ritual that is described in chapter XII. Whereas this problem in based on the previous AP chemistry course description, the revised AP chemistry curriculum includes more emphasis on "science practices" so that there is less tension between the priorities of AP chemistry and those of the NGSS (College Board, 2011).

In the ways described above, aligning instruction and assessment with the NGSS performance expectation could improve the activities associated with the soil project. However a deeper analysis of explanations students wrote during the soil project reveals that seeking alignment between the NGSS performance expectations and problem-posing science curriculum may be more problematic. The first example involves the follow-up question on the quiz above, which also demonstrates how the NGSS may divert the focus of the soil project away from the SSI that inspired it. Even though the follow-up question only required a very brief explanation, it focused on how an understanding of the reaction (especially the water solubility of lead (II) carbonate) impacted the distribution and persistence of toxins in the local environment, rather than on explaining the outcome of the reaction itself. The focus of the soil project was not on explaining the reactions involved in the combustion of coal so much as it was on developing an understanding of them that would allow students to explain their impact on the local environment. This distinction between the concerns of “pure” and “applied” chemistry is important in understanding how the NGSS performance expectations may be at odds with a problem-posing approach and is evident in the final lab reports students wrote for the soil project.

Soil project lab reports.

All nine of the participants submitted the soil project lab report among their artifacts. Students were given the choice between using the La Lucha science department instructions or the lab report guidelines from the university we visited for their soil study lab report. All nine participants elected to use the more rigorous university lab report guidelines, which may be an indication of the level of academic achievement that was encouraged by the soil project. I did not provide a minimum or maximum length for the soil project lab report, but the nine lab reports submitted for this study ranged in length from 6 to 8 double-spaced typed pages. At the time, I evaluated students’ work on the soil project lab reports favorably using grading guidelines from the university chemistry department we visited.

Marisol provided one of the most well developed explanations of the phenomena we were studying in the soil project lab reports. In her introduction, she explained:

> Lead is a heavy metal that can volatize during high temperature (Okieiemen and Wuana, 2011). The power plants operate at very high temperatures and would have perfect

> conditions to volatize lead. Toxic substances like heavy metal particulates can then bind to parts in the soil called colloids.

Here, Marisol focuses on explaining the mechanism by which the coal power plant contaminates the surrounding area with heavy metals, which is the focus of the soil project. If the focus was on fulfilling the NGSS, she could have taken her explanation one step further to explain how the properties of lead might allow us to predict that it would be vaporized in elemental form rather than simply oxidized in the high temperature conditions in the coal power plant. She could even connect these properties to lead's electron configuration or its location on the periodic table. In fact, if I pushed students to make these sorts of connections in the revisions of their lab reports, it may have resulted in deeper understandings of the concepts. But absent that sort of push, Marisol went on below to complicate the mechanisms by which lead is deposited in urban soil and to thus justify the soil project's consideration of mercury concentrations in soil:

> The power plants are not the only source of lead contamination though. Through aerial emissions of lead from the combustion of leaded gas from cars can be another source of contamination (Okieiemen and Wuana, 2011). This is especially found in urban areas near busy streets and roads. Looking at heavy metals like mercury is more accurate because the only source of mercury could the coal power plants.

Overall Marisol cited three scholarly sources along with course materials produced by me and by Professor Hernandez in her introduction. She concluded her introductory explanation with a prediction that "Since most of the particulates are airborne, higher levels of lead and mercury will be found near areas east of the power plants: in close proximity."

In the conclusion of her lab report, Marisol used data from the study to revise her introductory explanation, noting that the highest concentrations of lead and mercury were not found in close proximity to the plant. Marisol included two graphs of the samples she analyzed to illustrate this point, the first of which is shown in Figure 3, with the name of the power plant redacted. Marisol generated this graph using spreadsheet software and included correct labels for axes and a legend to distinguish between the results for lead (Pb) and mercury (Hg, the curve for which is not visible).

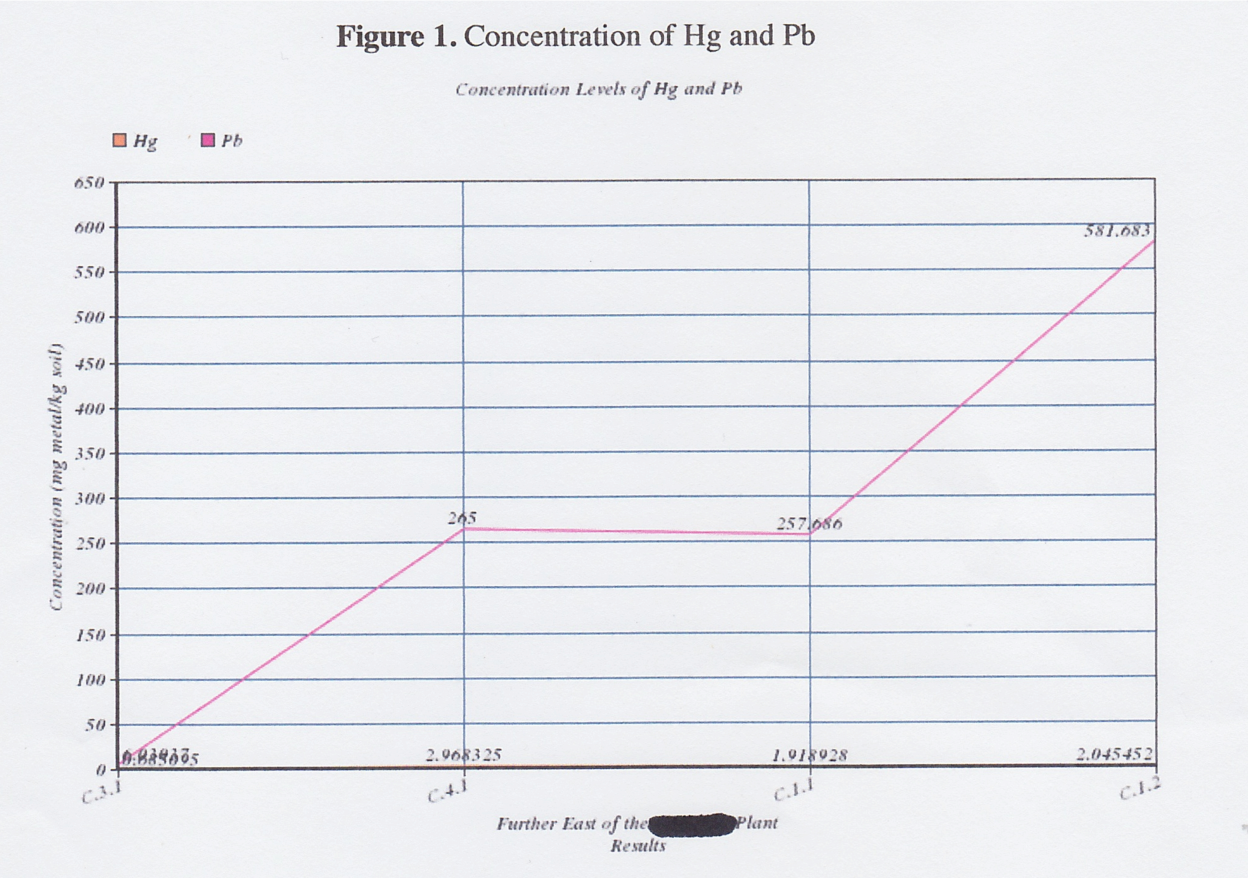


Figure 3: Graph from Marisol's soil project lab report

Marisol stopped short of specifically hypothesizing about the cause of these unexpected results or fully constructing a revised explanation, which would have matched better with the science practice described by the NGSS. Instead, she goes on to suggest several possible follow-up studies that could clarify the results, including an isotope fingerprinting study that Professor

Hernandez originally proposed, increased use of statistical tools, and, “possibly looking at the health effects of the power plant through a different lens, a biological lens.”

These excerpts from Marisol’s report highlight the tensions between problem-posing science education and the NGSS performance expectations. These tensions are related to the specificity of the performance expectations, but also indicate an implicit idealization of science within the NGSS that problem-posing science education challenges. In the above excerpts, Marisol exhibits sophisticated academic writing and sound scientific reasoning about a real problem in her community. Her writing explicitly references peer-reviewed literature and includes graphs she constructed to present the data from an investigation she conducted. In this way, Marisol’s performance could be evaluated favorably according to the framework that guided the development of the NGSS and according to components of the performance expectation in Table VII above (NGSS Lead States, 2013; NRC, 2012). But at the same time, in seven pages of writing, Marisol did not fully demonstrate proficiency with respect to any of the specific NGSS performance expectations.

For simplicity sake, I will continue to focus on the targeted performance expectation, HS.PS1-2. The first misalignment between the soil project and this NGSS performance expectation was discussed above, namely that the soil project focuses on constructing an explanation about the environmental distribution of the products of chemical reactions as opposed to explaining the formation of these products in the first place. As I asserted above, this misalignment is related to the fact that the NGSS focus on “pure” chemistry, or the study of isolated chemical systems for the purpose of understanding them as opposed to “applied” chemistry, or the study of the interactions between chemistry and the world or environment. There are other NGSS performance expectations that focus on the environmental impact of human activities, but these also do not match up with the content of the soil project. NGSS performance expectations weave together the three strands (practice, ideas, concepts) in a predetermined way that limits teachers' ability to capture the spirit of the NGSS by tailoring the specifics to their context.

The need for more adaptable expectations is illustrated by Odette and Raquel's lab reports. In constructing explanations about why we should undertake the soil project in their lab report introductions, these young women strayed even further from the NGSS disciplinary focus than Marisol, but still managed to make impressive scientific insights that are relevant to the local context. For example, Raquel cited the same peer-reviewed journal article as Marisol to point out that the piles of fly ash stored behind the coal plant could also be another source of wind-blown mercury and lead pollution. In her conclusion, Raquel suggested phytoremediation (decontaminating soil by growing certain plants) as a method to clean up soil contaminated with heavy metals. Odette focused on the potential health impacts of heavy metals and noted the prevalence of backyard vegetable gardens in the neighborhood to suggest that heavy metal soil contamination was a particularly urgent concern locally. She also cited the Okieiemen and Wuana (2011) article to be specific about which types of vegetables are most likely to be contaminated. All three of these students thus submitted work that illustrates the goals of justice-centered science pedagogy by combining knowledge of and concern for the community with information from a peer-reviewed scientific journal article to explain the significance of the soil project scientifically and locally. These sorts of explanations were present in all of the nine soil project nine reports and demonstrate how justice-centered science pedagogy has the potential to develop scientific expertise among youth who also posses local knowledge that Corburn (2005) documents as important to addressing issues of environmental racism in urban communities. But at the same time, none of the nine reports included explanations that dealt specifically with the outcomes of the chemical reactions as required by HS.PS1-2, in part because of the way the three strands of the NGSS are braided together in a pre-determined way.

The second misalignment between the NGSS and problem-posing science education arises from the fact that the NGSS focus on simplicity and predictability whereas investigating real SSI inevitably forces us to deal with complexity and uncertainty. This contrast is evident in the focus of HS.PS1-2 on “simple chemical reactions” whereas Marisol’s discussion of other possible sources of lead contamination highlights the complexity of chemical reactions in an urban environment. This contrast also becomes apparent upon further examination of cross cutting concepts and science and engineering practices shown in Table VII above. These NGSS strands focus on “evidence for causality in explanations of phenomena” and “the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future,” respectively. While these phrases certainly reflect the ideals of scientific inquiry, Marisol’s report indicates that our soil project did not find such clear “evidence for causality,” which is arguably a more likely outcome of real scientific research. It also may explain why Marisol did not attempt to revise her initial explanation other than to present the data and suggest possibilities for future research.

Some other students did attempt to explain the unexpected results. For example, in the discussion of his report, Jackson wrote:

> Therefore, my hypothesis that the soil close to the power plants would have high concentrations of lead and mercury, even higher than the maximum exposure limit, was incorrect. This could be because of the height of the smokestacks. The power plant has

> smokestacks [that] are 450 ft. tall. The smokestacks are tall enough for the smoke to drift over West Ridgevale and fall on areas further out.

In this excerpt, Jackson cited a recent newspaper article that mentioned the height of the smokestacks. Jackson also took seriously the limitations of the soil project, which examined just two of many contaminants emitted by the coal power plant and did so in one limited way. In the conclusion of his lab report, he wrote, “The power plants did not cause high levels of lead and mercury in Ridgevale soil. However, this does not mean that the power plants did not pollute communities.”

Professor Hernandez’ larger study, of which the soil project was part, ultimately corroborated Jackson’s assertion. Professor Hernandez found alarmingly high levels of heavy metals outside of Ridgevale, further downwind from the power plants. The larger study also documented a statistically significant increase in lead concentrations when comparing concentrations upwind from the plant in Ridgevale with concentrations between the two plants or downwind from both. Professor Hernandez had not completed his analysis at the time students wrote their reports and students’ reports only focused on the soil samples their small group or our class had collected in the neighborhood and digested in the lab. It should also be noted that Professor Hernandez presented his results as relatively inconclusive, but as providing enough concern about the impact of the power plants to warrant further study. It is also worth reiterating that the soil project, by focusing on heavy metal soil deposition, only measures one of many possible impacts of the coal power plants on Chicago communities.

The soil project provides evidence that: “In the everyday world of a community, science emerges not as a coherent, objective, and unproblematic body of knowledge and practices. Rather, science often turns out to be uncertain, contentious, and unable to answer important questions pertaining to the specific (local) issues at hand" (Roth & Calabrese Barton, 2004, p. 7). This reality puts problem-posing science education at odds with the focus in the NGSS on explanations involving causality and predictability. But excerpts from student work above demonstrate that the soil project still supported the development of sophisticated academic skills within a relevant community context. Meanwhile the messiness and authenticity of the soil project also supported students to think in complex ways about the relationships between science and struggles for social and environmental justice. The next two sections continue my analysis of data from the soil project as they, respectively, (1) elaborate my analysis of student academic achievement using the lens of select Common Core State Standards, and (2) consider the maintenance of cultural competence and the development of critical consciousness through the four components of socio-transformative constructivism (Rodriguez, 1998).

Analysis of academic achievement through the lens of the CCSS.

Through the writing assignments summarized in Table VI, the soil project created opportunities for students to "Write routinely over extended time frames (time for reflection and revision) and shorter time frames (a single sitting or a day or two) for a range of discipline-specific tasks, purposes, and audiences" (CCSS.ELA-LITERACY.WHST.11-12.10). Students demonstrated proficiency with respect to this standard even though it was not one that I explicitly planned to support in the soil project. The authentic context provided by the project necessitated these various sorts of writing, many of which I assigned as these needs arose as opposed to planning them at the beginning of the year.

The CCSS writing standard that I originally planned to teach in the soil study was CCSS.ELA-LITERACY.WHST.11-12.1: "Write arguments focused on discipline-specific content" (National Governors Association, 2010). The discipline-specific content I targeted in this unit is described within the College Board’s AP Chemistry course description in sections III and IV: “Reactions” and “Descriptive Chemistry.” The reactions section includes knowledge of types of reactions including acid-base, precipitation, and oxidation reactions. The descriptive chemistry section notes, “descriptive facts, including the chemistry involved in environmental and societal issues, should not be isolated from the principles being studied” (College Board, 2012, p. 8).

The two letters to the governor that students wrote during the summer session (on July 16 and July 19) provide initial examples of students’ “arguments focused on discipline specific content” as preliminary writing activities. Later in the semester, while we were preparing to write formal lab reports for the soil study, students wrote a short summary of the soil project in preparation for the lab report (October 11), then a draft lab report, and a final lab report (November 1). The lab reports provided an opportunity to write a longer “informative/explanatory text” that students revised over time (as evidenced by peer-edited drafts included in several of the students’ lab report portfolios or course binders). When Professor Hernandez completed his larger study, students read and annotated it and wrote a short reflection on his findings also (March 5). Thus the soil study provided the routine and varied types of discipline-specific writing assignments required by the CCSS. The shorter artifacts mentioned here are included in the appendix.

A time-series analysis of the two letters to the governor written during the summer session as compared with the final lab report indicates that students did improve their ability to “write arguments focused on discipline-specific content” of descriptive chemistry and chemical reactions. But it also indicates that, besides the final lab reports, I did not provide much in the way of support and scaffolding for student writing. The student artifact data include 6 complete pairs of initial and final letters to the governor from the soil study (some included in course binders and others attached to soil study lab reports). All six of these students encouraged the governor to veto the bill that would have paved the way for the building of a coal gasification plant in Chicago in both letters. In the first letter, students wrote generally about "pollution" and some noted that their point of view was informed by growing up in a neighborhood with a coal power plant, but no students used specific content knowledge to support their position. In the final letters, 5 of the 6 students used some limited knowledge of chemical reactions from the summer session curriculum to support their point of view. For example, Jade wrote:

> Another problem with this power plant is the mercury emissions from burning coal. Coal is not a pure source. Mercury is an impurity in coal. So when coal is burned the mercury does not oxidize and it escapes out of smoke stacks as a gas.

Here Jade correctly identifies mercury as an impurity in coal that is emitted in gaseous form during combustion. While some of the mercury in coal plant emissions may be oxidized by other combustion products, Jade's assertion that mercury volatilizes rather than oxidizes demonstrates a correct understanding of the chemical reactions involved in coal combustion and is used in her letter to support her position that the governor should veto the bill in question (Koson et al., 2009). My analysis shows that 5 of 6 students were able to improve their letters by using knowledge about chemical reactions to support their position that the governor should veto the bill. However, Francisco's letter remained virtually unchanged from the start of the week to the end and there were examples of content misunderstandings in two of the five letters. Still Francisco's two letters to the governor and an excerpt from the final lab report illustrate a trend in the improvement in students' use of content knowledge to support arguments. The first two sentences from Francisco’s initial letter to the governor summarize his argument in this short letter.

> I believe that you should not sign the bill. I believe this because Chicago does not need more pollution. After getting rid of two coal power plants there is no point in building a new one.

In the remainder of the letter, which is only one paragraph long, Francisco does not mention any specific pollutants or make use of science content knowledge. Francisco’s initial letter was representative of others in that “pollution” was used only as a general term with no specific contaminants mentioned. But his pair of letters were unique among the pairs of letters submitted as artifacts in that he made no improvements in terms of including science content knowledge between the initial and final letter. While he did add some specifics to his argument related to the creation of jobs and cost of electricity, his thesis remained essentially the same:

> I believe you should not sign Senate Bill 3766. You [should] not sign the bill because it really isn’t beneficial to the city. Building a new power plant will just cause more pollution. Chicago really needs to lower its pollution rate.

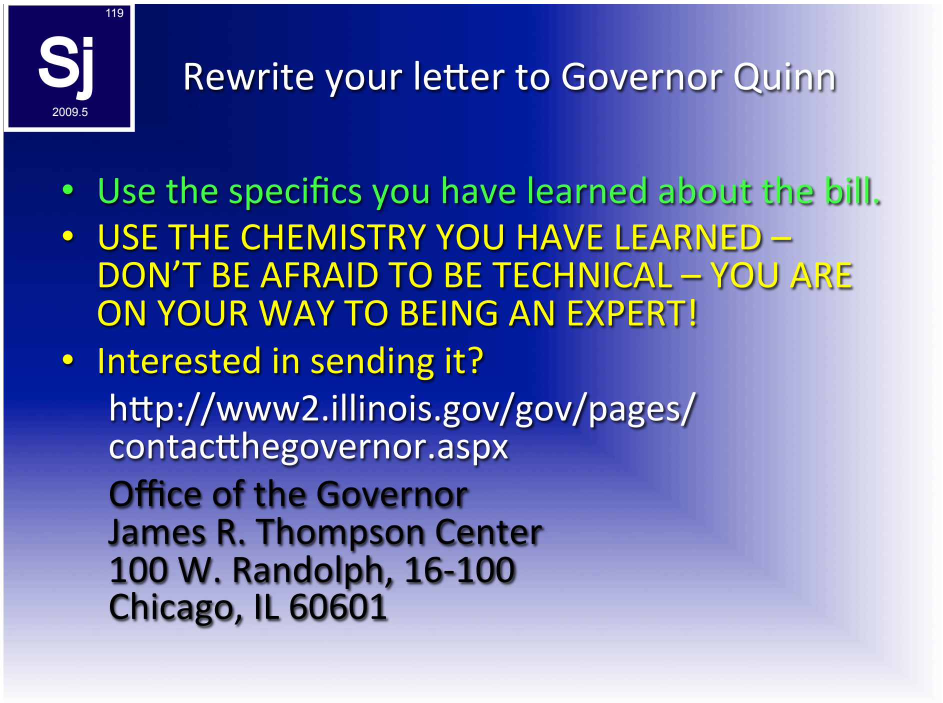
In contrast, Francisco’s final lab report shows a much more sophisticated approach to argumentation that makes use of scientific content knowledge and quantitative evidence obtained from the soil project. Here is an argument from his results section:

> I concluded that the power plants have not highly contaminated the land with mercury but one location was highly contaminated with lead…The highest amount of lead contamination was 646 mg of metal/kg of soil in the location C.3.1 which is above the harmful level of 400 mg of metal/kg of soil… C.3.1 is near the expressway so there is a possibility that car emissions have caused a part of that lead contamination.

This excerpt from Francisco's lab report implies considerable data analysis work on his part and also includes an important mistake I found upon careful analysis. Francisco has taken raw data from the ICP-AES, used the units from this data to guide his calculation of the concentrations of heavy metals in the soil samples. He has ensured that the result of this calculation matches the units used by the state regulations. He then compared all data points with these regulations and found one outlier. Unfortunately, the outlier he found actually corresponded with the site labeled C.1.2, which occupied an adjacent row to C.3.1 in the spreadsheet of raw data. The site labeled C.1.2 was not nearly as close to the expressway as C.3.1. So while Francisco's interpretation does not ultimately hold up, he still communicated an evidence-based claim in academic language with proper units and finally provided a possible reason for the anomalous data point. In terms of academic achievement as defined by several CCSS, this marks a significant improvement from the argument Francisco made in his letters to the governor. Reflecting on the case study class in his interview, Francisco credited his science classes at La Lucha with helping him improve his ability to develop and write arguments about issues of social justice across academic disciplines. He noted that his science classes developed his ability to use data as evidence in support of any argument.

Despite Francisco's reflection, it is not clear to what extent improvements in student arguments over time truly reflect an increase in student abilities. These improvements must also be considered in light of increased time, scaffolding, and support allotted to the final lab reports as compared with the initial letters to the governor. Student letters to the governor from the summer session ranged from Francisco's one paragraph to slightly more than one handwritten page. Students completed these letters during the first and last summer sessions in roughly 20-30 minutes of class time. For the initial letter, students were only given brief oral instructions to

“Write a letter to the Governor expressing your views about whether he should sign this bill and why.” For the final letter, students received the instructions shown in Figure 4. In contrast for the final report, students were given several pages of printed instructions. They wrote rough drafts of their lab reports for homework over a period of two weeks and had a chance to complete a peer review of their draft reports in class before revising and submitting a final version. This resulted in final lab reports that ranged from 6-8 typed pages with five clearly defined sections plus abstracts and references sections. I am not presenting the letters to the governor and the final lab reports as forms of pre- and post-assessments designed to measure student growth. Instead I am suggesting that with substantial time, support, and expectations, students demonstrated proficiency with respect to several CCSS for writing in science and technical subjects during the soil project.



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Sj
2009.5

Rewrite your letter to Governor Quinn

- Use the specifics you have learned about the bill.
- USE THE CHEMISTRY YOU HAVE LEARNED – DON’T BE AFRAID TO BE TECHNICAL – YOU ARE ON YOUR WAY TO BEING AN EXPERT!
- Interested in sending it?

  http://www2.illinois.gov/gov/pages/contactthegovernor.aspx

  Office of the Governor
  James R. Thompson Center
  100 W. Randolph, 16-100
  Chicago, IL 60601

Figure 4: Instructions for final letter to the governor

Student learning, cultural competence, and critical consciousness

The previous two sections document student achievement during the soil project, as determined by two sets of nationally important standards documents and the AP chemistry course description. But the analysis of student artifacts through the lens of the NGSS above indicates that standards are inadequate to evaluate the complexity of student thinking and learning in the context of a problem-posing science education. In order to push my analysis of student learning further, this section uses the socio-transformative constructivism (sTc) framework (Rodriguez, 1998) to analyze interview data and extend my analysis of student work from the soil project. I consider student learning through the four components of sTc (authentic activity, the dialogic conversation, metacognition, and reflexivity). My analysis indicates how students' engagement with the production and critique of scientific knowledge supported the maintenance of cultural competence and the development of critical consciousness alongside academic achievement (Ladson-Billings, 1995).

Authentic activity positions students as intellectuals in their communities.

The soil project constitutes an example of what Rodriguez (1998) calls "authentic activity," one component of an sTc approach to teaching and learning science. In this approach, "in addition to doing minds-on, hands-on activities, students are urged to reflect on how the subject under study is socioculturally relevant and tied to everyday life" (Rodriguez, 1998, p. 600). For example, as she was reflecting on writing the soil project lab report in our interview, Cristina emphasized this relevance:

> We're not just reading a report by other people. We're doing our own report by ourselves as people who live in the community and are exposed to the environmental issues here. And we're doing something – not necessarily to fix it, but to understand it, which makes

> a huge difference. And I really liked it because I was taking what I was learning in class and applying it to my community.

As an example of "authentic activity," the soil study provided a context for learning where the development of critical consciousness and the maintenance of cultural competence were interwoven with academic achievement. By engaging with an SSI that was important in their community, the soil study pushed students not only to learn chemistry, but also to think about the relationship between science and social change, to develop critical consciousness with respect to the issue of environmental racism, and to consider the importance of maintaining cultural competence as it relates to communicating scientific ideas to their families and neighbors. In this way, the soil study supported students development as transformative or "barriorganic" intellectuals (Morrell, 2008; Romero, 2014).

Together with COVER and officials from the Region 5 US EPA, students from the case study class helped to organize a family science night, which was held on a Thursday evening in the school cafeteria in March 2013. The first part of the event was organized like a science fair with students from several science classes at La Lucha presenting projects from their classes on tri-fold boards set up on cafeteria tables. EPA officials and COVER organizers also set up fair-style presentations at tables where they promoted their own environmental investigations, community gardens, art projects, and other campaigns. The sign-in sheet from that evening contains 126 names of parents, teachers, students, and other community members. For most of the evening, the cafeteria (which accommodates about 350 students during each lunch period) was a little less than half full. After the fair-style portion of the event, EPA officials presented the results from the various studies they were conducting in the neighborhood. Eight students from the case study class (including participants Cristina, Curtis, Odette, Marisol, and Gabriel) contributed their own 17-minute presentation of the results of the soil study. They were followed by Professor Hernandez, who expanded on their presentation by communicating the results of his larger study. Family science night garnered some local media attention as two outlets, including a daily Spanish-language newspaper, covered the event.

Reflecting on the science night presentation in our interview, Cristina described the impact this way: "[Community members] weren't being told just by some PhD EPA officials or city officials what's in their neighborhood, but they were being told by their own kids, their own young people from the neighborhood, which is even more important or impactful." Cristina's comments echo Corburn's (2005) assertion that the people living with the impacts of environmental racism have important contributions to make to the ways scientific experts study and remediate urban contamination. But Cristina also pushes this idea one step further by arguing that the development of experts from within the community is a powerful way to understand and address these issues. Odette had a similar understanding of the impact of science night and also speculated that by embracing their role as intellectuals, students may have decreased the distance between science and their fellow community members:

> It was cool to have the science out for the people and I feel that it was even more important that it was…high school students who live in the community doing the science …it makes the distance closer…So it's like people have the realization that they can do science. They don't have to necessarily work for the government like the EPA guys…in order to be able to do science.

Ms. Avila, who was in the audience that night, also echoed Cristina and Odette's comments about the unique ability of community youth to communicate with their parents and neighbors. Ms. Avila told me, "…when it's the youth doing it, I think that's incredibly powerful. They have this wonder about themselves…the excitement of being able to show something that is true, and important, and vital for the people that live in communities like Ridgevale."

If science education is going to be a catalyst for social change, it must position young people as transformative intellectuals, as producers of knowledge and culture who are capable of solving the problems facing their communities (Duncan-Andrade & Morrell, 2008; Morrell, 2008; Romero, 2014). This requires that science education support academic achievement, both in terms of providing access to the STEM "pipeline" but also in terms of educating scientifically literate community members. Students' reflections on the importance of their presentation at family science night underscore the importance of learning opportunities that encourage the simultaneous development of critical consciousness and cultural competence in support of these sorts of academic achievement.

Gabriel's reflections also provide insight into his development of critical consciousness about the relationship between science and social change. He characterized students' presentation at family science night as "a kind of protest, but more academic." Odette was more measured about the potential role of science in social change:

> So when people were protesting the coal power plant, the rest of the community and people driving by saw the activism. And science wasn't – I mean, it was obvious, like let's shut this down because it's bad for our health and that's science, but it wasn't really the science that people noticed, it was the activism.

Certainly the science students presented at family science night had no role in the closure of the coal power plants, as the soil project had not even begun when the closure of the plants was announced. But Odette questions whether science played a meaningful role in the campaign that led to that announcement. She positions the negative health impacts of the coal plant as a given and credits activism, rather than science, with galvanizing the community in support of their closure. Still Odette’s career goals challenge the simplicity of the relationship she communicates here as she aspires to be a chemist and “specifically having my work in the lab connecting to activism.” Justice-centered science pedagogy is concerned with inspiring exactly these sorts of goals, conversations, and questions among students, teachers, and community members.

The dialogic conversation requires the maintenance of cultural competence.

Cristina’s and Ms. Avila’s comments above attribute the impact of students’ science night presentation to their positionalities as community members and youth who thus have credibility and vigor in the eyes of the community audience. In sTc, this interpretation of science night can be understood in terms of the “dialogic conversation.” In other words, it was not just what the students said which mattered to the audience, but also who they were. Students also emphasized that having the opportunity to share their findings with their community was important for their own learning as well. They emphasized how difficult it was to prepare for that presentation, especially in terms of the language demands. The students presented bilingually in English and Spanish, which they noted in our interviews as a challenge. But Marisol (along with others) explained how there was more to it than just translating their presentation to Spanish:

> And so, I was just going back and forth not only in terms of [English and Spanish] but in terms of scientific language and taking away all this jargon. And so I realized the importance of being able to go back and forth. I also realized the importance of having that connection with the community. Because I feel like when the people from the EPA spoke, I feel like a lot of people tuned out, not because they were bored or anything, but just because they couldn’t understand what was in the slide shows. I remember even I had trouble understanding and keeping up with what they were doing. They had a lot of data,

> a lot of information in their slide shows and they would just read off and they wouldn't explain it back to the people as well. So I realized the importance of having that connection and being able to translate and how effective that is as you try to communicate with the community. It felt good to be able to sort of help them understand. And not as a form of belittling them or anything or being like, hey we're the EPA, we're this organization that knows more than you. But being we're also part of the community and we just want to share this with you as well.

Marisol's comments indicate the complexity of the language demands that students were grappling with in preparing for their presentation. They were presenting bilingually, but were also trying to communicate complex scientific ideas with audience members, many of whom did not have access to much formal science education. Because of my own limitations in Spanish, my ability to support students with this component of the presentation was limited to providing an occasional translation of a technical term that I happened to know or asking questions and pushing students to consider "what matters" and what claims they could make collectively. The eight students who presented at family science night also practiced their presentation in front of the case study class and received feedback from their classmates about how their presentation would be received by family and community members.

Marisol comments above also underscore the importance of "who is doing the talking?" which is a central question in sTc as it relates to the dialogic conversation. Marisol emphasizes that she and her classmates were uniquely positioned to communicate the results of their study in a meaningful way as "part of the community," which is the essence of an organic intellectual who remains grounded in solidarity his or her social class (Gramsci, 1971/2014). Marisol's interpretation underscores the nuanced thinking in which students were engaged about their positionality. Several EPA officials and Professor Hernandez also presented bilingually in English and Spanish, but still students and Ms. Avila agreed that students' presentation was received differently by the audience because of their status as youth from the community.

In my interviews, all five participants who presented at family science night (Cristina, Curtis, Odette, Marisol, and Gabriel) intentionally emphasized the richness of their parents' or neighbors' knowledge while also noting that their own science education extended beyond what others in their families or communities had been able to access. Through their personal humility and familial and cultural pride, these students indicate a commitment to maintaining cultural competence as they achieve academically and matriculate through educational institutions that do not place such high value on their parents' and neighbors' wisdom. Marisol said that the presentation at science night was the work from the course of which she is most proud because of her ability to make the soil study understandable to the audience. She said that the most impactful lesson she learned from the experience was the importance of code switching. But some students were more critical of their presentation, like Curtis who said "the educators that were there knew what the hell we were talking about. But the community members, the parents still needed some elaboration." He blamed himself for failing to provide this elaboration. Curtis also recalled how his father's response to his explanation of the soil study indicated that his father was trying to show support but did not really understand the science. Gabriel shared a similar interpretation of his conversations with his parents about the soil study.

Critical metacognition.

Regardless of students' varying interpretations of their own effectiveness, presenting at the family science night constituted an authentic activity, which underscored for students the idea of science learning as a dialogic conversation. But it also provided students an opportunity to engage in the metacognition of science learning. As illustrated by the quotes above, students were seriously grappling with metacognitive questions like, “Can I explain this to someone else?” while also reflecting on the social relevance of their learning. Students’ metacognition enabled them to focus on the components of the study that would be most meaningful to their audience, as opposed to the other presenters who did not make these adaptations as effectively.

Students took the soil project as an opportunity to reflect on their own learning more broadly. Marisol’s reflection on the importance of code switching provides one example. Curtis also credits the soil study with encouraging him to be more collaborative in his schoolwork:

> I started helping more people out because of that [soil] research project. Because before, it was like, I gotta do what I gotta do to do well academically. You know how we collaborated a lot on that analysis part and all that stuff. So I feel like my senior year was a lot different from my junior year because I helped out students more. Or tried to solve math problems together as opposed to just doing it myself. So I guess that was extracted from my participation in the [soil] study. And I didn’t realize that until I was reflecting back at the end of my senior year on how senior year went. I was like dang! I saw that correlation basically.

Curtis, who was a junior during the case study class, credits the soil project with pushing him to be more collaborative in his approach to learning whereas previously he took a more individualistic approach to his schoolwork. Given the individualistic nature of assessment and achievement in US schools, Curtis’ change in approach may be interpreted as a critical form of metacognition. The importance of community-oriented and collaborative views of learning in the case study class is extended in chapter VII.

Odette’s description of her metacognitive processes while she wrote the soil project report also shows that students were also grappling with some of the more explicitly critical metacognitive questions valued by sTc:

> But then as the science gets more defined, it’s kind of like it is more difficult to make a claim and blame somebody for doing something wrong…Like with the lab report with the coal power plant, there’s no definitive conclusion that the coal power plants did cause an increase in asthma attacks and stuff like that, but there is a correlation. But you can’t blame the people who owned the plant for that, so it does get more difficult. I found that hard to accept.

Here Odette is describing the metacognitive process she went through while trying to make claims in her soil study report. This quote was part of her response to my question about the work that made her most proud in the case study class. She mentioned that she was actually more proud of the work she did in her sophomore chemistry class because there was less complexity, which allowed her to make more straightforward assertions. In this quote, she uses the soil project to explain how her own biases were challenged by the complexity she encountered in AP chemistry.

Reflexivity.

Besides metacognition, Odette is also engaged in reflexivity as defined by sTc as she is thinking about “how science knowledge is produced and reproduced” (Rodriguez, 1998, p. 601) and also about the relationship between science and the social change. When I have presented my approach to teaching science, other educators sometimes question whether I am imposing my own biases on the students. Odette’s thoughts indicate that the soil project actually put her in an uncomfortable position where she was unable to verify her biases, let alone assume mine.

Students struggled to reconcile the fact that they did not find levels of mercury or lead that exceeded state regulations with the fact the coal power plant was still an unwelcome polluter in their community. For example, Cristina wrote in her lab report:

> The safety limit should not determine whether or not we should move forward and clean the soil. Ridgevale has the right to be informed about what was found in their neighborhood soil. Lead and mercury are both very harmful if they are directly ingested, if the residents have any contact with the soil...

Frustrated by the lack of conclusive findings in the soil project, Cristina asserts in this statement that, with or without levels of heavy metals that exceed state regulations, Ridgevale residents should be informed about and in control of the land in their community.

Cristina and Odette's frustrations suggest that they agree with science educators who have asserted that science is "merely one of many resources that people can draw on in everyday collective decision-making processes" (Roth & Lee, 2004, p. 264) or that "citizen thinking may offer a more comprehensive and effective basis for action than scientific thinking" (Roth & Calabrese Barton, 2004, p. 7). This is related to the complexity of problem-posing science education in general and the limitations of the soil project in particular. Contrary to the NGSS focus on simplicity and causality discussed above, authentic activities like the soil project are likely to be messy and provide results that are inconclusive. In this way, the soil project is like almost any research endeavor in that it concludes, "further research is necessary." While the soil project did not find levels of lead or mercury that consistently exceeded state regulations, Professor Hernandez' larger study did find some troubling and interesting patterns. Furthermore, the soil study is only one way of considering the residual impact of decades of coal power plant pollution and, like all scientific research, our instruments and tools limited our methods. Given the airborne and more temporary nature of most of the pollutants emitted by the plants (like sulfur dioxide, nitrogen oxides, particulate matter, carbon dioxide), the real damage of the plants may be better assessed by different means (as Marisol suggested in the conclusion of her report).

The way Cristina and Odette are reflexively grappling with the impact of the coal power plant and the impact of their science knowledge on the community provides more evidence of the soil project supporting the development of critical consciousness. Cristina and Odette were two of five students who wrote about the concept of environmental racism in their lab reports in the introduction, conclusion, or both. Their discussions ranged in tone from Odette who wrote, "The location of the power plants suggests environmental racism" to Cristina who described the company who owned the plants as having "invaded two predominantly Latino communities." Francisco, who was one of four students who did not explicitly write about this concept in his final lab report, still credited the soil study with developing his critical consciousness with respect to environmental racism as he reflected on the senior capstone project he completed the following year:

> I did my [senior capstone] project on environmental racism because I started realizing that if you really look at where these power plants are located it's always in communities where it's mainly inhabited by minorities or low income families … it's unfair. My [senior capstone] project was basically to make more people aware of what's going on.

Considered alongside the earlier excerpt from Francisco's report, which demonstrated competency in terms of several CCSS for writing in science and technical subjects, this reflection provides evidence that the soil study was able to support academic achievement alongside the development of critical consciousness and the maintenance of cultural competence.

Braiding the three criteria for culturally relevant pedagogy

The interrelatedness of these three criteria for culturally relevant pedagogy (academic achievement, cultural competence, and critical consciousness) is important if science curriculum is going to be a catalyst for change. Rather than happening in parallel or simply competing for class time, there is evidence in the data that these three pedagogical goals motivated and supported each other in the soil project. For example, Marisol speculated that her classmates "would not have been as interested or as motivated to do well in the class if it wasn't for the fact that they were able to apply these skills to the community or be able to relate what they were learning to social justice issues." Marisol confirmed that this was the case for herself. Indeed, several students described their motivation as being improved by the social or community relevance of the curriculum, like Odette who described the class as a "good type of struggle." She added "but I was more than glad to struggle because I thought it was relevant…" Grappling with issues of racial, social, and environmental justice motivated students to learn canonical chemistry content and associated skills.

Cristina provided another example of the connections between community relevance and academic "rigor." She told me that she really did not have any expectations at the beginning of the course because she had not gotten anything out of the sophomore chemistry class that she had taken, and failed, at a different high school. But Cristina explained that as the year went on, she began to think more about her motivations and goals in the class:

> Putting connections on the community into the curriculum – it was like, I'm learning this for my community. It's not just for me. It's not just for me to get a good paying job when I graduate. It's for me to help. That really developed as the year went on just because – I

> really came into AP chemistry thinking I was going to fail and really wanting to drop it even before the year started.

Cristina’s quote pushes back against the “learn to earn” definition of success that is far too prevalent in our schools in favor of defining success as learning to contribute to the well being of the community. This is a theme that emerged from the interview data and is elaborated in Chapter VII.

It is also important to note that as Cristina and Odette’s remarks suggest, students did not find any component of their learning in this class to be easy. From an academic point of view, Raquel said that the case study class was the most difficult class she has ever taken, including her first semester of college coursework at a more selective research university. Marisol, who is a second year student at an Ivy League university, said calculus was the only class in her academic career that was more challenging than the case study class. Francisco wrote in an end-of-the-year reflection in his binder that this was the hardest class he had ever taken. And in our interview, he described the class as requiring him to develop the study habits that have buttressed his success in his university science courses. Four of the five student participants (Francisco, Cristina, Jade, and Odette) who have taken chemistry in college indicated that they felt well prepared by the case study course even as they are all critical of the failure of their college chemistry courses to place learning in an authentic context. These reflections are supported by their grades, as discussed in Chapter VI. Gabriel is the fifth participant who has taken college chemistry. Gabriel expressed some uncertainty about his preparedness, but attributed his struggles in general chemistry at the university to his struggle to adapt to the sociocultural environment of the university rather than being the result of academic rigor. Gabriel also shared that he scored a credit-earning score of 4 on the AP chemistry exam while he was in the case study class. This supports his interpretation that his struggles in college chemistry are due to sociocultural issues rather than being unprepared academically.

In terms of critical consciousness, Odette highlighted repeatedly in our interview how much the class challenged her understandings of the social components of SSI. And along with Gabriel, Marisol, and Curtis, she also described struggling with the cultural and linguistic components of preparing to present the soil project at family science night. In this way, some of the work required to develop critical consciousness or maintain cultural competence was an outgrowth of the academic achievement embedded in the soil project. In these ways, students debunk the idea that there is a dichotomy between curriculum that is socially just or relevant and curriculum that is academically challenging.

Youth as transformative intellectuals: Three orientations

Not only was this braiding of cultural competence, critical consciousness, and academic achievement an important motivating factor for students to engage in challenging work, but it also has implications for the question, “science education in whose interests?” Marisol criticized science education that does not grapple with this question in our interview:

> If you don’t have social justice [in the curriculum], I feel like you’re just sort of creating these people who are very science-focused, but yet they don’t realize the implications or the power that they hold or the change that they can do with that sort of intelligence or skills or knowledge.

One of the goals of justice-centered science pedagogy is to educate young people to understand and embrace their collective agency. This understanding includes grappling with the ways that developing knowledge of science and tools to critique science may contribute to our ability to struggle for social transformation. The soil project gave students the opportunity to engage in the components of sTc: dialogic conversation, authentic activity, metacognition, and reflexivity. Together, these components encourage students' development as intellectuals because sTc conceptualizes learning beyond coming to know facts or demonstrate skills. Engaging in the components of sTc forces students to become critical about the production of knowledge which pushes them to ever more critically examine their own beliefs and knowledge.

Some of the students who participated in this study are, to use Marisol's words, "very science-focused." Others are not. But all of the student participants in this study expressed agency and hope with respect to transforming their communities and/or the world. They differed in how they viewed their role or the role of science in social change. A pattern matching analysis of these different viewpoints led me to identify three orientations towards science among the student participants. The three orientations adopted by students in this study provide science educators with an initial framework for thinking about how students who are committed to social change might view science and, in some cases, mobilize their scientific knowledge for social justice goals. The notion of urban youth as transformative intellectuals has been put forward by critical pedagogues (e.g. Morrell, 2008; Romero, 2014) who build on the Gramscian (1971/2014) concept of an organic intellectuals who represent their social class of origin and Said's (2012) notion of intellectuals as working in solidarity with marginalized peoples. Given the tendency of Western science to be represented as apolitical and objective, the relationship between the work of intellectuals in scientific fields and social transformation has been under-theorized.

This chapter opened by contrasting Curtis' and Odette's responses to an interview question about how well the case study class balanced the learning of chemistry with studying issues of social justice. While Curtis characterized the curriculum as losing its critical and connected approach over time, Odette said that it was the "default" for our class to engage in science through the study of an important sociopolitical action. Both Curtis and Odette were very much involved in the soil project outside of class. But in Odette's quote at the beginning of this chapter, she indicates that the curriculum of the case study class led her to choose chemistry as her college major whereas Curtis was not interested in a science major. Jackson, on the other hand, was not involved in the soil project outside of class. Jackson even wrote in the pre-lab report activity that he found the soil project boring and that he did not want to write the lab report. Ironically, Jackson then wrote what I judged at the time to be the best lab report in the class. He also decided to pursue physics as his college major long before he enrolled in the case study class. This contrast between Curtis, Odette, and Jackson's orientation towards the curriculum initially led to my identification of three orientations towards science.

When I asked Curtis whether he is part of the culture of science, he responded, "I'm more like a tourist in that." I borrowed this term from Curtis to describe students with his orientation as "tourists in the culture of science." At the time of their interviews, Gabriel, Marisol, and Raquel were also tourists in the culture of science. All of these students were very involved in the soil project outside of class. They all expressed an interest in using science to solve problems in their communities, but did not choose science majors and do not consider themselves part of the "culture of science." Students like Jackson and Francisco are those students who Aikenhead (2006) describes as a having a "Western sciencelike worldview" (p. 112). Their academic trajectory is focused on moving through the STEM pipeline. I refer to this orientation as "concerned scientists" because these students see themselves as contributing to the greater good, but do not see their involvement in science as directly motivated by their desire to eradicate oppression or address inequality. In describing her experience presenting at family science night, Marisol commented, ""it was very interesting being that sort of bridge between the community and these very important scientific findings.” In this comment, Marisol extends the concept of science teachers as “*nepantler@s”* to include students as guides through the often-painful third space between their culture and the culture of Western science (Aguilar-Valdez et al., 2013). While the coal power plants were already shut down by the time of the soil project and students did not find dangerously high levels of mercury and lead in neighborhood soil, they expressed pride in being the ones responsible for communicating these (somewhat comforting) results with their families and neighbors. Cristina, Jade, and Odette have embraced this third orientation as science *nepantler@s* by choosing to major in science with the intention of changing the culture of science and using science to change their communities and the world.

Figure 5 illustrates these orientations, with the names of students who had adopted each orientation at the time of their interview. The arrows and dotted lines are meant to symbolize the flexibility of orientations, which can be changed. The direction of each arrow indicates the pathway towards social change as viewed by students of each orientation. It is important to note that concerned scientists are not oriented away from their communities, as both students with this orientation also expressed care and concern for their community. Instead they are oriented towards science, but continue to value their community of origin. Likewise students with a tourist orientation are not oriented away from science. Tourists in the culture of science view science as potentially useful but not their primary focus, nor the primary lever or mechanism by which they imagine social change to occur. Students of both of these orientations are comfortable crossing the metaphorical bridge through the third space when it is useful or necessary. Meanwhile, *Nepantler@s* view the third space as the place where they belong and where transformative change in science, their community, and the world will occur. I am not suggesting that these orientations are the only possible orientations or that any one orientation is preferable to the other. That all student participants exhibited one of these three orientations indicates that they believe social change is possible and see a role for themselves (and for science) in this transformation.

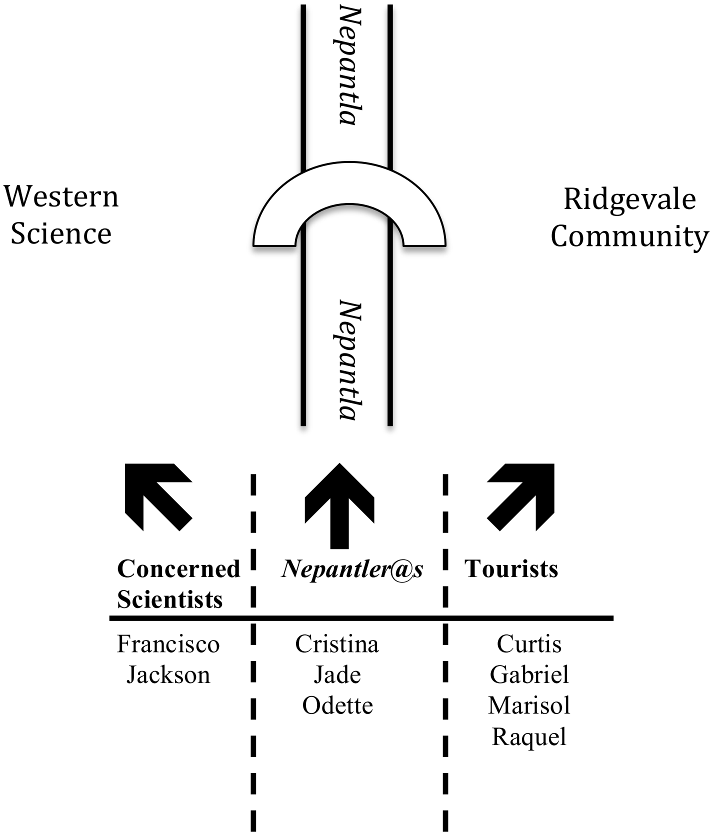


Figure 5: Three orientations towards science

Chapter V: The Aspirin Unit

I'm an African American

They sell drugs in the hood, but the man he move the medicine

He'll prescribe you Augmentin for everything

A little stuffy nose, tell you get some Claritin

You know I'm hip to it

And it's hard to claim the land

when my great great great grands was shipped to it

- David "Styles P" Styles in Trotter et al, 2008

The epigraph from a song by the band The Roots captures the SSI that is at the heart of the "aspirin unit." This chapter follows the structure of the previous one as I use the extended case method to examine the aspirin unit by first considering the SSI as a generative theme, considering the role of my political clarity in identifying this SSI, and then considering students' academic achievement through the NGSS, CCSS, and sTc. Student work artifacts along with interview data are used to consider how this academic achievement was intertwined with the maintenance of cultural competence and the development of critical consciousness. In the conclusion of this chapter, I attempt to reconstruct a theory of socially transformative science curriculum using evidence from the chapter to reify and add nuance to the justice-centered science pedagogy framework presented in Chapter II.

The SSI: Drug development

One of the crowning achievements of Western science is the development of countless “miracle” drugs from antibiotics and analgesics to synthetic hormones and chemotherapy. Many of these drugs were originally derived from indigenous people’s knowledge of plants (Conner, 2005). But while Western scientists are celebrated for their development and pharmaceutical corporations rake in profits, indigenous communities receive neither intellectual credit nor financial remuneration for the successful co-optation of that knowledge (Smith, 1999). The Western co-optation of indigenous knowledge of plants is also responsible for the extraction or synthesis of illegal street drugs like cocaine and heroin, but neither champions of Western science nor the corporations involved in these “discoveries” are so quick to claim credit for these drugs (LeCouteur & Burreson, 2003). Meanwhile young people of color (especially African American and Latino men) are racially profiled and disproportionately adjudicated for possession or sale of illegal drugs (Mauer, 2011). The epigraph above from a song by hip-hop band The Roots captures this contradiction in the SSI that is at the heart of “the aspirin unit.” In these lyrics, Styles P points out the hypocrisy inherent in US drug policies and drug economies by focusing on the language used to differentiate illegal street drugs from legal pharmaceuticals. He connects his critical consciousness on this issue by troubling his “American” identity, given that his ancestors were brought to this continent as enslaved people. The history and politics of modern drugs (legal and illegal) is very much intertwined with the history of European colonization and racist oppression and also with the complex relationship between capitalism and Western science. This complexity is the basis for the aspirin unit that was consistently named by students as the most or second most relevant curricular unit of the case study class.

Drug development as a generative theme?

To examine the ways in which the SSI of drug development may or may not have been a generative theme once again requires an extension from the case to the community context. When I asked Curtis what problems or obstacles his community faces, he immediately responded, “The first thing that comes to mind is like the drugs, drug war.” But Curtis was the only participant to include drugs or the drug war as the most pressing issue faced by the community. It is interesting to note that he immediately amended his initial response of “drugs” by adding “drug war.” In a follow-up interview, I asked Curtis what he meant by identifying the “drug war” as a problem in the community. He explained that the way drug laws are enforced in the community constitutes a set-up wherein young men are baited into this underground economy and then prosecuted for their involvement. In a recent piece of investigative journalism, Serrato (2014) contrasted police statistics and the views of local residents with media reports and US DEA statements to argue that the community surrounding La Lucha is falsely characterized as a hub of heroin distribution. This article also noted the substantial visible police presence and history of criminalized street organizations in the neighborhood. Community member Ms. Avila mentioned police brutality and harassment as priority issues in the neighborhood. Several participants in this study identified the violence associated with street organizations as an issue of concern in the community and one student even indicated that it was the most pressing concern. But only one of these participants connected the problem of street organizations with the problem of drugs. A sociological understanding of street organizations recognizes them as originating in the need for young men of color to defend themselves against oppression (Hagedorn, 2009). In my interviews, both students and community members connected the persistence of street organizations to the stresses families feel as the result of parents working multiple jobs to make ends meet, highlighting again the centrality of economic hardship.

Connected to the prevailing issue of economic hardship, community member Ms. Juarez noted that access to affordable health care is an important issue in the community. As she envisioned the community ten years in the future, she hoped that community members would not have to decide between "going to the doctor or paying your rent." When I asked her about the role of science in society, Ms. Juarez said:

> We are people of science and math. And I think that the role is *para el mejoramiento de la communidad* [for the improvement of the community] and self. And I think that science has been – just like they say education is not politicized; science is political. And it is how we use it. Do we use our natural elements to sustain and flourish a community? Or do we use these natural elements, privatize them, and use them for profit. So, to me, the way I see the role of science is for the betterment of the community.

Ms. Juarez, who is a Chilean immigrant, identifying herself and others in the community as "people of science and math" pushes back against stereotypical images of white male scientists and traditional explanations for the underrepresentation of Latin@s in science education. Understanding underrepresentation within the larger historical context of colonialism allows us to value the contributions and empirical understandings of non-dominant peoples that is deeper than taking a tokenistic approach to highlighting individual modern scientists of color. Reflecting on her participation in the aspirin unit, Cristina took this broader view when she commented that she and her classmates could relate to the aspirin unit because a lot of their parents use herbal remedies that derive from their indigenous ancestors' knowledge of plants. The theme of drug development sits at the intersection of these community strengths and community concerns.

The role of the teacher’s political clarity.

Once again, I must extend my analysis to consider my role as a participant in identifying drug development as a generative theme. Throughout my teaching career, students have approached me with questions about medical issues. Often these questions are related to the side effects of prescription drugs or about the scientific interpretation of the home remedies prescribed by a mother or grandmother. Even though students call me “MD” (short for Morales-Doyle), they know I have no medical degree or expertise. Instead, they often view me simply as an approachable person who is knowledgeable about chemicals like those contained in both prescription drugs and in teas or tinctures. While I cannot provide medical advice, these interactions have shown me that science education should help students build the confidence to ask these questions of doctors or pharmacists while also teaching them to value the wisdom in their own families (even as they also learn to interrogate their own cultural practices). This belief is the origin of a tenth grade chemistry unit called “Pills and Bills,” which culminates in the class collaborating to write a set of questions to potentially ask a doctor or pharmacist for clarification or additional information about a prescription. I have written elsewhere about the development of “Pills and Bills” and the aspirin unit as they relate to the programmatic vision of our science department (Morales-Doyle, 2014).

Racial profiling and police harassment is another topic that students frequently raise in side conversations or during class discussions about issues of injustice. Not surprisingly, young men of color often share stories and frustrations about being stopped and frisked, harassed, or brutalized in some way. Often this harassment is explicitly or implicitly motivated or explained by unfounded accusations related to the possession or sale of illegal drugs. My political clarity with respect to the SSI of drug development was actually informed by the lyrics in the epigraph that began this section. But it was crystallized by the comments of a former student just after he graduated from La Lucha High School in 2009. During a youth-led workshop at the Free Minds Free People Conference in Houston, Texas, Claudio, who identifies as Afro-Mexican, told participants in a workshop called, "Science Education for Liberation?":

> By not giving them credit and not acknowledging them, we are led to believe that our people were not advanced and they needed to be colonized. But we know that our people were advanced and that they were only looking to benefit their own people. But the colonizers came and they took that knowledge to make profits.

As I have written elsewhere (Morales-Doyle & Frausto, forthcoming), Claudio's comments echo the work of scholars who criticize the role of Western science in colonization and maintaining oppression. This role is complex as it involves the co-option or theft of indigenous knowledge (reframed as "discoveries"), but also includes the use of science and technology to establish, maintain, and justify domination (Brown & Mutegi, 2010; Harding, 2006; Smith, 1999). My political clarity around the SSI of drug development was informed by academic critiques of Western science, but also by critical perspectives communicated in popular culture and the stories and socio-historical analyses of both colleagues and students. As with the issue of environmental racism, understanding both white supremacy and capitalism as totalizing hegemonic forces was central to my understanding of the issue (Stovall, 2006a).

Implementation: What we did in class

The aspirin unit (referred to as "Synthetic Chemistry" in my curriculum planning documents) took place in May after the AP Chemistry Exam. While some teachers of AP classes assume that the course is essentially over after the exam, I try to consistently de-emphasize and critique standardized exams with students. Even as I told students about AP chemistry when they were sophomores in introductory chemistry, I emphasized that the primary goal of the course was not the AP exam and thus we pushed forward to continue learning afterwards. Of course, Curtis astutely noted during our interview that the aspirin unit marked the revival of relevance for him and he wondered whether this was because I felt free to diverge from more traditional curricular topics after the AP exam had passed.

I opened the aspirin unit by engaging students in a whole class discussion about the following three questions:

1. Think of the way people talk about heroin and other addictive street drugs. Who is usually blamed for the problems associated with these drugs?
2. Think about the way people talk about aspirin and other highly effective pharmaceutical drugs. Who usually gets the credit for their success?
3. Does it matter who gets the blame for science gone wrong or the credit for successful science? If so, how can we start to change the way people talk about these topics?

Opening the unit with this sort of dialogue is a way to “re-present” the generative theme to students as a problem, a practice that is central to Freire’s (1970/2001) “problem-posing education.” Teaching and learning for social transformation requires foregrounding and privileging students’ ideas, knowledge, and experiences; “who is going the talking” is important in a dialogic conversation (Rodriguez, 1998). After this initial discussion, we watched a speech given in Spanish (with English subtitles) by Bolivian President Evo Morales (2009) to the United Nations Commission on Narcotic Drugs. In this speech, President Morales demands that coca leaves be removed from the United Nations’ list of banned narcotic substances. He explains how the practice of chewing coca leaves is an important part of his and other indigenous cultures in the Andes Mountains and also that coca leaves do not have the same dangerous narcotic properties as the pure cocaine that is extracted from them using chemical techniques. Using this speech as a text, we extended our previous class discussion around the ways different groups of people are impacted by lines that are drawn (or not drawn) between plants, illegal drugs, and sanctioned drugs. Here again, the positionality of the speaker is an important consideration in our discussion. President Morales is both an authority figure with some influence over laws and regulations and also an indigenous South American whose cultural practices are outlawed by more powerful imperialist governments in the United Nations.

Students were given time in class to read and annotate a laboratory procedure that guided them through the extraction of salicin from willow bark and through the synthesis of acetylsalicylic acid (aspirin) from acetic anhydride and salicylic acid. Students were required to complete a familiar pre-lab exercise where they wrote an abstract of the experiment (without results, of course) to check their understanding of the objectives and procedures. Students then began the extraction of salicin from willow bark using a procedure that requires several days of waiting between active steps.

In subsequent days, as students continued with the willow bark extraction, we read an excerpt form Connor's (2005) *Peoples' History of Science* (pp. 93-95), which problematizes the dominant narrative of the history of science in the same way as the famous text by Howard Zinn (2005) troubles typical accounts of US history. The excerpt we read focuses on "ethnobotany" and the ways indigenous peoples' knowledge of plants informed Western medicine. Students then read several more applicable texts using a jigsaw approach where small groups of students focused on a particular text and then students taught each other about their assigned text in small groups that were reorganized to include one or two representatives from the original group formations. These texts included an article published in the journal *Science* in 1975 that used modern biochemistry to analyze the empirical knowledge of medicinal plants catalogued by the Mexica people prior to the Spanish invasion of Mexico (Ortiz de Montellano, 1975). There was also a recounting of the stories of the original syntheses of aspirin and heroin (LeCouteur & Burreson, 2003), an essay on the medicinal practices of Native Americans that included the use of willow bark (Kidwell, 2008), and an article from the University of Maryland Medical Center about the medicinal use of willow bark (Erlich, 2008). Students were encouraged to use what they learned during the jigsaw to decide which of these texts they would also read on their own in preparation for their lab report. As the unit went on, we synthesized aspirin using a procedure from the lab manual for one of the organic chemistry courses I took as an undergraduate at UC Berkeley (Pavia, Lampman, Kriz, & Engel, 1998). We also completed our attempt to extract salicin from willow bark and began to write sections of the lab report. After the synthesis of aspirin, students analyzed their products using a titration and by testing both their willow bark extract and their final aspirin product with iron (III) nitrate solution, which forms a purple complex with salicylic acid.

Analysis of student achievement

An analysis of the lab reports that students wrote for the aspirin unit shows similar results to the analysis of student work from the soil project. This time, seven of nine students elected to use the university lab report guidelines whereas two elected to follow the La Lucha science department lab report guidelines. Student reports analyzed for this study ranged in length from four to eleven double-spaced pages. There is not evidence in the artifacts from the aspirin unit of students meeting any of the specific NGSS physical science performance expectations. But there is evidence that some students met the draft version of the NGSS performance expectation that I included in my planning documents for the aspirin unit and also addressed components of the

College Board's AP Chemistry Course description. There is significant evidence of student achievement as measured by the CCSS for literacy and writing in history, science, and technical subjects. There is also evidence in student work and interviews that this academic achievement occurred in ways that supported cultural competence and connected with the development of critical consciousness. A summary of the standards that I targeted in my unit plan for the aspirin unit is included in Table IX.

Table IX: Standards or Canonical Chemistry Content Targeted by the Aspirin Unit

Standards Document	Performance or Content Descriptions	
NGSS (Lead States, 2013)	2012 Draft HS.PS-CR-c. Analyze and interpret data to make claims that reaction conditions can be used to optimize the output of a chemical process.	Final NGSS.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.
CCSS (National Governors Association, 2010)	WHST.11-12.2: Write informative/explanatory texts, including the narration of historical events, scientific procedures/experiments, or technical processes."	
AP Chemistry Course Description (College Board, 2012)	Chemical Calculations: Stoichiometric relations using the concept of the mole; titration calculations Recommended Experiments: 22. Synthesis, purification, and analysis of an organic compound	

Analysis of academic achievement through the lens of the NGSS

The NGSS performance expectation in the synthetic chemistry unit plan came from a 2012 draft of the NGSS:

> HS.PS-CR-c. Analyze and interpret data to make claims that reaction conditions can be used to optimize the output of a chemical process. [Assessment Boundary: Limited to simple reactions. Reaction conditions are limited to temperature, pressure, and concentrations of all substances in the system.]" (NGSS Lead States, 2012).

There was evidence in lab reports submitted by Cristina, Francisco, Curtis, and Marisol that they met this draft version of the performance expectation. For example, the following excerpt from

Cristina's lab report uses evidence from the lab to make the claim that the products of her synthesis contained residual starting materials:

> We found the acetylsaclicylic acid we obtained from the lab was impure when testing it with drops of Fe^{3+}. The drops of Fe^{3+} indicate the presence of salicylic acid. The acetylsalicylic acid we obtained still had leftover salicylic acid. We were able to obtain acetylsalicylic acid from synthesizing the salicylic acid and acetic anhydride; however, the reaction may not have gone to completion because there was still a remainder of salicylic acid.

In this excerpt, Cristina uses evidence from the lab to make a claim that reaction conditions did produce product but did not produce an optimal outcome. Cristina later goes on to suggest that a longer reaction time would have yielded more products, thus meeting the original performance expectation in the draft NGSS. Francisco, Marisol, and Curtis explicitly suggested increasing the temperature of the synthesis to increase the yield.

The draft performance standard above does not exist in the final version of the NGSS. The closest analog is "NGSS.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." (NGSS Lead States, 2013). In some ways, it seems as though students may have met this performance expectation by writing about changes needed to improve the synthesis, but the clarification statement which follows the performance expectation led me to conclude that they did not:

> Clarification Statement: Emphasis is on the application of Le Chatelier'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 (NGSS Lead States, 2013).

Curtis, Marisol, and Francisco correctly identified temperature as the only applicable variable among those listed in the final version of the performance expectation. Since this synthesis involves the reaction of a liquid and a solid that are both pure substances, the variables of concentration and pressure cannot be manipulated. Still the synthetic reaction is not the sort of equilibrium reaction where Le Châtelier's principle would normally be applied. Students did address this performance expectation more directly in the chemical equilibrium unit discussed in Chapter VI. Given the significant change that occurred between the NGSS performance expectation with which I was working and the final version, it is difficult to say how the aspirin unit may have been different if it was designed to address NGSS.HS-PS1-6. Reflecting on what I asked students to do, I should have provided opportunities for them to change the synthetic procedure in some way based on their results from the first experiment and try it again. Still, given the opportunity to redesign the aspirin unit to align with the final version of the NGSS, the more applicable performance expectation may be:

> 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.]

(NGSS Lead States, 2013)

In order to complete their aspirin lab report, students were required to complete several stoichiometric calculations related to the titration of their aspirin product and the percent yield of their synthesis. In so doing, students demonstrated proficiency with respect to the fifth of 11 chemical calculations included in the College Board's AP Chemistry Course Description, "stoichiometric relations using the concept of the mole; titration calculations" (College Board, 2012, p. 9). But these calculations were not undertaken with the explicit purpose of supporting the law of conservation of mass as the NGSS performance expectation requires. This once again indicates that the specificity of the way the NGSS link practices, ideas, and concepts is limiting in curricula that emerge from SSI. Still, I examined the aspirin lab reports to determine whether students addressed the clarification statement with an "emphasis…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" (NGSS Lead States, 2013). Among the nine aspirin lab reports I examined, six students correctly calculated the molar mass of their aspirin product from experimental data, but only three students successfully explained their calculation. Seven students correctly calculated the percent yield for their synthesis, but only one student correctly interpreted the meaning of this calculation. Three of the students who correctly calculated but incorrectly interpreted their percent yield conflated percent yield with percent purity, which their methods did not allow them to determine. Table X summarizes student performance with respect to stoichiometric calculations that were embedded in the aspirin lab report artifacts.

Table X: Summary of stoichiometric calculations in aspirin lab report

Student	Correctly calculated molar mass of aspirin product	Successfully explained molar mass calculation	Correctly calculated percent yield	Correctly interpreted percent yield
Cristina				
Curtis	✓		✓	
Francisco	✓	✓	✓	
Gabriel	✓	✓	✓	
Jackson				
Jade	✓		✓	
Marisol	✓		✓	
Odette	✓		✓	
Raquel		✓	✓	✓

The following excerpt from Raquel's lab report demonstrates her successful explanation of her molar mass calculation from experimental data and an error analysis where Raquel explains one potential reason for the low empirical molar mass in terms of data from a different part of her analysis:

> The average molar mass was calculated by turning the mL in table 3D into moles of NaOH. Then with that number we made a mole-to-mole ratio, which was one mole of NaOH to one mole of acetylsalicylic acid. Once we had that number we divided the mass of aspirin titrated by the moles of acetylsalicylic acid we got. We did that with each trial and then added all the values up and divided by 3. This gave us the average molar mass for the 3 trials we did. For percent error what we did was subtracted 111.34 from 180.17, which is the actual molar mass of acetylsalicylic acid, then divided by 180.17 and multiplied by 100. This gave me the percent error of 38.208%, which means that the molar mass I got was far from the actual molar mass for acetylsalicylic acid. I believe that my percent error is high. The reason for my high percent error would have to be due to residual salicylic acid, the most obvious test that proved to me that there was still salicylic acid left was 3C because my sample tuned purple, which means the Fe atoms

> formed a complex ion reaction with the salicylic acid. Since there is still salicylic acid present that means that not all of the salicylic acid turned into aspirin therefore having a lighter weight than the actual acetylsalicylic acid.

The percent error for Raquel's experiment is relatively high and the molar masses she includes in her explanation should be labeled with units. But despite these flaws and some grammatical issues, this excerpt shows that Raquel understands the data from the aspirin synthesis deeply enough to make connections between quantitative and qualitative data in order to explain her flawed results. Unfortunately, the results in Table X above indicate that Raquel was in the minority in this regard.

Students were given eight data analysis questions to scaffold the multistep calculations of molar mass and percent yield. The imbalance in correct calculations as compared to successful explanations of these calculations is a red flag that this assignment may have encouraged or at least allowed for the "rote application of problem-solving techniques," which is explicitly discouraged by the clarification statement of the NGSS performance expectation and is also certainly something I strive to avoid in my teaching. More metacognitive scaffolding that asked students to explain their reasoning as they moved through the various steps of the calculations may have supported students to develop and communicate deeper mathematical understandings.

Analysis of academic achievement through the lens of the CCSS

As with the soil study, students' artifacts from the aspirin unit were rich with evidence of meeting CCSS for writing in science and technical subjects. The CCSS literacy standard that I targeted in my unit plan for the aspirin unit was: "WHST.11-12.2: Write informative/explanatory texts, including the narration of historical events, scientific procedures/experiments, or technical processes." Eight of the nine of the aspirin lab reports contained clearly written procedures for the synthesis of aspirin and also contained evidence of students thinking in interdisciplinary ways by placing their experiment within an historical or a social context. Marisol's report, while well written, showed some misunderstandings about the relationships between the synthesis of aspirin and the extraction of willow bark as it was carried out in the lab. Meanwhile, Curtis' description of the synthesis of aspirin provides a particularly concise, but representative example of the "narration of…scientific procedures":

> Salicylic acid powder (2.99 g) was measured and placed inside an Erlenmeyer flask. Acetic anhydride (6.0 mL) was measured into a small graduated cylinder and added to the flask. Sulfuric acid (8 drops) was carefully added as well. The flask was placed in a hot water bath under the fume hood to release acetic acid vapor produced in the synthesis reaction. Distilled water (3 mL) was added after heating. Water (40 mL) was added to the flask and allowed to return to room temperature. [The] flask was placed into a cold ice bath. A Buchner funnel vacuum filtration set-up was performed to collect the aspirin crystals formed.

This excerpt demonstrates Curtis' ability to "develop the topic thoroughly by selecting the most significant and relevant facts" and "use precise language [and] domain-specific vocabulary," two of the skills valued by the subsections of CCSS.ELA-Literacy.WHST.11-12.2. Curtis included "domain-specific vocabulary" to refer to chemicals and equipment by their accepted names while also including relevant measurements and some reasoning about the purpose of various steps in the procedure. Even with this level of specificity, Curtis communicated what he and his partner did in the laboratory in less than one third of the words included in the original instructions for this portion of the experiment. This ability to succinctly describe a procedure for a chemical synthesis not only meets the CCSS cited above, it also demonstrates Curtis' understanding of the expectations of technical writing within the culture of chemistry, which is a sub-culture of the dominant Western culture and part of the "culture of power" (Aikenhead, 1997; Delpit, 2006).

Student learning, cultural competence, and critical consciousness

The four components of sTc highlight some of the possibilities created by the aspirin unit for students to learn to operate within this dominant culture without experiencing this learning as forced cultural assimilation (Aikenhead, 2006). There is evidence that the aspirin unit provides an approach to socially transformative science education that may mitigate the potential for harm as students cross the borders between their culture and the culture of Western science (Aguilar-Valdez et al., 2013; Jegede & Aikenhead, 1999). In an end-of-the year reflection that was included in the partial course binder of artifacts that Curtis submitted for consideration in this study, he demonstrated metacognition as he wrote:

> I have definitely improved on my scientific writing...My recent lab reports show much more formal, scientific diction and knowledge as I become more conscious of issues by researching them more thoroughly. The content shown in lab reports is much more sophisticated than first reports. I learned to make claims that are supported by evidence through quantitative practices in a lab, not claims that are irrelevant to the topic being written on. I learned not to be vague when describing a concept, what was used in an experiment, how it was used, etc...

This reflection about "sophisticated" writing and "scientific diction and knowledge" is substantiated by the excerpt from Curtis' procedure above and shows impressive self-awareness about his writing and thinking. But metacognition with a socio-transformative orientation pushes students to consider more critical questions about learning, such as "Why am I learning this?" and "What control do I have in how to proceed?" (Rodriguez, 1998, p. 600). Curtis and his classmates provided evidence of this deeper sort of metacognition in their aspirin lab reports and also in my interviews with them. For example, in considering himself “more like a tourist” in the culture of science, Curtis prefers to “just extract what I need” from science. This utilitarian view of science is consistent with a collateral learning approach (Jegede & Aikenhead, 1999) and may have been supported by Curtis’ feeling that “science class [at La Lucha High School] was a space where culture was not denied.” In fact, Curtis discussed science classes at La Lucha as one of the few educational experiences he had where he felt like his Mexican and Chicano cultures were affirmed, citing the aspirin unit as an example of this affirmation. Thus, the aspirin unit allowed Curtis, as a self-identified tourist in the culture of sciene, to safely cross the bridge between his home culture and the culture of Western science, supporting him in the *nepantla*, or in-between space (Aguilar-Valdez et al., 2013). The aspirin unit provided this support in part by acknowledging that his ancestors played a critical role in the development of Western medicine and the original construction of the bridge between these cultures.

Other students shared Curtis’ utilitarian view of Western science and his sense of the aspirin unit as culturally affirming. For example, Cristina, who is now a chemistry major and also works as an organizer for COVER, commented that when she is discussing issues of pollution in the community, her knowledge of chemistry provides her with a level of credibility that she would not otherwise have. At the same time, when I asked Cristina the question about whether she is part of the culture of science, she responded that she does not consider herself part of the “traditional culture of science,” but does see herself as potentially playing a role in changing that culture. Like Curtis, Cristina also identified the relevance in the aspirin unit as stemming from affirmation of her ethnic culture. She noted in our interview that her own parents and those of many of her classmates still use ancient herbal remedies and that the aspirin unit encouraged her to learn how chemistry might explain those practices. In the acknowledgements section of her aspirin lab report, Cristina wrote, “It gave me an incentive to really understand the science behind synthesizing [acetyl]salicylic acid and trying to imagine ways of how my ancestors cured their aches and pains.” By creating a connection between the culture of Western science and the way she views her indigenous ancestors, the aspirin unit supported Cristina’s science *nepantler@* orientation as she reconciled the various aspects of her Latina identity in a way that is consistent with the underlying framework, Anzaldua’s (1987) “new mestiza consciousness.”

In the conclusion of her report, Cristina chose to take an explicit stance with respect to the curriculum, making a connection between the aspirin lab report and an assignment from the summer session where I asked students to interview a family member with scientific funds of knowledge (Gonzalez et al., 1995):

> I believe that when future generations come into La Lucha High School and are in the process of this lab, they should be taught about the history that indigenous people have. Before the school year began, Mr. Morales-Doyle asked us to write about somebody in our family who was a scientist or works with science but aren’t recognized. I feel that indigenous people of all around the world should be accredited [sic]...

Considered together with the quote from her lab report above, we can see that for Cristina, imagining the scientific practices of her indigenous Mexican ancestors motivated her learning of Western science concepts, which in turn contributed to her appreciation of her ancestors’ wisdom and current familial knowledge. Cristina was the only student who clearly identified with an indigenous identity in her lab report, but Marisol wrote in her conclusion: “People of color need to regain the knowledge passed down from their native ancestors.” While they were not prompted to do so, Cristina and Marisol are engaged in critical metacognitive writing here as they take a position on the question of “Why am I doing it this way?” (Rodriguez, p. 600). The aspirin lab report provided opportunities for students to engage in the sTc component of reflexivity as they reflected, in critical ways, on the production of scientific knowledge. Eight out of nine students used the introduction and/or conclusion of their report to problematize the production of science knowledge as it pertains to the development of drugs. An excerpt from Gabriel’s introduction provides an illustrative example:

> It is important to acknowledge the indigenous populations in discovering the curative properties plants contained that lead to the creation of other medicines for people in modern medicine instead of ignoring them throughout history and only viewing them as savages instead of people. Colonialism has lead to this view. According to an excerpt from Native America by Clara Sue Kidwell, “Science in the Western European tradition is an elitist activity, and American Indian societies had their specialists who acquired, guarded, and passed on explanations of natural world. These explanations have generally been dismissed as myth or folklore, certainly not acceptable science in a modern sense”; however, “Many people are aware that aspirin is a synthetic form of natural components found in willow bark, which was widely used by Indians in teas brewed to treat fever and pain” (Kidwell, 2008) [citation expressed as an endnote in original student artifact]. Although many people may have viewed Indians as savages due to their complex religions and customs, their knowledge of plants were used in creating medicines people use today.

In this excerpt, Gabriel is engaged in the sTc component of reflexivity by problematizing the role of indigenous knowledge of plants in the development of Western medicine. But he is also demonstrating the ability to meet another standard: “CCSS.ELA-LITERACY.WHST.11-12.9: Draw evidence from informational texts to support analysis, reflection, and research” (National Governors Association, 2010). While I had not identified this standard in my planning documents, eight of nine reports I analyzed met this standard by quoting or paraphrasing and citing the texts we read during the aspirin unit in order to support their analysis of the social relevance of the lab activity.

My analysis of student work and my curriculum archives for the aspirin unit leads me to be highly critical of my planning with respect to the sTc component of authentic activity. The extraction of acetylsalicylic acid, the synthesis of aspirin, and the analysis of the aspirin product could be described as a “cookbook” activity; students were given little control over their approach in the lab and instead were asked to follow long, detailed procedures. In a lab practicum that served as the first semester final in the course, students showed immense creativity and problem solving ability as they designed experiments to identify an unknown compound responsible for killing a houseplant that was used to decorate our classroom. Also, during a previous unit, students had demonstrated content understandings (solubility as explained by intermolecular forces) that would enable them to design an extraction set-up. So while our cookbook procedure to extract salicin from willow bark was unsuccessful, we may have had more success had I allowed students to exercise creativity and apply their content knowledge to design their own method.

Opening up the aspirin unit to more student-led experimentation may also allow for better alignment with the NGSS. For example, allowing students to design their own extraction procedure (based on knowledge of the molecular structure of salicylic acid and various possible solvents) may allow them to indirectly demonstrate performance expectation “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" (NGSS Lead States, 2013). Although, even here, we can see how the predetermined weaving of the three strands of the NGSS may unnecessarily limit authentic activity. The purpose of this redesigned extraction of salicylic acid would be more aligned with the science and engineering practice of "Constructing Explanations and Designing Solutions" found in HS-PS1-6 (discussed above), while the content of this activity is aligned with the "Structures and Properties of Matter" disciplinary core concept, which is the focus of HS-PS1-3.

Despite my own critiques of the aspirin unit as an example of an authentic activity, there is evidence that students experienced it as such. In other words, students found the synthesis of aspirin to be a "hands-on, minds-on" activity that also challenged them to consider the "sociocultural relevance of the science content in everyday life" (Rodriguez, 1998, p. 600). For example, Raquel thanked me in the acknowledgements section of her aspirin lab report for "For actually connecting science to the real life problems. Also for giving us problems that we can actually encounter and that affect our lives." More substantively, Jade wrote in her introduction about how synthesizing acetylsalicylic acid clarified for her the notion that generic and brand name drugs are equivalent chemically. She noted that this understanding could help her fellow "minorities" avoid being manipulated by profit-driven pharmaceutical companies who sell brand name pills for substantially more than their chemically equivalent generic counterparts. In our interview, Jackson identified the aspirin unit as the unit in the class during which he learned the most. He elaborated by noting with a proud smile that it was the opportunity to synthesize aspirin himself that was particularly impactful, "That's just kind of one of those cool things that I'll always have. These things that I buy at the store to get rid of my headache, I made that once!"

Whereas his classmates took the aspirin lab report as an opportunity to critique Western science, Jackson saw the synthesis of aspirin as an example the awe-inspiring accomplishments of Western science, while at the same time making him feel that these feats are within his own ability:

> There are a lot of things that we use everyday that we don't really understand how it works or how we got to that point, but we use it everyday…there are people who don't know how their microwave works or why their microwave works. There are people who don't know how their remote control controls the TV…these aren't super hard things to understand…It kind of showed me that we aren't as far away from these kind of complicated everyday things that we use as people think we are.

This viewpoint is consistent with Jackson's "concerned scientist" orientation. While he did draw from the course readings in his lab report, Jackson did not take the same sharply critical approach to understanding the historical relationship between Western science and indigenous knowledge that many of his classmates did. In our interview, Jackson used aspirin as an example to push back against ill-informed critics of Western medicine who equate modern pharmaceuticals with poison, noting that Western medicine often merely isolates the biologically active compounds in known herbal remedies. Jackson's concerned scientist orientation provides further evidence that justice-centered science pedagogy pushes students to grapple with the complexity of SSI, rather than to adopt a particular worldview.

Justice-Centered Science Curriculum as a Catalyst for Social Change?

The final extension of the extended case method is the reconstruction of theory. To conclude this chapter, I draw from my analysis of data from the soil project and aspirin unit to reify and add nuance to the Justice-Centered Science Pedagogy framework presented in Chapter

II. In order to apply the “catalyst for change” metaphor elaborated in Chapter II to science curriculum, this curriculum would have to support the development of critical consciousness in order to facilitate social change faster and under less harsh conditions. A curricular catalyst for change would also need to support the ability of disenfranchised and dispossessed communities to self-determine a more just and sustainable future. Given the role of US schools in maintaining oppression, this sort of departure requires providing opportunities for students from these communities who wish to pursue STEM pathways (like concerned scientists and science nepantler@s) and also for those students who do not (tourists in the culture of science). In a world wrought with complex SSI and ever-changing technology, communities that have been historically disenfranchised and dispossessed will have little say in their own future (or our collective future) without scientifically literate community members *and* homegrown experts. The former are necessary for democratic decision-making and mobilizing people power when the community is faced with an SSI. The latter must be organic intellectuals who understand the struggles of the community while also being able to leverage their expertise in service of community health or sustainable development. Science curriculum as catalyst would thus have to support students of all three orientations to achieve academically. And it would also have to support students in maintaining or developing cultural competence in order to remain grounded members of their communities as they struggle to determine a more just and sustainable future. The soil study and the aspirin unit provide two noticeably different examples of problem-posing curricula developed from SSI as generative themes that support academic achievement while also supporting students to develop critical consciousness and cultural competence.

While the soil project provided students an opportunity to produce and disseminate scientific knowledge, the aspirin unit provided opportunities to reflexively interrogate and critique the dominant narrative about the production of scientific knowledge. Curtis said that he felt a connection with the aspirin unit because tracing the roots of aspirin to indigenous peoples' knowledge of plants was an example of pushing back against US education that consistently denied the value of his Chicano culture and Mexican roots. Other students, including Odette and Cristina shared similar interpretations and shared ways that they continue to challenge Eurocentric views of science as they have matriculated to college science courses and are involved in environmental justice organizations.

The limit of the catalyst metaphor: Reinvention required

In chemistry, what separates a catalyst from other reactants is that, at the end of the reaction, it remains unchanged. Herein lies the limit of the metaphor of science education as a catalyst for social change. Unlike a catalyst, "problem-posing…education roots itself in the dynamic present" and is "constantly remade in the praxis" (Freire, 1970/2001, p. 84). Or as Freire has emphasized throughout his writing, the work of critical pedagogy must be constantly reinvented in each context. This is true for socially transformative science curriculum, which cannot be blindly transported from one context to another. The context-specific nature of the soil project is obvious, but the aspirin unit also emerged from the particular context of La Lucha and Ridgevale. Science educators who wish to enact justice-centered pedagogy in their context will not be able to import the aspirin unit or the soil project. Instead, we must search for SSI that are generative in these other contexts. Still one of the goals of this study is to provide context-specific lessons learned that might be informative for practitioners in other contexts. So what lessons have I learned about developing justice-centered science curriculum?

Data from interviews and student work show that students experienced the soil project and the aspirin unit, which were developed from SSI as generative themes, as more relevant than units that were developed using canonical chemistry concepts as a starting point. This was the case even though I tried to inject these latter units with relevant contexts. If we seek to center justice in our pedagogy, then prioritizing or beginning with canonical science concepts in our curriculum planning does not make sense, except as a strategy to negotiate forces that require this sort of approach. To begin from the canonical chemistry content described in the NGSS is a curricular orientation that centers and prioritizes the worldview of Western science. Even though the NGSS espouse an individual constructivist view of learning and the framework that guided their development considers many of the critiques of past science standards, ultimately they represent the same cultural transmission model of science education that has been criticized in earlier standards (Mutegi, 2011; NRC, 2012; Rodriguez, 1997). This does not mean that we should not consider the NGSS in our planning, merely that we should not consider them as the starting point for our curricula.

If I were to re-design either the aspirin unit or the soil project now with the ability to consider the NGSS in their final form, I believe I could achieve better alignment than I did in the units described here. The aspirin unit, in particular, could be strengthened by more explicitly addressing some of the science and engineering practices valued by the NGSS. Still achieving tight alignment with the performance expectations would force me to stray from the true focus of each unit. This is the case because the predetermined braiding of specific disciplinary core ideas with science and engineering practices and cross cutting concepts exacerbates the mismatch between the NGSS and problem-posing education. Real world problems (like studying the impact of polluting industry or considering the development of pharmaceuticals) are interdisciplinary in nature and require flexibility. They also require students and teachers to deal with complexity and uncertainty, whereas the NGSS value simplicity, causality, and predictability as scientific ideals.

The NGSS would better support teaching that focuses on authentic activity if teachers were entrusted to braid the three strands together on our own. There is no reason why teachers could not create context specific performance expectations by selecting for ourselves which of the core ideas, science practices, and cross cutting concepts are applicable to a particular lesson or unit. The rigidity implied by the NGSS performance expectations as they have been written does not lend itself to curriculum organized around SSI or generative themes. This rigidity reeks of "teacher-proofing" or distrust of teachers' ability to execute the spirit of the standards and thus pushes the NGSS away from standards as high expectations and towards standards as imposed uniformity. This critique applies to the NGSS whether or not we view science curriculum as potentially transformative.

Another lesson learned that may resonate with teachers in other contexts is the importance of what critical pedagogues have called "political clarity" in identifying SSI as generative themes. SSI are necessarily complex and critical pedagogy requires considering how issues of oppression or domination are part of this complexity (Dos Santos, 2009). Understanding the ways coal power plant pollution and drug development intersected with students lives required me, as a teacher, to understand racism as endemic and structural and to have a critical view of the history of Western medicine as linked with colonialism. The evidence suggests that I would not have been able to identify these SSI as potential curricular topics without political clarity. This political clarity was developed through my own grassroots political engagement and by listening to students as they developed critical consciousness. Serious study of social theory, philosophy of science, and critical educational texts also played a role. Much of this study was motivated by my desire to develop relevant curricula.

One of the major shortcomings I have identified in my curriculum planning documents or journal reflections is that they do not suggest a systemic approach where teachers can work with community members and students to identify SSI as generative themes. Other critical pedagogues have described systematic approaches to identifying generative themes or beginning the curriculum development process in dialogue with students and/or community (Duncan-Andrade & Morrell, 2008; Gutstein, 2012; O'Cadiz et al., 1998). And science educators have documented organized ways of using teacher-student dialogues to inform curriculum and pedagogy (Emdin, 2010d; Tobin & Roth, 2005). Bang and colleagues (2010) have even developed a community-based design model that develops science curriculum with culture as a starting point. Still as science educators, we need more ways of working with community members and students to identify those SSI that are generative for the contexts in which we teach. Also in order to enact justice-centered science pedagogy, we must think beyond curriculum development. The curriculum analyzed in this chapter was supported (or sometimes undermined) by day-to-day teaching practices and classroom structures that are the focus of Chapter VII.

Chapter VI: Injected Relevance?

Initial content analysis of student interview transcripts identified the stoichiometry unit and the equilibrium unit as the most salient units besides the soil project and aspirin units. In the previous two chapters, I classified the soil project and the aspirin unit as problem-posing education (Freire, 1970/2001) in a secondary science classroom. This means that those units were organized around socio-scientific issues (SSI), which evidence suggests were generative themes for the students and the community. By organizing the curriculum around these SSI, students were supported to develop academic achievement, critical consciousness, and cultural competence in interconnected ways. In contrast to the problem-posing approach, I classify the stoichiometry and equilibrium units as examples of "injected relevance." These units were organized around the canonical chemistry concepts of stoichiometry and chemical equilibrium, respectively. By injected relevance, I mean that I inserted connections that I believed students would find meaningful into this study of canonical chemistry. The injected relevance approach characterizes the majority (7 of 9) of units in the case study class (with the soil project and the aspirin unit being the two exceptions).

The connections between canonical chemistry and community concerns that characterize injected relevance took two forms. The first was to use a relevant SSI to frame or introduce a concept or calculation as potentially important. The second form of injected relevance involved challenging Eurocentric and androcentric chemistry curricula. These two forms of injected relevance were intended to support the development of critical consciousness and cultural competence within the context of learning canonical chemistry. In this chapter, I present and interpret examples of these two forms of injected relevance from the stoichiometry and equilibrium units through the lenses of sTc (Rodriguez, 1998). Then I analyze selected student artifacts using the NGSS (Lead States, 2013) and the AP chemistry course description (College Board, 2012) alongside student reflections on these units. Finally, I reconsider how different students view the relevance of the class retrospectively based on their current involvement in science or social justice organizations.

Injected relevance is regular, but not central

The fundamental difference between injected relevance and problem-posing education is whether the science content or the social context drives the curriculum. This difference is illustrated by brief analysis of the long and short term planning documents and homework assignments for both the stoichiometry and equilibrium units, summarized in Table XI. Coincidentally both units were slightly more than four weeks long, each taking place over 22 total instructional days. Each unit contained 3 laboratory experiments and four weekly problem sets, which were assigned as homework. The stoichiometry unit was the first unit of the school year and was planned to teach the concepts, calculations, and techniques required to make precise measurements of chemical amounts and quantitative predictions about the outcomes of chemical reactions. An analysis of the daily planning documents I have for the stoichiometry unit indicates that 12 of 22 days included examples of injected relevance, including one of the three laboratory experiments. Out of approximately 90 total problems on these four assignments, only three problems involved injected relevance. All but one of the examples of injected relevance in the stoichiometry unit was of the first type, using SSI to frame a concept or introduce a calculation.

The equilibrium unit stretched across four weeks of instruction from early March to mid-April, with a weeklong spring break in the middle. It was originally planned as a two-week unit on chemical equilibrium in general and a one-week unit on acid-base equilibrium, but my daily planning documents show that these were combined in practice. An analysis of these daily planning files indicates that 11 of 22 total days of instruction in the unit included examples of injected relevance, including two of the three laboratory experiments. Out of 56 total problems on the four weekly problem sets, only 3 included examples of injected relevance. Of these fourteen total examples of injected relevance, 11 involved SSI while 3 were related to challenging Eurocentric or androcentric science curricula which incorrectly imply that science is the domain of white men. Table XI summarizes the analysis of daily planning documents for injected relevance. In following sections, I explain these two types of injected relevance in more detail and provide examples of each from each unit.

Table XI:Frequency of Injected Relevance in Daily Lessons and Weekly Homework

Unit	Daily Lessons		Homework Problems		Laboratory Experiments		Injected Relevance as…	
	Total	With injected relevance	Total	With injected relevance	Total	With injected relevance	Examples of SSI	Examples of challenging Eurocentric and androcentric curricula
Stoichiometry	22	12	0	3	3	1	14	1
							- childhood lead poisoning - coal mining - metal mining - alternative energy	- explicitly addressing racism as the cause of underrepresentation in science
Equilibrium	22	11	56	3	3	2	11	3
							- water contamination - uranium mining - toxic beauty products - fossil fuel dependence	- nixtamalization - Mario Molina - “Baghdad battery”

SSIs as injected relevance.

In Chapter IV, I argued that the theme of environmental racism as it relates to coal power plant pollution was a generative theme in the context of La Lucha High School. Unfortunately the coal power plants were not the only sources of industrial or post-industrial pollution in the surrounding communities. In environmental science classes, students at La Lucha also learn about a superfund site in the surrounding neighborhood that was contaminated with carcinogens associated with the production of asphalt and about an illegal landfill in East Ridgevale, where most of La Lucha's African American students live. In fact the problems associated with various contaminated sites and pollution sources are so numerous in the surrounding neighborhood that COVER, one of the organizations that was instrumental in forcing the closure of the coal power plants in the neighborhood, leads "community asset/toxic tours." On these tours, organizers educate community members and others about the various hazards and victories related to environmental justice in the neighborhood.

Unlike the problem-posing units in previous chapters, the SSI in these units were addressed as a series of relatively isolated examples of how the concept at hand might be relevant, rather than as an ongoing problem to investigate. My planning documents indicate that I framed the stoichiometry unit as part of a general commitment to fighting environmental racism. For example, one of the three essential questions listed in my unit plan is: "How can quantitative analysis help us defend our communities against environmental racism (e.g. preventing and decontaminating the siting of coal power plants)?" But the various topics indicated in Table XI indicate that I relied on numerous unrelated examples rather than focusing on a particular problem. It is worth noting that these topics were also included in the curricula of previous science classes that most of the students in the case study class had taken, including sophomore chemistry and environmental science.

Childhood lead poisoning.

On the 5th day of class (8/17/12), I introduced solution stoichiometry with a short youth-produced documentary about the concentration of lead in the drinking water of schools in an African American community in New Jersey. Unfortunately childhood lead poisoning is also a problem in Chicago that is caused in part by industrial pollution (see Chapter IV), but also by the deterioration of leaded paint in dilapidated housing stock and lead deposited near roadways by years of leaded gasoline exhaust (Fokum, Simpson, & McAfee, 2012; Wuana & Okieimen, 2011). Lead poisoning is an issue of environmental racism that disproportionately impacts African American and Mexican American children, especially those who live in older urban housing stock (Bullard, Mohai, Saha, & Wright, 2007). After a brief class discussion of this documentary, I asked students to work in small groups on a problem that I designed to introduce the importance of using the correct number of significant figures in chemical calculations through the problem of childhood lead poisoning:

> Imagine a child's blood lead level is tested. A 1.00 mL sample of blood is drawn and it is found to contain 0.000001 g of lead. The medically defined threshold of lead poisoning is 10 micrograms of lead in 1 deciliter of blood. Does the child have lead poisoning?

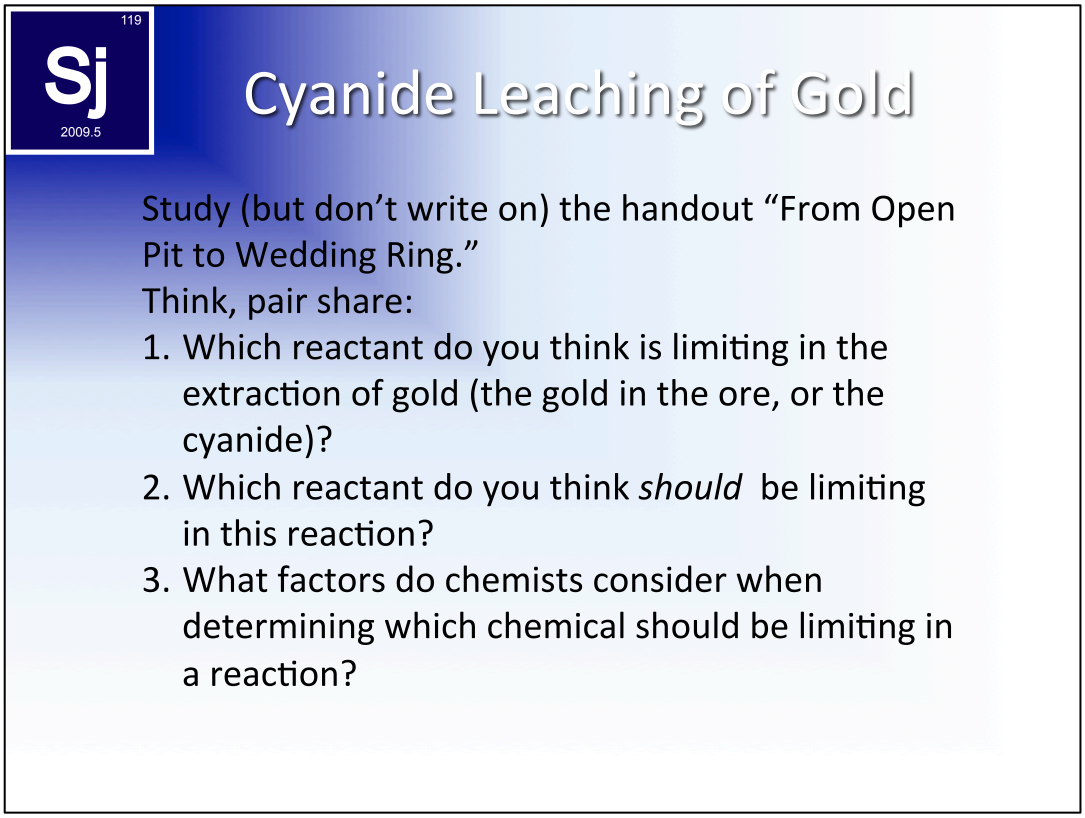
The solution to the problem (10 micrograms of lead per deciliter) indicates that this hypothetical child is right on the threshold of being officially lead-poisoned. I followed up by asking students to repeat the calculation assuming that 0.000001 g of lead was actually rounded up from 0.0000005 g or that it was rounded down from 0.00000149 g. These two changes result in two very different interpretations, that the child is only halfway to the threshold or that the child has

149% of the blood lead level indicated by the threshold. This problem thus demonstrates the potential impact of being imprecise with significant figures. Childhood lead poisoning as injected relevance appeared again in homework problems in the stoichiometry unit and in the equilibrium unit and as an extended multi-step problem in the review of the stoichiometry unit. One of these examples is included in the analysis of student work below.

The problem described here attempts to inject relevance into my instruction about the typically rote and tedious skill of using the accepted number of significant figures during calculations in chemistry. While this skill is important to master in the contexts of the AP chemistry exam, college chemistry courses, and scientific data analysis, students are often simply asked to memorize a set of rules about how to determine that number of significant figures they should include in a particular number. By using a local problem of environmental racism that was connected to the soil project and to some students' experiences to contextualize the importance of this skill, students were "urged to reflect on how the subject under study is socioculturally relevant and tied to everyday life" (Rodriguez, 1998, p. 600). However after this initial contextualization, my daily planning documents indicate that I essentially encouraged students to apply the rules for rounding to the correct number of significant figures, just as they likely would have been taught in a traditional chemistry class. So this particular example of injected relevance falls short of authentic activity despite contextualizing the instruction of a canonical science skill within a relevant social problem. But this example also illustrates the dilemma that leads me and other teachers to lean on injected relevance. Given limited instructional time and pressure to teach numerous such conventions alongside more complex concepts and skills, the amount instructional time and planning we can devote to embedding each of these skills within authentic activities is limited. Perhaps compromises like this are sometimes necessary given the constraints.

The human and environmental impacts of metal mining.

On the 18th day of class (9/7/12), I introduced the concept of limiting reactants, which is central in stoichiometric calculations. Just after introducing the concept, I gave students a handout entitled, "From Open-pit to Wedding Ring" from a report about the environmental and human impacts of mining and refining metal ores (Earthworks & Oxfam, 2004, p. 2). This one-page handout illustrated the process of mining, refining gold including the process of cyanide heap leaching, which is a toxic process used to isolate gold from very poor ores. I asked students to use this handout to consider the questions shown on the presentation slide in Figure 6.



Cyanide Leaching of Gold

Study (but don't write on) the handout "From Open Pit to Wedding Ring."

Think, pair share:

1. Which reactant do you think is limiting in the extraction of gold (the gold in the ore, or the cyanide)?
2. Which reactant do you think *should* be limiting in this reaction?
3. What factors do chemists consider when determining which chemical should be limiting in a reaction?

Figure 6: Problematizing the concept of limiting reactants through an SSI

The handout explained that the process of heap leaching uses excess cyanide to extract a maximum amount of gold. This results in significant toxic pollution in gold mining communities, which are largely located on indigenous lands (Earthworks & Oxfam, 2004). Through this example of environmental racism, I problematized the value-judgments associated with limiting reactants, which is often considered only as a technical concept in solving stoichiometry problems. Our follow-up discussion contrasted “green chemistry” which prioritizes minimizing environmental impact with the practice of chemistry that prioritizes profit above all other considerations. In the former, chemists design processes where the most toxic chemical is the limiting recant to minimize the environmental impact. In the latter, processes are designed to make the most expensive chemical the one that is limiting in order to cut costs and maximize profits. This second example of injected relevance goes beyond the first example provided above. Besides providing students with an opportunity to consider the social relevance of an important canonical chemistry concept (limiting reactants) I also asked them to consider how this seemingly “objective” concept actually involves making value judgments. We practiced reflexivity (in an sTc sense) as we discussed as a class how the design of chemical systems is a technical undertaking that often has very real social justice implications, especially in the context of neocolonial exploitation of resources and people in the Global South by mining companies that are often based in Europe, Canada, or the United States. The SSI of the environmental impacts of metal mining appeared again on an exam for the stoichiometry unit and a homework problem in the equilibrium unit. These examples are included in the analysis of student work below to consider how students were able to demonstrate proficiency with respect to the canonical skills and concepts of chemistry as they are embedded in a problem that is framed by a relevant social context.

Challenging Eurocentric and androcentric curricula

The four problem sets that were assigned in the equilibrium unit are summarized in Table XII below. The third column of this table summarizes the canonical chemistry content on each problem set and notably includes the names of eight European or European American men. For eight such names to be included in the content of the problem sets from one four-week unit highlights the way canonical chemistry content itself positions the discipline as something white men do. In the college chemistry text we used in the case study class, there is some brief biographical information about seven of these eight men, including a more extended biography and picture of Svante Arrhenius (Zumdahl & Zumdahl, 2007, pp. 132-133). While researchers have been calling for multiculturalism and gender equity in the science classroom for years (Atwater, 1993; Atwater & Suriel, 2010; Barba, 1995; Brickhouse, Lowery, & Schultz, 2000), this example suggests that these calls have done little to loosen the Eurocentric and androcentric stranglehold on mainstream science curriculum in the US. While science curriculum is often framed as objective or neutral, these examples provide evidence that US science curricula are subject to Sleeter's (2011) critique of mainstream US curriculum as "Euro-American" studies. By encouraging students to question these curricular materials, I hope to engage them in the sTc practice of dialogic conversation with the authors of the text, to consider why the field of chemistry is framed in this way and whose voices are left out.

Table XII: Problem Sets in the Equilibrium Unit

Problem Set #	Problem Set Title	Canonical Chemistry Content	SSI (Injected Relevance)
20	Equilibrium Expressions and Electrochemical Cells	Equilibrium Expressions **Galvanic**/**Voltaic** Cells	None explicit
21	Le Châtelier's Principle & K_{sp}	**Le Châtelier's** Principle Solubility Product Constants **Gibbs'** Free Energy & Spontaneity	Lead Poisoning as an issue of environmental racism
22	Spring Break Equilibrium (miscellaneous problems)	Equilibrium involving solubility, **Lewis** acids, gaseous phase reactions, and fuel cells	1. Uranium mining on Navajo reservations as an issue of environmental racism 2. Hydrogen fuel cells as potential alternative energy storage technology
23	Acid-Base Equilibrium	Equilibrium involving **Arrhenius**, **Lewis**, and **Brønsted-Lowry** Acids and Bases	None explicit

Some critics may point to the practice of referring to canonical concepts by the names of the scientists credited with their discovery as important to traditions of science and scholarship. But it is important to consider the way this practice reinforces and normalizes the racist, sexist, and exclusionary history of a field like chemistry. If students are not taught the context surrounding the development of Euro-American science, specifically that, "Western knowledge and science are 'beneficiaries' of the colonization of indigenous peoples" (Smith, 1999, p. 59), then Eurocentric curriculum (at best) implicitly suggests white men may somehow be better suited to do science. Many texts and teachers try to mitigate this effect by including token examples of non-white or women scientists in their curriculum. I teach about the contributions of women chemists and chemists of color who have made substantial individual contributions to the field. But in science classes at La Lucha High School, challenging white supremacy and patriarchy in the history of science goes beyond this tokenistic approach in at least four ways by: (1) valuing the contributions and knowledge of non-professional scientists, (2) referring to ideas by the names of concepts not men, (3) introducing students to examples of their ancestors' collective contributions, and (4) explicitly addressing racism and sexism in science. These practices are illustrated by three examples of injected relevance from the stoichiometry and equilibrium units below and ask students to consider who are recognized as scientists and who is excluded from science, components of reflexivity in sTc. Students are also encouraged to consider their answers to these larger questions within the historical context of colonialism and the political contexts of capitalism, white supremacy, and patriarchy.

On the first day of the stoichiometry unit, we read the abstract and introduction to William Tate's (2001) article "Science education as a civil right: urban schools and opportunity-to-learn considerations" aloud as a class. I used this article to frame students' enrollment in AP chemistry class as laying claim to their civil rights and to contextualize the problem of underrepresentation of scientists of color as one of a lack of opportunities rather than a lack of ability. This reading built upon articles that students read throughout their science classes at La Lucha, which framed the issues of the underrepresentation of women and African American and Latin@s in science as issues of racism and sexism rather than issues of interest or achievement. These issues are also addressed on the first page of the course syllabus, an excerpt of which is included here:

> Indigenous peoples in Africa and the Americas have long traditions of understanding nature experimentally. People have also long used that knowledge for healing and engineering. However, in the US, Black and Latino students have not had equal or adequate access to careers in chemistry or other fields in science, engineering, or medicine. One of the ways that under-represented students have been excluded from these fields is that introductory college courses in chemistry (and other science disciplines) have been treated as "weed-out" courses with rigorous requirements and little

> or no support. These classes are especially difficult for students who did not have opportunities to take advanced science courses in high school.

Reflecting upon this passage, I noticed that the exclusion of women from science is not addressed and it should be. Still in the syllabus, I emphasize that students' ancestors have strong empirical traditions and that systemic racism has prevented access to science fields in the US.

The equilibrium unit also provides examples of how I try to challenge Eurocentric and androcentric traditional science curricula. For example, my titles for the problem sets in Table XII suggest that I generally refer to concepts without using the name of the scientist credited with their discovery, so instead of learning about Galvanic or Voltaic cells, we learn about electrochemical cells. Instead of emphasizing the contributions of Josiah Gibbs, we simply refer to "free energy." Table XII also shows that I am not always consistent with this practice because I did not come up with an alternative way to describe Le Châtelier's principle, which figures prominently in the student work artifacts below. This practice illustrates another tension in my application of injected relevance. For concepts that are almost universally known by the name of a scientist, I do feel some obligation to expose students to the canonical name in order to familiarize them with the culture of power (Delpit, 2006). These cases illustrate the importance of also exposing students to frameworks that can help them understand the larger context that has allowed European and European-American men to shape science in their image.

Another example that illustrates the ways I tried to decenter maleness and whiteness in the chemistry curriculum is in the way that I introduced the various acid-base concepts included in Table XII. Before introducing students to Lewis, Arrhenius, or Brønsted-Lowry acids and bases, we discuss how indigenous women from Mesoamerica were among the first people in the world to use acid-base chemistry in impactful ways. The process of *nixtamalización* (from the

Nahautl word nixtamal) uses an alkaline (basic) solution prepared from hardwood ashes and crushed seashells to transform corn into hominy. Prior to introducing the traditional definitions of acids and bases, I used an acid-based indicator and ashes I collected from a campfire to model for students how a strong base could be produced from water and hardwood ashes. This chemical process of *nixtamalización* is the basis of corn becoming the staple of the major civilizations in ancient Mexico. When European colonizers learned about corn from indigenous peoples in the Americas, their failure to understand the importance of *nixtamalización* led to malnutrition when trying to appropriate a corn-based diet because this chemical process allows for the biological absorption of the essential vitamin niacin (Keoke & Porterfield, 2003). We discuss that while the three major acid-base concepts in chemistry may be named after European men, indigenous people in Mexico, probably most of whom were women, were innovators of acid-base chemistry through this process. I also remind students throughout the year that the word “chemistry” itself indicates African roots. Ancient Egyptian civilizations were among the first to master metallurgy and so these processes were likely named after the Ancient Egyptians’ name for their homeland *khem* (Loyson, 2011). In this way, I emphasize the contributions of my students’ ancestors in a way that also highlights the role of Indigenous and African peoples, women, and the collective contributions of ordinary people rather than the contributions of famous individual scientists.

Analysis of student work

In this section, I examine student work artifacts connected to three of these examples of injected relevance: (1) a problem from the stoichiometry unit exam that is connected to the impact of metal mining, (2) a homework problem from the equilibrium unit that is connected to childhood lead poisoning, and (3) a homework problem from the equilibrium unit that is connected to uranium mining on Navajo lands. The student work artifacts demonstrate students’ ability to complete many of the calculations required by the AP chemistry course description and to explain one of the central concepts of chemical equilibrium that is highlighted by the NGSS and this course description (College Board, 2012; NGSS Lead States, 2013). The analysis that follows also includes reflections from student interviews to provide insight into their thinking that is not visible in the work artifacts.

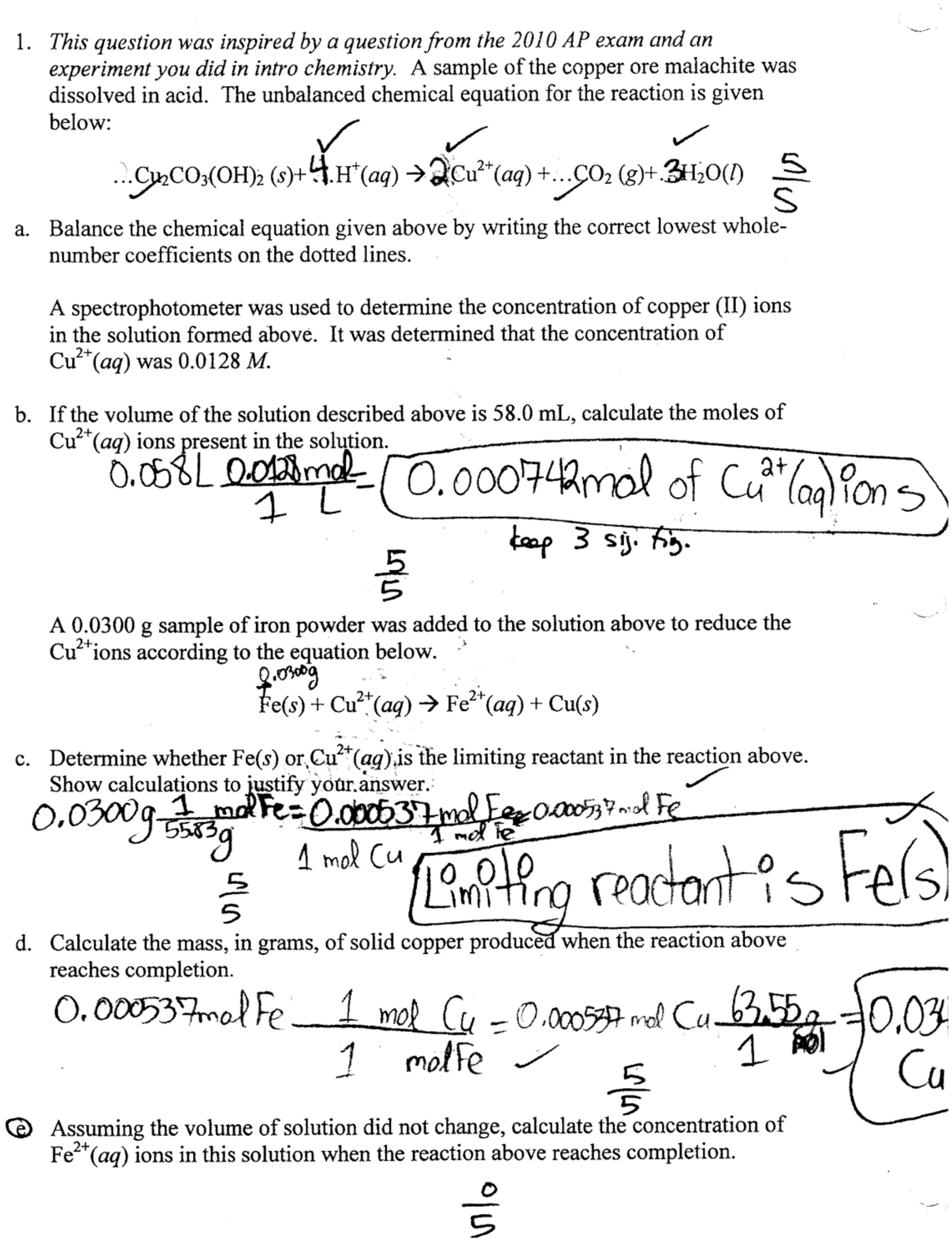
Stoichiometry Exam.

The following problem was inspired by two units that I taught every year in sophomore chemistry, a course taken by 27 of the 29 students in the case study class. Two of the seniors in the case study class had a different teacher, but he used the same curriculum. These sophomore chemistry units are connected to the example of injected relevance above that focused on the impacts of gold mining. In the “Fools’ Gold” unit, we teach about the properties of metals within the context of the potential residual economic impact of more than 185,000 kilograms of gold and 16,000,000 kilograms of silver that were stolen by Spain as conquistadors ravaged Latin America between 1503 and 1660 (Galeano, 1993, p. 23). In the “Tricknology” unit, we teach about electrochemistry by examining the conflict-ridden origins of some of the metals that are used in students’ consumer electronics. In some years, we combine these two units. One of the central activities in this unit is the laboratory extraction of copper metal from the ore, malachite (SEPUP, 2005). Through this laboratory activity, students model the extraction of a metal from its ore to construct an understanding of oxidation-reduction reactions but also to model and understand the amount of waste produced by this process and its impact on local communities and workers. The problem below was also loosely modeled after a problem that appeared on Form B of the 2010 AP chemistry exam (College Board, 2010). I have included Odette’s response with my scoring marks below and the others in the Appendix. I include Odette’s as a representative sample because she earned the median score on this problem among the five I received for this study. A brief summary of students' performance on this question are included in Table XIII.

Table XIII: Student Performance on Stoichiometry Exam Problem #1

Student	(a)	(b)	(c)	(d)	(e)	Score (max=25)
	Balanced Equation	Calculated moles of Cu^{2+}	Determined limiting reactant	Calculated mass of Cu product	Calculated concentration of dissolved Fe^{2+}	
Cristina	✓	✓	✓			17
Curtis			✓	✓		21
Francisco	✓	✓	✓		✓	22
Odette	✓	✓	✓	✓		20
Raquel		✓	✓			14

Francisco, who mentioned in our interview that this exam boosted his confidence for the rest of the course, demonstrated the most well developed skills with stoichiometric calculations, earning 22 out of 25 points on this problem. Francisco, Odette and Cristina correctly balanced the equation in part (a) of this problem. Raquel's equation was missing the coefficient in front of the Cu^{2+} ion and Curtis' equation was balanced but all of the coefficients were doubled. Four of five students correctly calculated the number of moles of Cu^{2+} moles present in the solution. Curtis set up the calculation correctly, but made a minor computation error, which caused his final answer to be off by one order of magnitude. All five students correctly identified iron as the limiting reactant, with supporting calculations. Odette and Curtis correctly calculated the mass of solid copper that was produced in the reaction. Both Francisco and Cristina used the moles of Cu^{2+} to calculate the yield when they should have used the moles of the limiting reactant, iron. Raquel did not answer parts (d) or (e). Francisco was the only student to arrive at the correct answer to part (e), but Curtis solved this portion correctly and his answer would have been correct were it not for his previously erroneous answer to part (b).



1. *This question was inspired by a question from the 2010 AP exam and an experiment you did in intro chemistry.* A sample of the copper ore malachite was dissolved in acid. The unbalanced chemical equation for the reaction is given below:

$$\ldots Cu_2CO_3(OH)_2\,(s) + 4\,H^+(aq) \rightarrow 2\,Cu^{2+}(aq) + \ldots CO_2\,(g) + 3\,H_2O(l) \qquad \frac{5}{5}$$

a. Balance the chemical equation given above by writing the correct lowest whole-number coefficients on the dotted lines.

A spectrophotometer was used to determine the concentration of copper (II) ions in the solution formed above. It was determined that the concentration of $Cu^{2+}(aq)$ was 0.0128 *M*.

b. If the volume of the solution described above is 58.0 mL, calculate the moles of $Cu^{2+}(aq)$ ions present in the solution.

$$0.058\,L\,\frac{0.0128\,mol}{1\,L} = \boxed{0.000742\,mol\ of\ Cu^{2+}(aq)\ ions}$$

keep 3 sig. fig.

$\frac{5}{5}$

A 0.0300 g sample of iron powder was added to the solution above to reduce the Cu^{2+} ions according to the equation below.

0.0300g

$$Fe(s) + Cu^{2+}(aq) \rightarrow Fe^{2+}(aq) + Cu(s)$$

c. Determine whether $Fe(s)$ or $Cu^{2+}(aq)$ is the limiting reactant in the reaction above. Show calculations to justify your answer.

$$0.0300\,g\,\frac{1\,mol\,Fe}{55.83\,g} = \frac{0.000537\,mol\,Fe \quad 0.000537\,mol\,Fe}{1\,mol\,Cu \quad 1\,mol\,Fe}$$

Limiting reactant is Fe(s)

$\frac{5}{5}$

d. Calculate the mass, in grams, of solid copper produced when the reaction above reaches completion.

$$0.000537\,mol\,Fe\,\frac{1\,mol\,Cu}{1\,mol\,Fe} = 0.000537\,mol\,Cu\,\frac{63.55\,g}{1\,mol} = 0.03\ldots\ Cu$$

$\frac{5}{5}$

ⓔ Assuming the volume of solution did not change, calculate the concentration of $Fe^{2+}(aq)$ ions in this solution when the reaction above reaches completion.

$\frac{0}{5}$

Figure 7: Odette's response to question #1 on the stoichiometry exam

On this exam problem, all students showed some ability to carry out the stoichiometric calculations expected by the College Board's (2012) AP chemistry course description. They also showed some of the skills emphasized in the clarification statement of the applicable NGSS performance expectation:

> 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.] (NGSS Lead States, 2013).

Similar to my analysis in of student work on the aspirin lab reports in Chapter V, it is difficult to determine whether student work on the stoichiometry exam demonstrates a use of mathematical thinking or rote memorization of problem-solving techniques, a distinction emphasized by the NGSS. Once again, this underscores the need for me as a practitioner to include more frequent opportunities for explicit metacognition in problem solving exercises.

Fortunately, student reflections during our interviews provide more insight. In our interview, Curtis identified stoichiometry as the most memorable unit of the course and also the largest source of pride and learning for him during the course. He reflected that, "it also enhanced my math skills. So that's why it's probably my most memorable." When I asked Curtis to elaborate on what he learned, he responded, “So the thing I liked about stoich was that when you see a problem, it’s like how do I approach this? Stoich kind of allowed me to see ok, they’re giving me these units and they want this. So what do I have to do to get there?” Curtis’ comments indicate that, at least for him, the stoichiometry unit allowed him to engage in creative problem solving and metacognition as opposed to the rote application of techniques.

Francisco and Cristina’s comments about learning stoichiometry do not provide much clarity about the extent to which they viewed the unit as encouraging mathematical thinking or rote application of techniques, but they both agreed that the skills assessed on this problem and in the larger unit have been important in their college chemistry classes. Cristina’s reflection below implies that repeated practice with multi-step problems was important in her preparation:

> So stoichiometry was the hardest one [unit], but now I actually like it. I actually enjoy it. And it’s a lot easier than I thought. So again, it really prepared me for college. Having to go through all those steps and doing all those practice problems really prepared me very well for college. I like it so much now. But that was probably the most difficult one.

It is not clear whether Cristina believes that practice problems enhanced her mathematical thinking or simply sharpened her ability to apply problem-solving techniques. Francisco echoed Cristina’s comments about feeling academically prepared for college chemistry in general, “I feel really prepared because with chem 101, I see so many people struggling…But it’s like everything that’s in my chem 101 class, I felt like I learned in my AP chem class and chemistry class sophomore year.” Francisco also specifically highlighted the skills he learned in the stoichiometry unit like balancing chemical equations (assessed by part (a) of the problem included here), “I can do balancing just by looking at it and I can do it in my head. And people [college classmates] will just look at me like how do you understand it so well?” Francisco attributed the ease he felt with this skill to his experiences in the case study class. But Francisco's reflections are also ambiguous about how exactly the case study class prepared him, referring to a "trick" I showed them to balancing equations, which we called RIP charts. This "trick" is a simple technique that helps students to keep track of the number of atoms of each element in the reactants and products of a chemical equation as they balance it. On one hand, students can benefit from problem-solving techniques like this as Francisco indicates. On the other hand, we do not want these techniques to become rote or applied blindly at the expense of developing metacognition or deeper modes of thinking. While it is not clear where exactly on this continuum these students fall, they credit the stoichiometry unit with developing their ability to solve quantitative problems. Cristina and Francisco found this to be useful preparation for their general chemistry course in college. Injected relevance was one of my attempts to deal with the tensions between preparation for success in traditional academic contexts and the more liberatory goals of justice-centered pedagogy. These work samples and student reflections provide evidence that injected relevance had some impact on the former.

The specificity of NGSS performance expectations and chemical equilibrium

My analysis of student work for the equilibrium unit focuses on two problems that provide additional examples of how I tried to inject relevant SSI into canonical chemistry. This analysis shows that students demonstrated high levels of proficiency with some of the central concepts and calculations associated with chemical equilibrium. It also suggests that students' ability to solve quantitative chemistry problems increased between the stoichiometry unit in the fall and the equilibrium unit in the spring. Finally, my analysis suggests that units organized around canonical chemistry may be more easily aligned with the NGSS than problem-posing units organized around SSI, but even in the equilibrium unit the specificity of the NGSS performance expectations was problematic. A description of the draft and finalized NGSS performance expectations (NGSS Lead States, 2012; 2013) and the portions of the AP chemistry course description that I planned to address in the equilibrium unit are included in Table XIV.

Table XIV: Standards or Canonical Chemistry Content Targeted by the Equilibrium Unit

Standards Document	Performance or Content Descriptions	
NGSS (Lead States, 2013)	2012 Draft HS.PS-CR-c. Analyze and interpret data to make claims that reaction conditions can be used to optimize the output of a chemical process.	Final NGSS.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.
AP Chemistry Course Description (College Board, 2012)	Chemical Calculations: 8. Equilibrium constants and their applications, including their use for simultaneous equilibria 9. Standard electrode potentials and their use; Nernst equation Topics: Reactions Equilibrium Concept of dynamic equilibrium, physical and chemical; LeChatelier's principle; equilibrium constants Quantitative treatment a. Equilibrium constants for gaseous reactions: Kp, Kc b. Equilibrium constants for reactions in solution (1) Constants for acids and bases; pK; pH (2) Solubility product constants and their application to precipitation and the dissolution of slightly soluble compounds (3) Common ion effect; buffers; hydrolysis Recommended Experiments: 7. Determination of concentration by acid-base titration, including a weak acid or weak base 21. Measurements using electrochemical cells and electroplating	

The following problem from "Problem Set 21: Le Châtelier's Principle and K_{sp}" provides an example of injected relevance in the equilibrium unit as it addresses the problem of childhood lead poisoning, earlier established as a problem of environmental racism.

> **Applying Le Châtelier's Principle to a real problem:** When the concentration of Pb^{2+} ions in a child's blood reaches a concentration of 10 μg/dL, the child is considered by the Centers for Disease Control to be officially lead-poisoned. One of the treatments for lead poisoning is called chelation therapy. In this therapy, a chemical called EDTA is used to remove lead ions from the blood by forming water-soluble complex ions. While chelation therapy is very effective at removing lead from the blood, it cannot remove lead

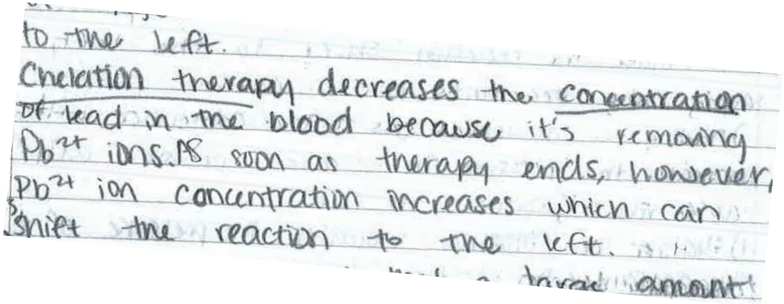
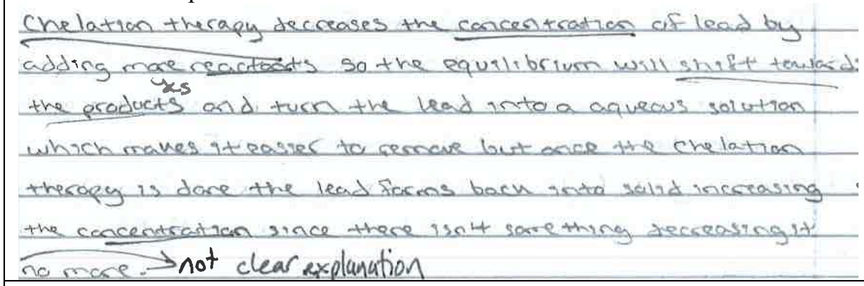
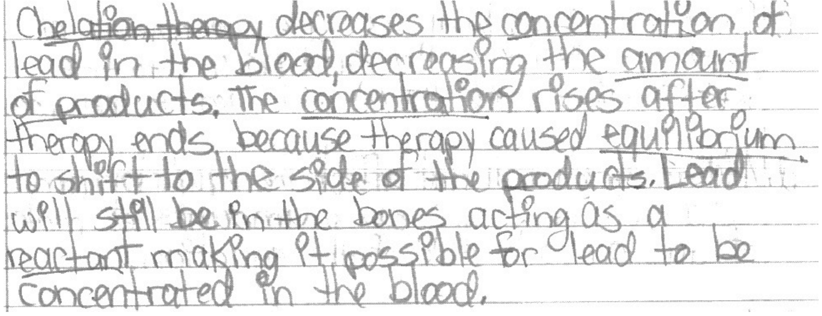
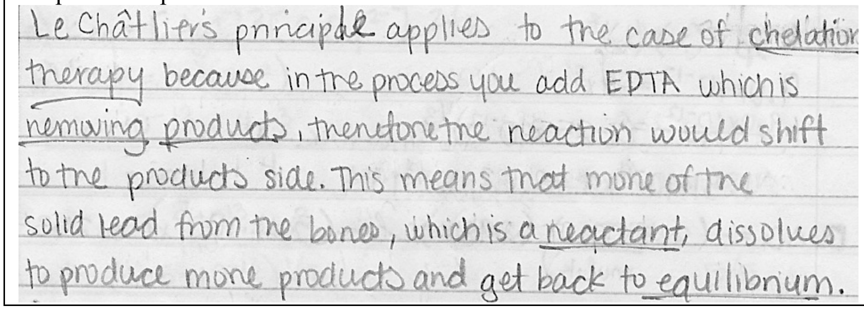
> that has deposited in a child's bones. The lead in a child's bones is mostly in the form of $PbCO_3(s)$. If we think of blood as an aqueous solution, lead can diffuse from the blood into the bones or from bones into the blood by the following process:
>
> $$PbCO_3(s) \rightleftharpoons Pb^{2+}(aq) + CO_3^{2-}(aq)$$
>
> While chelation therapy decreases the concentration of lead in the blood, it usually rises again as soon as therapy ends. Use Le Châtelier's principle and the reaction above to explain this. In your answer, use the terms: equilibrium, reactants, products, concentration, and chelation therapy.

I have the Problem Set 21 artifact from the four students who submitted complete course binders. My analysis of their work indicates that two students, Odette and Raquel, demonstrated the ability to apply LeChâtelier's principle to this problem while two students, Francisco and Cristina, submitted answers that were less successful. Their answers, with my underlines and two comments I wrote on Francisco's answer, are included alphabetically in Table XV below.

Odette and Raquel's responses demonstrate their ability to apply Le Châtelier's principle, which predicts that when a chemical reaction in a state of dynamic equilibrium is disturbed, the reaction will proceed in the direction needed to counteract the disturbance. This skill is emphasized in the College Board AP chemistry course description and in clarification statement of the targeted NGSS performance expectation (deconstructed in Table XVI). All four students understood that chelation therapy removed Pb^{2+} ions from the blood. Raquel and Odette interpreted this as a disturbance of the equilibrium and labeled this disturbance as "removing products," which is correct according to the way the equilibrium is represented in the problem. They also both correctly applied Le Châtelier's principle to predict that this removal of products would lead the equilibrium to proceed in the forward direction (to the right) as more solid lead carbonate dissolves from the bones into the blood. Francisco misinterpreted the disturbance of equilibrium as one where reactants were added, which would be equivalent to adding lead to the bones. He also misunderstood the formation of solid as leading to an increase in blood lead concentration. Cristina seems to have understood the spike in blood lead concentration that happens after chelation therapy ends as the disturbance of the equilibrium as opposed to the response to the disturbance (which was the chelation therapy itself). Given this misinterpretation of the problem, Cristina seems to have correctly understood Le Châtelier's principle as she predicts that an increase in products will shift the equilibrium towards the reactants.

Given this analysis, Odette, Raquel, and Cristina all demonstrated some proficiency with respect to the science and engineering practice of constructing an explanation, the disciplinary core ideas of dynamic equilibrium and the cross cutting concept of stability and change captured by NGSS.HS-PS1-6. I wrote this problem as a way to show how the concepts of equilibrium we were studying are applicable to an SSI that many previous students had identified as relevant in their lives or neighborhoods. Beginning from the canonical chemistry concepts makes alignment with content area standards more straightforward as we are viewing a complex SSI through a particular disciplinary lens. If I were to organize a unit around the SSI of childhood lead poisoning, I could certainly still include this problem for practice as I did here, but in trying to actually address the problem at the center of the unit, it is unlikely that our focus would have fit so cleanly into the concept of chemical equilibrium.

Table XV: Students applying Le Châtlier's Principle to Lead Poisoning Problem

Cristina's Response:  to the left. Chelation therapy decreases the concentration of lead in the blood because it's remaning Pb^{2+} ions. As soon as therapy ends, however, Pb^{2+} ion concentration increases which can shift the reaction to the left. a large amount
Francisco's Response:  Chelation therapy decreases the concentration of lead by adding more xs reactants so the equilibrium will shift towards the products and turn the lead into a aqueous solution which makes it easier to remove but once the chelation therapy is done the lead forms back into solid increasing the concentration since there isn't something decreasing it no more. → not clear explanation
Odette's Response:  Chelation therapy decreases the concentration of lead in the blood, decreasing the amount of products. The concentration rises after therapy ends, because therapy caused equilibrium to shift to the side of the products. Lead will still be in the bones acting as a reactant making it possible for lead to be concentrated in the blood.
Raquel's Response:  Le Châtlier's principle applies to the case of chelation therapy because in the process you add EDTA which is removing products, therefore the reaction would shift to the products side. This means that more of the solid lead from the bones, which is a reactant, dissolves to produce more products and get back to equilibrium.

Still even with this narrow disciplinary focus we see that this problem does not align perfectly with the NGSS performance expectation as written, even though it does address the three strands emphasized in the performance expectation. The particular performance expectation assumes that an increase in products is the most desirable outcome of a chemical reaction in equilibrium. This represents an orientation to chemistry that is focused on the industrial or experimental production of chemicals as opposed to the use of chemistry to understand environmental problems. This provides another example where the NGSS exclude certain forms of “applied” chemistry even as they have an emphasis on engineering. In the problem I wrote about lead poisoning, the shift of the equilibrium towards more products is a negative outcome in terms of the hypothetical child’s health. In another experiment that I wrote for the equilibrium unit, students are asked to refine the chemical system of an electrochemical cell by manipulating the variables of temperature and concentration to maximize the potential difference, a quantity that is mathematically related to the “distance” from chemical equilibrium. This provides another example that requires proficiency with all components of this NGSS performance expectation and yet still does not match up with the narrow way the final performance expectation is written.

Despite this critique, a close look at the problem I wrote in terms of the NGSS allows me to consider ways of improving my line of questioning. For example, I could have asked students to consider possible follow-up treatments and to explain how they might work in terms of the concepts of chemical equilibrium. While I am not sure whether students would have been equipped to answer this question, it would have emphasized problem-solving as opposed to simply understanding and explaining a problem without considering ways to address it.

Table XVI: Deconstructed NGSS Performance Expectation HS-PS1-6 (NGSS Lead States, 2013)

NGSS.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 Chatelier'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.*]		
Science and Engineering Practices: Constructing Explanations and Designing Solutions: Refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. ***ETS1.C: Optimizing the Design Solution** Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed.	**Disciplinary Core Idea:** **PS1.B: Chemical Reactions** In many situations, a dynamic and condition-dependent balance between a reaction and the reverse reaction determines the numbers of all types of molecules present.	**Cross-cutting concept:** **Stability and Change** Much of science deals with constructing explanations of how things change and how they remain stable.

Growth over time?

The following problem from Problem Set 22 is another example of the ways I tried to inject relevance into the canonical chemistry concept of equilibrium by referring to an SSI associated with environmental racism that we had previously discussed in class. During our short unit on nuclear chemistry, we watched and discussed a documentary film about the mining of uranium on Navajo reservations. The film used the lens of environmental racism to consider the elevated cancer rates among Navajo men that were caused by this industry historically and the community's contemporary struggle to prevent the industry from re-establishing itself on their land (Grossman, 2005). The problem appears below as it did on the problem set with the first sub-problem labeled (b) rather than (a) because of my typo.

Earlier in the year, we learned about a group called the Eastern Navajo Dine Against Uranium Mining (ENDAUM) that successfully preventing *in situ* leech mining on their reservation in New Mexico. In the documentary *Homeland* that showed their struggle, one of ENDAUM's founders and leaders named Mitchell Capitan talked about how in experiments he did in his job as a lab technician, all of the uranium could never be extracted from the water in this process.

(b) In this process, uranium is often precipitated out of ground water as $Na_2U_2O_7$. Write the dissociation equation for this compound as it dissolves in water.

(c) The K_{sp} for this compound is 8.13×10^{-29}. Calculate the maximum concentration of diuranate ions ($U_2O_7^{2-}$) at equilibrium.

(d) The EPA limit for uranium is 30 µg/L of drinking water. Complete the calculations necessary to determine if the saturated solution in the previous part of this problem will exceed these limits.

(e) People often add salt, NaCl, to their cooking water. Use LeChâtelier's principle to explain what this would do to the solubility of $Na_2U_2O_7$ in water. Explain whether this would make the water more or less dangerous in terms of uranium content.

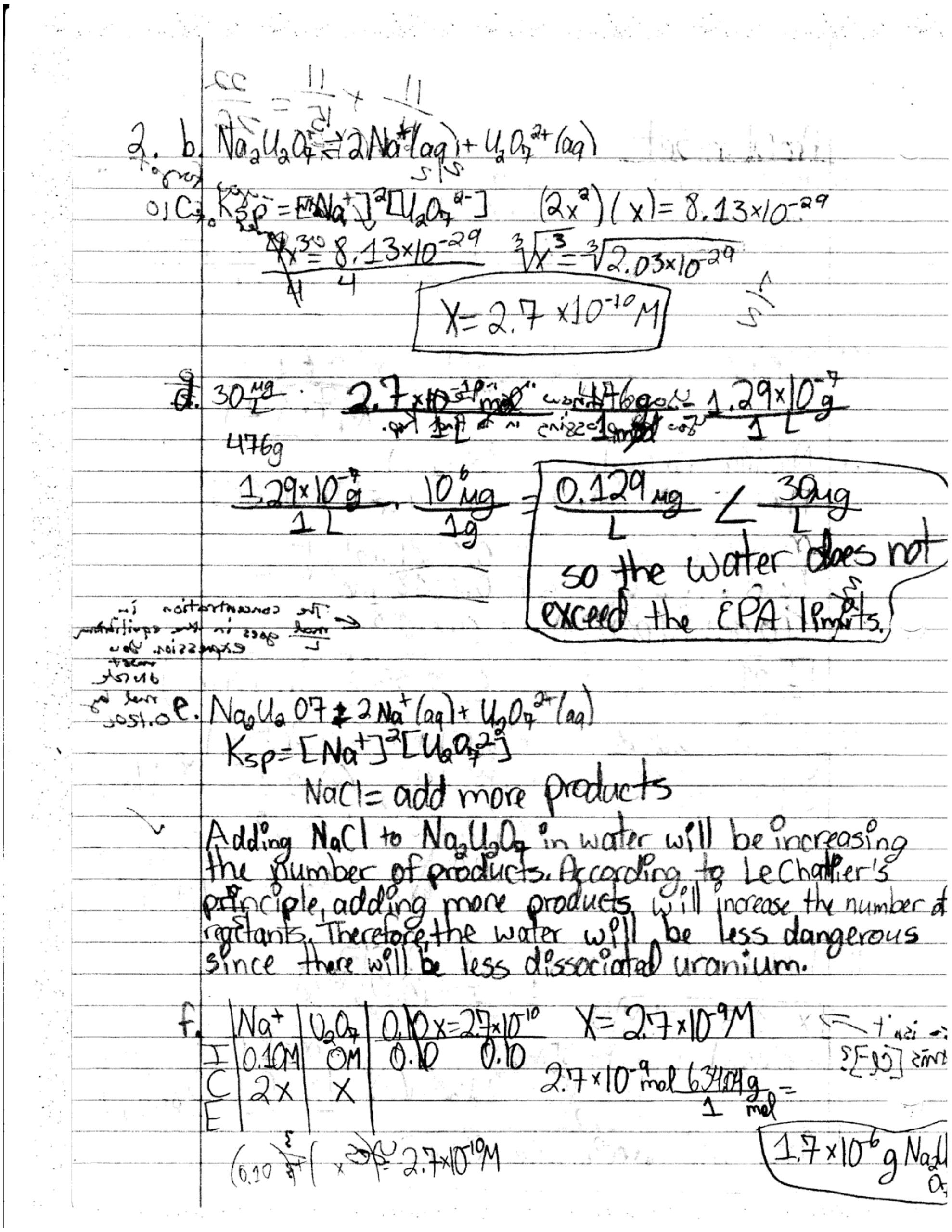
(f) Calculate the mass of solid that would form if 0.10 moles of NaCl were added to 1 L of the saturated solution from part (b). Assume no volume change.

This problem itself challenges the notion that science curriculum dealing with issues of social justice somehow comprises academic rigor. All four students were able to successfully answer the first three parts of the problem (b, c, d) with the level of supporting calculations, units, and attention to significant figures required by the AP chemistry exam. This problem specifically addresses the AP chemistry course description's inclusion of "Solubility product constants and their application to precipitation and the dissolution of slightly soluble compounds" (College Board, 2012). I discuss student responses to part (e) in more depth below. None of these four students successfully answered part (f), which is a challenging problem even in the context of a college general chemistry class. It requires significant proficiency with algebra and an ability to understand and manipulate extremely small numbers. Still Francisco's work on part (f) demonstrated sound chemical reasoning and mathematical skills, but he used the value for the undisturbed equilibrium concentration of diuranate ions where he should have used the value for the solubility product (K_{sp}), otherwise his answer would have been correct. Raquel and Odette correctly set up a table to solve part (f), but Odette did not complete the final row of this table and Raquel did not attempt the subsequent algebra. Cristina did not attempt part (f) at all. Each students' complete response to this question is included in the Appendix, but I include Odette's problem below for the sake of comparing it with her work here (which was dated (3/25/13) to her work on the stoichiometry exam (which was dated 10/4/12) that was included above.

Table XVII: Student Performance on Uranium Mining Equilibrium Problem

Student	(b)	(c)	(d)	(e)	(f)
	Wrote dissociation equation	Calculated $[U_2O_7^{2-}]$ at equilibrium	Compared with EPA limits	Explained common ion effect	Calculated mass of solid formed
Cristina	✓	✓	✓	✓	
Francisco	✓	✓	✓		
Odette	✓	✓	✓	✓	
Raquel	✓	✓	✓		

Odette's work on parts (b) through (d) demonstrates some of the same skills of unit analysis and conversion that she also demonstrated on the stoichiometry test. The work on this problem also includes the successful application of algebra techniques to find unknown chemical quantities and the correct set-up for an Initial-Change-Equilibrium (ICE) table as a problem solving technique. While Odette did not successfully complete the last part of the problem, she is engaging with problem solving techniques here that are more sophisticated than those on the stoichiometry exam and that are prioritized on the AP chemistry exam and in college chemistry courses (College Board, 2012). **Table XVII** indicates that Odette's work was slightly more successful than some of her classmates, but her classmates made similar strides in their work and were equally successful with parts (b) through (d) as discussed here.



2. b. $Na_2U_2O_7 \rightleftarrows 2Na^+(aq) + U_2O_7^{2+}(aq)$

c. $K_{sp} = [Na^+]^2[U_2O_7^{2-}]$ $(2x^2)(x) = 8.13\times10^{-29}$

$\frac{4x^3}{4} = \frac{8.13\times10^{-29}}{4}$ $\sqrt[3]{x^3} = \sqrt[3]{2.03\times10^{-29}}$

$\boxed{X = 2.7\times10^{-10} M}$

d. $30 \frac{\mu g}{L}$ · $\frac{2.7\times10^{-10} mol}{1 L} \cdot \frac{476 g}{1 mol} = \frac{1.29\times10^{-7} g}{1 L}$

476g

$\frac{1.29\times10^{-7} g}{1 L} \cdot \frac{10^6 \mu g}{1 g} = \frac{0.129 \mu g}{L} < \frac{30 \mu g}{L}$ so the water does not exceed the EPA limits.

e. $Na_2U_2O_7 \rightleftarrows 2Na^+(aq) + U_2O_7^{2+}(aq)$

$K_{sp} = [Na^+]^2[U_2O_7^{2-}]$

NaCl = add more products

Adding NaCl to $Na_2U_2O_7$ in water will be increasing the number of products. According to LeChatlier's principle, adding more products will increase the number of reactants. Therefore, the water will be less dangerous since there will be less dissociated uranium.

f.

	Na^+	U_2O_7
I	0.10M	0M
C	2x	x
E		

$0.10 x = 2.7\times10^{-10}$ $X = 2.7\times10^{-9} M$

0.10   0.10

$2.7\times10^{-9} mol \cdot \frac{634.04 g}{1 mol} =$

$\boxed{1.7\times10^{-6} g\ Na_2U_2O_7}$

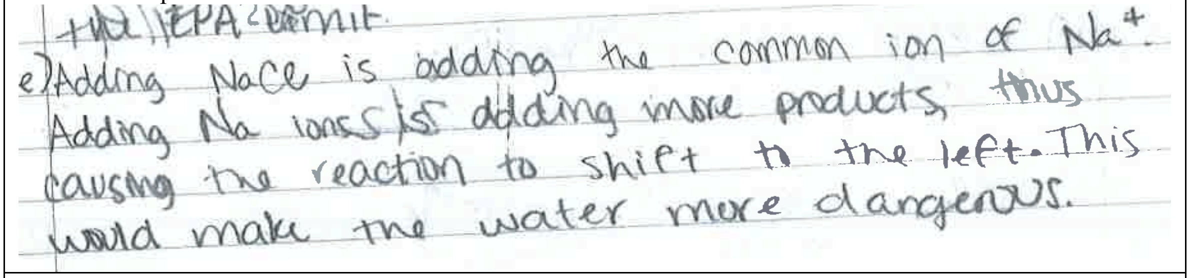
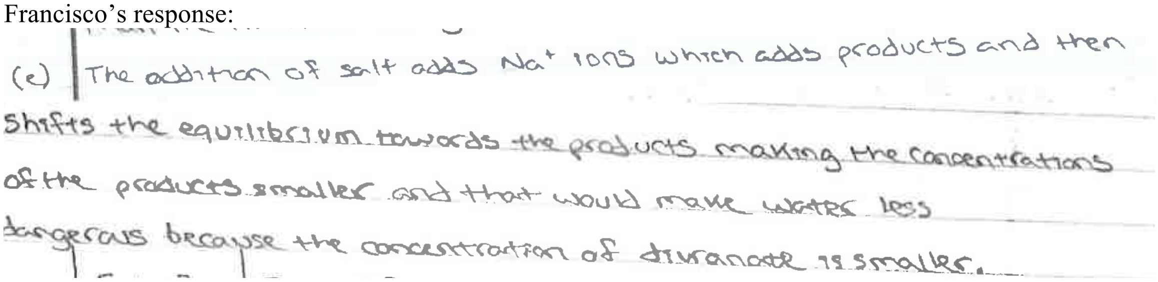
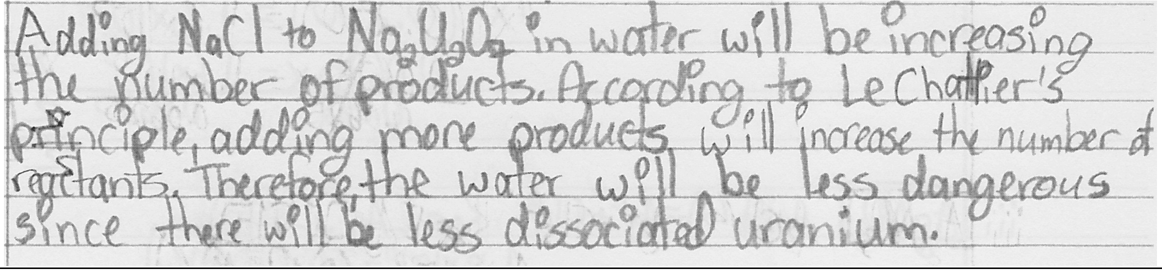
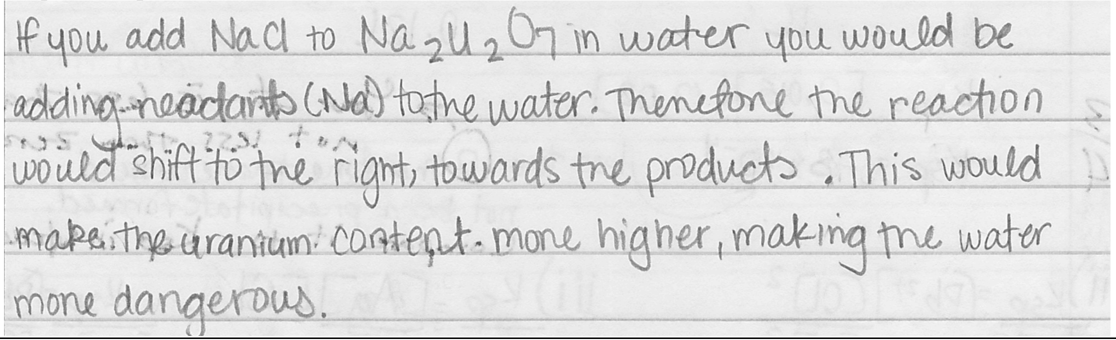
$(0.10)^2 (x) = 2.7\times10^{-10} M$

Figure 8: Odette's response to uranium mining problem

Here I focus in more depth on part (e) because it deals with Le Châtelier's principle and this concept is the focus of the NGSS performance standard about chemical equilibrium. This also allows me to consider whether students' understandings of this concept improved as compared with the earlier problem from problem set 21, which was completed about two weeks prior to this problem set which was due immediately after spring break. Whereas the earlier problem asked students to use Le Châtelier's principle to explain a given prediction, this problem asks students to make their own prediction about how a process in equilibrium will respond to a disturbance. Looking back on this problem, I realize that the uranium in cooking water is likely to be equally dangerous whether in solvated or precipitated form, so I will evaluate students' responses to the last part of problem (e) based on whether they explain their reasoning and/or whether this reasoning matches with the other parts of their answer. Each student's response to part (e) is included alphabetically in Table XVIII below.

In the earlier problem about the treatment of lead poisoning, Odette demonstrated an ability to apply Le Châtelier's principle to explain how a chemical equilibrium responded to a disturbance. Her answer to part (e) here shows that by this time in the unit, she was able to apply Le Châtelier's principle to make a prediction about a specific disturbance of an equilibrium called the "common ion effect," which is arguably a more sophisticated application of this concept as compared with the previous problem. Odette's response that this change will make the water safer is explained by the fact that there will be less dissociated uranium and matches with the rest of her answer. So while precipitated uranium is not safe in cooking water either, there is an internal logic to this response that shows understanding of the concepts at hand.

Table XVIII: Student responses to uranium question part (e) from Problem Set 22

Cristina's response:  +the EPA permit e) Adding NaCl is adding the common ion of Na^+. Adding Na ions is adding more products, thus causing the reaction to shift to the left. This would make the water more dangerous.
Francisco's response:  (e) The addition of salt adds Na^+ ions which adds products and then shifts the equilibrium towards the products making the concentrations of the products smaller and that would make water less dangerous because the concentration of diuranate is smaller.
Odette's response:  Adding NaCl to $Na_2U_2O_7$ in water will be increasing the number of products. According to Le Chatlier's principle, adding more products will increase the number of reactants. Therefore, the water will be less dangerous since there will be less dissociated uranium.
Raquel's response:  If you add NaCl to $Na_2U_2O_7$ in water you would be adding reactants (Na) to the water. Therefore the reaction would shift to the right, towards the products. This would make the uranium content more higher, making the water more dangerous.

Raquel was the other student who successfully answered the earlier problem on lead poisoning. Her answer to this uranium problem demonstrates her ability to apply Le Châtelier's principle to make a prediction, but her initial classification of sodium as a reactant is incorrect in the context of this problem, so ultimately her prediction is backwards. Her conclusion that the water will be more dangerous is consistent with the rest of her response. Cristina’s response to the lead poisoning problem above suggested an understanding of Le Châtelier’s principle, but a misunderstanding about when the equilibrium was disturbed. Here Cristina correctly applies Le Châtelier’s principle to predict what will happen with the addition of sodium ions and correctly identifies this as a case of the common ion effect. While the problem did not ask for this information, her identification of sodium ions as a common ion show a good understanding of this particular application of Le Châtelier’s principle and an improvement as compared with her response in Table XV. Cristina’s assertion that the water will be more dangerous is not explained and so is difficult to evaluate. Francisco’s response to the previous problem did not demonstrate an understanding of Le Châtelier’s principle, and his response to part (e) here still indicates some confusion. Francisco correctly identifies the addition of sodium ions as the addition of products, but then incorrectly predicts that this will shift the equilibrium towards the products. His answer then correctly predicts that the concentration of the products will decrease, which does not match with his assertion that the equilibrium will shift towards the products, but does align with his earlier classification of sodium ions as products. Based on his answer here I cannot tell whether Francisco simply misunderstood the phrases “shift towards the products” or “shift towards the reactants” while understanding the underlying concept of how a chemical equilibrium responds to a disturbance or whether he did not understand this underlying concept. It is also difficult to say whether his understanding increased from problem set 21 to problem set 22. His assertion about the water becoming safer is consistent with the first and third parts of his response.

This analysis provides limited evidence that some students made progress with respect to their understanding of how chemical equilibriums respond to disturbances between problem set 21 and problem set 22. The student work included here also provides examples of students grappling, to varying degrees of success, with sophisticated chemistry concepts within the context of a SSI. As with the previous problem, the uranium problem does not create an opportunity for students to meet the NGSS performance expectation exactly as it is written. However, students demonstrate proficiency with the three embedded strands of the NGSS and performed challenging chemistry calculations that are well aligned with the College Board's AP chemistry course description.

Injected relevance as socially transformative science curriculum?

The analysis of student work above demonstrates that students were able to engage in problem solving skills that are highly valued on the AP chemistry exam and in college chemistry courses within the context of an SSI. But my analysis of student work from the stoichiometry and equilibrium units through the lens of sTc suggests that the injected relevance curricular approach mostly fell short of engaging students in "authentic activity" (Rodriguez, 1998). Student work artifacts for these two units do not contain evidence of students reflecting in deep ways on the connections between science and social justice or on the production of scientific knowledge as they did in the artifacts analyzed for the soil project and the aspirin unit. The way I attempted to inject relevance into these canonical chemistry units prioritized the development of the highly valued skills and understandings shown in the work above. Thus rather than being "urged her to reflect on how the subject is socioculturally relevant" (Rodriguez, 1998, p. 600), I essentially told students how I understand the relevance of the particular skill or concept, at least when it came to their written work.

My planning documents and memories suggest that there were opportunities for students to engage in this sort of reflection during class discussions, especially during the stoichiometry unit. For example, the slide included above asked students to consider in a think, pair, share activity, “what factors do chemists consider when considering which chemical should be limiting in a reaction?” in the context of cyanide heap leaching of gold ores. The slide that followed asked students to consider “What is the difference between a green chemistry approach and a profit-driven approach?” Unfortunately, due to a multitude of factors, I do not have data that captured the content of that discussion.

Reflexivity, from an sTc perspective includes “a discussion of how science knowledge is produced and reproduced, who are (were) recognized as scientists, how their work influences society at large, and how social issues determine which scientific work is worth funding” (Rodriguez, 1998, p. 601). Even if class discussions promoted this sort of reflexivity, a more thoughtful execution of injected relevance would have provided students with opportunities, like those provided in the problem-posing units, to continue to develop and demonstrate these modes of questioning and thinking in writing or other more formal work products (Morrell, 2008). In this way, it is difficult to separate the strengths and weaknesses of my practice from the strengths and weaknesses of an injected relevance approach to socially transformative science curriculum. On one hand, reflecting on my practice illuminates ways that I could have more effectively implemented injected relevance. On the other hand, the centering of Western science content that characterizes this approach influenced my planning decisions, especially in the context of preparing students for success in college chemistry and on the AP chemistry exam and other required high stakes standardized tests.

The retrospective design of this study limits my ability to consider classroom discussions or student engagement in injected relevance at the time. However it has the advantage of considering academic achievement and student perceptions of the relationships between science and social justice as they have moved onto college and various forms of community involvement as young adults. There were five participants in this study who had taken at least one semester of general chemistry in college at the time of their interviews. Table XIX summarizes their performance in these courses as compared with their performance on the AP exam, both of which they self-reported during their initial interviews or during follow-up interviews or member checks. Considering student trajectories through college science courses provides some additional evidence that students were prepared academically by the case study class. Given the focus of injected relevance on developing canonical chemistry content and skills, I limit this brief analysis to these five students who have continued to study chemistry.

Cristina and Francisco earned an A and B+ in their first college chemistry courses, respectively, which corroborates their quotes above that they felt very prepared by the case study course. In her first semester of college chemistry, Cristina coincidentally took general chemistry with Professor Hernandez who led the larger study of contaminated soil discussed in Chapter IV, but also has a reputation for rigor in his instruction. Francisco's success came at a flagship state university where his introductory chemistry class was a large lecture with hundreds of students, a large proportion of who failed the course. Jade had a negative experience during her first year in college, which she largely attributes to an unsupportive racial atmosphere at a predominately white institution. But she noted that her chemistry class was "the one class I looked forward to everyday." She describes feeling confident and "over-prepared" for chemistry 101. On the other hand, Gabriel failed general chemistry at the large state university he attends, despite having earned a score of 4 on the AP exam that would have allowed him to receive credit for the very class he failed. As previously discussed, Gabriel attributed his struggles to the social challenges he faced in college in general and chemistry class in particular. At the time of his initial interview, Gabriel was on the borderline between a B- and a C+ in his chemistry class, but indicated during our follow-up interview that he stopped attending class for the latter part of the semester despite my repeated attempts to intervene and encourage him to continue. He indicated that he lost hope in his academic future because of his family's financial difficulties.

Table XIX: Self-reported traditional measures of achievement for participants who took general chemistry in college

Student	Score on AP chemistry exam	Grade in first semester of college general chemistry	Carnegie classification of collegiate institution
Cristina	3	A	Large Two-Year Public College in an Urban Setting
Francisco	2	B+	Large Public Research University (More Selective)
Gabriel	4	F	Large Public Research University in an Urban Setting (Selective)
Jade	1	B	Small Four Year Private College in a Rural Setting (More Selective)
Odette	2	B-	Small Four Year Private College in a Rural Setting (More Selective)

Gabriel's struggles are a sobering reminder that traditional academic achievement is necessary, but insufficient in order to achieve educational equity. This is reinforced even by the experiences of students who appear to have been more successful in college according to the data in Table XIX. Cristina is attending a community college despite being qualified to attend a selective four-year institution because her undocumented status prevents her from receiving federal financial aid. Francisco tried to declare biochemistry as his major, but was counseled to switch to biology because of low scores on his math placement test, which he attributes to essentially losing two years of math instruction at La Lucha. Two years prior to the case study class, when Francisco was in 9th grade, a new math teacher at La Lucha High School resigned midway through the year and the school was unable to find a permanent replacement, which meant that Francisco and his classmates had very little math instruction during 9th grade. Then in 12th grade, an administrator told Francisco that he could not fit a math class into his schedule. Unfortunately, despite emerging from a struggle against inequitable urban schools, La Lucha still faces many of the same challenges that most urban public schools face.

Jade's experience in college is the most troubling of these students when it comes to the barriers that still prevent African American and Latin@ students from earning college degrees. Jade experienced a campus climate at selective liberal arts college in the Midwest that she described as unsupportive for students of color. In the spring semester of her sophomore year, this unsupportive climate became potentially unsafe and hostile when a white male student on her campus, who framed himself as an advocate for conceal and carry gun laws, began making threats directed at students of color. Jade was involved with a group of students who called on the school administration to respond. When the administration did not do enough to make her feel safe amidst ever escalating threats, Jade's mother withdraw her from the college and brought her home to Chicago. Jade has since enrolled in a local community college with plans to transfer to a different four-year institution and change her major to biochemistry as she prepares for her long-term goal of attending medical school.

Finally, Odette has generally done very well so far in college, but would have liked a higher grade in her first general chemistry course. She attributed some of her struggles to the one-year gap between the case study class and her general chemistry course. But she also faced some cultural challenges in the college chemistry classroom that I describe below. These five stories of African American and Latin@ students, even those who are successfully navigating institutions of higher education, reinforce the notion that inequity in school science extends well beyond the walls of the science classroom. Justice-centered science pedagogy asserts that in order to address inequity in science education, we must see it as inseparable from larger issues of oppression in society to which we must respond with both pedagogy and organized activism.

Injected relevance and the culture of science

The three orientations towards science first described in Chapter IV seem to be related to the way students perceived my attempts at injected relevance. For Curtis, who exhibited a "tourist in the culture of science" orientation, the equilibrium unit described in this chapter was illustrative of the tendency of the class to become less critical and more "strictly just chemistry based." Specifically Curtis remembered the way I taught LeChâtelier's principle as an example of when I taught "to the book" or "to the test." In contrast, when I asked Odette, who exhibitied a science *nepantler@* orientation, whether the course met her explicit goal of learning more deeply about the connections between science and social justice, she responded:

> Yeah for sure. Because I think somewhere in my notes, we were learning something new and it was a lot of math and then, the final answer – I have it circled – it's like, 'no it's not safe.' And so that's kind of how I remembered the process.

The notes that Odette described here reminded me of her response to part (d) of the uranium mining problem above where she circled her answer, "so the water does not exceed EPA limits." I asked her if that was the problem to which she was referring, she said that maybe it was. I scoured her notes for a circled response with the words "no it's not safe." I found an example of injected relevance from Problem Set 2 where Odette wrote (but did not circle) "The child is not lead poisoned," but I could not find anything that matched more closely. But whether or not Odette is referring to either of these specific problems, the type of work that she is describing here is characteristic of the examples of injected relevance I included in this chapter. For Odette, injected relevance helped her to think more deeply about the connections between science and social justice. In this way, injected relevance allowed Odette to engage in socio-transformative constructivism because she was "urged to reflect on how the subject is socioculturally relevant" (Rodriguez, 1998, p. 600).

Jackson, who exhibited a concerned scientist orientation, dealt with homework problems that contained injected relevance differently. In a follow-up interview, he reflected on his approach to problems like those analyzed here:

> Even though on some of the problems you introduced the problem in kind of a real world situation…I can see why it's helpful – but even though you might mention the real world connection there, on the problem set sometimes it's kind of like ok I'm just going to ignore this and focus on the facts and work the problem out.

Jackson describes ignoring the social context of a problem to isolate crucial information in order to solve the problem at hand, a technique that is often encouraged by teachers. Jackson went on to describe these problems as helpful from an academic point of view, but mentioned that he did not find the injected relevance to be meaningful. Curtis, Odette, and Jackson's reflections on injected relevance typified the responses of other students with similar orientations. Contrasting these responses led me to think more deeply about the relationships between students' orientations towards science and their perception of injected relevance. In the final section of this chapter, I elaborate on the three orientations introduced in chapter IV and describe the way students of each orientation viewed injected relevance.

Tourists in the culture of science.

Curtis, who coined this term, typifies this orientation. Raquel, Marisol, and Gabriel also have developed orientations that could be described in this way. All four of these students were involved with collecting soil samples for the soil project outside of school hours. Curtis, Marisol, and Gabriel were also among the students who organized and presented during the family science night described in Chapter IV. All of these students describe connections to issues of social justice as central to their reasons for taking the case study course and as motivating their learning in the course. When asked about the balance between learning canonical chemistry and dealing with issues of social justice, all of these students pointed to the soil project as the primary example of the balance that we struck. They all also mentioned the salience of their experiences in sophomore chemistry, a course in which the entire curriculum was organized around generative themes.

None of these students were science majors in college at the time of their interview. None of these students consider themselves to be part of the "culture of science." They all describe their career goals as being motivated by a desire to serve or improve the communities where they come from, or other similar communities. For example, Raquel wants to return to Ridgevale or a nearby community as a social worker or an academic counselor at a high school. Marisol is not sure what she wants to do specifically, but she wants to use her career to facilitate communities like Ridgevale to secure more resources and control over their own destinies by amplifying their voices in public policy. Curtis currently volunteers as a Spanish instructor and math and science tutor for struggling students in the public schools of the small college town where he attends college. Students with a "tourist in the culture of science" orientation are committed to working for social change within their communities, and globally. They use science when it is relevant to these pursuits, but either do not consider science to be a primary lever for enacting social change or simply do not see their role in social change as a scientific one. Students with this orientation are motivated to cross the metaphorical border into the culture of Western science when it happens within the context of their commitments to social justice or community service. Tourists in the culture of science remember problem-posing units as relevant and impactful and are more critical of injected relevance, as is typified by Curtis' characterization of my teaching of LeChâtelier's principle as "teaching to the book."

Concerned scientists.

Francisco, who was one of four students to answer, "yes" to the question of whether he was part of the culture of science, typifies a "concerned scientist" orientation. Raquel, who attends the same university as Francisco, described him as "wired for science" in our interview. She marveled at Francisco's discipline and commitment to his science courses. Francisco wanted to major in biochemistry, but because he missed out on two years of math instruction at La Lucha was counseled to pursue biology instead and was considering a change to kinesiology at the time of the member checks. He hopes to become a biomedical researcher.

Jackson did not consider himself to be part of the culture of science, but his orientation still matches that of concerned scientists. Both of these students told me that they have always loved science. Neither of these two students participated in the soil project outside of class. As previously mentioned, Jackson wrote that he found the soil project boring and that he did not want to write the lab report. In fact, Jackson mentioned being frequently bored by the case study class, but also admitted that often in the class, "I felt like I was actually a chemist." Jackson majors in physics and hopes to make a breakthrough in the field of astrophysics someday.

Concerned scientists are motivated to solve scientific problems with or without a compelling social context. This orientation explains why Jackson admitted to divorcing examples of injected relevance from the problems they contextualized in order to focus on the scientific concept. However both students with this orientation credited the case study class with helping them to develop the skill of making connections between science and the larger world. They both said in their interviews that they have applied this skill in their subsequent science classes where explicit connections were not otherwise made. These young men both see their science pursuits as potentially contributing to society. Francisco wants to do cancer research or physical therapy to alleviate the suffering that he has witnessed and experienced as close relatives have suffered from cancer and he has suffered potentially debilitating sports injuries. Jackson perceives physics research as contributing to humans' understanding of our place in the universe, which he identifies as central to the survival of our species. These young men describe their contributions as applying to society as a whole. They want to solve seemingly unsolvable scientific problems. In our follow-up interview, Jackson said, "As bad as this sounds, my main focus isn't exactly social justice, but scientific advancement is what my goal for my career is." The work of concerned scientists could be described as humanistic, but not explicitly connected with social transformation. At the time of our interviews, neither of these students was involved in a particular cause or social justice organization. I have borrowed the label "concerned" from an organization of professional scientists who advocates for the socially responsible use of scientific knowledge, especially in pushing back against global warming deniers. Concerned scientists are by no means oblivious to social justice issues; they view their work as contributing to the greater social good. But they see their role as being one focused primarily on science rather than fighting oppression.

Science Nepantler@s.

Students with a science *nepantler@* orientation found examples of injected relevance meaningful and even adopted some of the curricular features described in this chapter to support their learning in college courses. Odette, Cristina, and Jade were the students besides Francisco who answered yes to the question about being part of the culture of science. Cristina actually answered:

> Yes and no. To me science is pretty much everywhere and everything, so you're kind of part of it. In terms of the traditional science, I don't think I'm part of that culture. Just because, like I said, usually we think of scientists as they're just in the lab and just doing things internally and just blocked from the rest of the world where I don't want to do that at all. So I guess the traditional culture of science, I don't feel like I'm a part of it, but the way that it's changing or the way that it's becoming more involved with the outside world than just the lab, I do feel like I'm a part of that.

Cristina describes the traditional culture of science as being cut off from "the rest of the world" and envisions herself as somebody who can change that culture by making connections between science and society in general, but also between science and her community in particular. Cristina's belief that "science is pretty much everywhere and everything" is shared by Francisco who when asked about the relationship between science and society said, "science is basically everywhere for me." But one of the important differences between Francisco, as a concerned scientist, and Cristina, as a *nepantlera*, is Cristina's commitment to be a part of changing the culture of science. Interestingly, all three students with *nepantler@* orientations in this study are women and both students with a concerned scientist orientation are men. This suggests that the ways Cristina, Jade, and Odette experienced sexism in their college science classes may have had some impact on their orientation.

Jade's response to the question of whether she was a part of the culture of science, typifies a science *nepantler@:*

> Yes, even though it's a heartless and inhumane culture. It's something that can be changed. But I feel like we need to incorporate new things to make it more helpful instead of just the old tradition with the old white man with a lab coat. Science was always my favorite subject as a kid, but we need to open it up.

Jade elaborated her characterization of science as inhumane by saying that science is not only exclusionary to women and people of color, but is also "missing the 'so what' about being human." She went on to criticize science for being too influenced by profit and not concerned enough with alleviating human suffering.

Odette, the third student to identify with the culture of science, described a conflicted understanding of the relationship between science and society. She reflected on her learning in a college chemistry class by saying, "I just took chem 103 and I have that knowledge, but then how am I going to relate it to people? That's kind of the main issue I have in general, in applying it." Odette repeatedly emphasized in her interview that it was important for her to work through this question on her own and in dialogue with other non-scientists in her community. She appreciated the opportunity provided by lab report assignments to reflect on this issue of application and relevance in framing the problem or discussing the implication of the results. Whereas concerned scientists Francisco and Jackson explained that the case study class increased their ability to make connections between scientific concepts and the larger world, these connections were troubled for Odette. She described these connections as becoming more complicated as she learned more science and more about SSI.

Both Odette and Cristina have chosen to major in chemistry and Jade plans to change her major from epidemiology to biochemistry after she transfers back to a four-year institution. In their interviews, all three of these women critiqued the culture of science for being exclusionary of women and especially women of color and also for failing to make connections between social justice issues and laboratory work. They lamented that the scientific understandings of regular people and scientists who are not white men are undervalued. But all three women also expressed agency and motivation to be part of changing the culture of science. Cristina and Jade's quotes above indicate this sort of agency, as does the following quote from Odette:

> There's just not opportunities open, but I feel like that's changing. But I feel like just being a woman and being of color, I feel it's really powerful for people to be doing that [becoming a chemist] and also coming from Ridgevale, I have a lot of pride telling people in college where I'm from, like specifically where I'm from in Chicago because they do ask like specifically where. They might not really know what Ridgevale is. But then I tell them and I have a lot of pride in myself because I have made it as far as them where for them it's like a norm to be in college.

This quote indicates that for Odette changing the culture of science includes opening access to opportunities not only for women, not only for people of color, but specifically for women of color from economically disadvantaged communities. She takes pride in pushing her way into some of those opportunities.

Further evidence of this agency is provided by a practice that Odette adopted from the class. Odette told me in her interview about how she continues to challenge Eurocentric and androcentric practices in her college science courses, which is not often warmly received by her professors at an elite liberal arts college in New England. In a first year seminar at this college, Odette wrote a reflection paper challenging an assertion in a course reading that science began in Greece. She said that she wrote about how science has origins all over the world and that it is a Eurocentric view that positions it as emanating solely from Greece. Odette said that her professor acknowledged her ideas, but pushed back and that this exchange led to some temporary hostility with her professor. Jade described similar experiences in college courses. She mentioned that she always tries to incorporate issues of social justice into her college papers and that some professors respond positively, while others admonish her to “stick to the class.” During a follow-up interview, Jade wondered about these professors: “They’re telling me to stick to the lesson, but what is the lesson then?” Here Jade hints at the idea discussed in Chapter IV that omitting political concerns from science curriculum is also a political decision. In these examples, we see Odette and Jade adopting the practice of “injected relevance” themselves in their college science classes. Or to use the terminology of sTc, they have tried to approach their learning in college by creating their own “authentic activities.”

Science *nepantler@s* like Jade, Odette, and Cristina intentionally challenge the hegemonic practices in science classes. Odette provides another example related to one of the practices of injected relevance described in this chapter. She reflected on carrying the practices from the case study class into her college chemistry courses:

> In my chemistry class, there was a lot of emphasis on the old dead white guys and when I would do my readings in the book, I kind of ignored those parts because they would introduce each chapter talking about a certain guy and his law. And even in some of the exams, it was like “describe this guy’s findings.” And I’m like I don’t know what he found. I didn’t focus on that. I know the concepts in the chapter, I just don’t know who they ‘belong’ to [makes air quotations with her fingers].

Odette’s reflection here is a powerful description of how this very simple practice of emphasizing the men who are credited with particular concepts in Western science can be alienating to women and students of color. Reflecting on her experiences in general chemistry in college Odette said:

> The professor definitely did emphasize [historical figures in chemistry] – like he was in awe with those guys. And I totally understand, because it was cool the things they found out. It definitely is. But, I don't know. Other people should also be credited for their science when it's not western science.

Here Odette does not advocate devaluing or ignoring the contributions of famous European men, but merely de-emphasizing or de-centering them in the study of chemistry along with acknowledging the context surrounding their work and the contributions of peoples and scientists who are "othered" (Said, 1979). Throughout her interview, Odette emphasized that her desire to do science is rooted in her desire to improve conditions for people in her community and people who are suffering worldwide. She consistently maintains a posture that science has multicultural origins and should be a tool to push back against injustice. In her previous quote above, her frustration with being asked to memorize to whom concepts "belong" also may indicate a frustration with science as being owned by particular people rather than being available for the uplift of others.

In their interviews, Jade, Odette, and Cristina repeatedly provided made statements that indicated their engagement with the sTc practice of reflexivity, which is:

> …aimed at learning science content, but also a discussion of how science knowledge is produced and reproduced, who are (were) recognized as scientists, how their work influences society at large, and how social issues determine which scientific work is worth funding. Therefore, reflexivity opens a window for students and teachers to

> examine the culture of power and explore ways to transform it for the benefit of all and not just the privileged few. (Rodriguez, 1998, p. 601)

Thus it is likely that even without explicit opportunities to engage in the various components of sTc during our units characterized by injected relevance, Jade, Odette, and Cristina created such opportunities for themselves. As science *nepantleras*, they seemed to have adopted and internalized an sTc approach to learning science.

Odette, Cristina, and Jade were involved in causes and organizations related to social justice at the time of their initial interview. Both Cristina and Odette have been extensively involved with COVER since their graduation from La Lucha. Odette actually attended COVER events in eighth grade, before she even attended La Lucha. Cristina has now been working as an organizer for COVER for a year and has redesigned and now leads the "community-asset toxic tours" mentioned earlier in the chapter. Cristina conducted an undergraduate research project this semester to begin to document the scientific and environmental funds of knowledge among community members in Ridgevale. Odette has been selected for summer internship with an environmental justice program at a university on the West Coast this summer. Through their ongoing commitment to exploring and pushing the role of science in struggles for social justice, these women are *nepantleras* as they bridge the strong traditions of social activism in Ridgevale and similar communities with their study of Western science.

Conclusion

I asked Odette whether her resistance to learning the names associated with concepts impacted her grade in her first college chemistry course. She responded that she lost a small number of points on exams that explicitly asked for the names of famous chemists, but that she often earned partial credit on these questions because she could successfully describe the concepts or the associated experiments without including the names of the scientists. Ultimately she could not quantify the overall impact on her grade, but she received a B- in her first semester of college chemistry. If we seek to support academic achievement alongside cultural competence, and critical consciousness, Odette's experiences in general chemistry in college highlight the tensions of creating socially transformative science curriculum that is capable of supporting access, dissent, and liberation. These tensions are negotiated differently by an injected relevance approach that prioritizes traditional canonical concepts and skills versus a problem-posing approach that embeds those skills within a focus on addressing real problems. But both approaches to developing socially transformative science curricula seek to equip students to push back against the forces that marginalize them, rather than suggesting that students assimilate into or retreat from the problematic culture of Western science.

Identifying three different orientations to science that emerged as students reflected upon the class has been useful to think about the various ways students experience my two approaches to developing socially transformative science curriculum: problem-posing science education and injected relevance. Tourists in the culture of science are drawn into problem-posing units, but remain skeptical of injected relevance. Concerned scientists seem willing to engage with learning science in any of these forms, but may ignore the social context provided by injected relevance in order to foreground canonical science understandings. *Nepantler@s* seem to have internalized an sTc approach to learning science and actively seek to understand the relationship between learning science and fighting for social justice. When it comes to this evaluation, there are two important considerations: the extent to which student perceptions of the two curricular approaches were related to the particular strengths and weaknesses of my teaching practice and the extent to which these two approaches are structurally different as it relates to reconciling relevance and standards. Unfortunately these issues are difficult to separate. But it is possible that providing explicit opportunities for students to engage in the components of sTc during injected relevance units would constitute a more effective approach. By enhancing injected relevance with opportunities for students to engage in more reflexivity and critical metacognition, injected relevance could be improved to be more meaningful to more students. Varelas (personal communication, June 10, 2015) suggests this approach could be called "infused relevance."

Justice-centered science pedagogy asserts that all three orientations towards science described in this study are necessary if science education is to be a catalyst for social change. Tourists in the culture of science are committed to social change, but see their role as one that is focused on something other than science. Concerned scientists are motivated by a desire to make advances in science that may contribute to society broadly. Finally, *nepantler@s* unite these two worlds by fighting oppression within the culture of science and also mobilizing their scientific knowledge to inform struggles for social justice. In the conclusion of the next chapter, I further explore the relationship between these three orientations to science within the context of my teaching practices, classroom structures, and student trajectories.

Chapter VII: Collective and Community Power

In this chapter, my analysis extends beyond the curriculum to focus on teaching practices and classroom structures and routines. My ability to capture the nuances of day-to-day practice is limited by the retrospective design of my study, but this approach provides a reflective view that captures the components of that practice that were meaningful to students in light of their subsequent experiences. For example, students have the opportunity to compare and contrast (implicitly or explicitly) their experiences in the case study class with experiences in college courses. Consistent with my approach in previous chapters, I relied on content analysis of interview transcripts to identify teaching practices and classroom structures that were particularly salient for students as they reflected on the class 15-18 months after its conclusion. From there, I applied the extended case method, using theoretical propositions to examine my planning documents and relevant press coverage. I also conducted a second analysis of student interview transcripts and transcripts from interviews with three other stakeholders (two community members and one parent). This second analysis allowed me to consider how teaching practices and classroom structures supported or impeded the implementation of the curriculum described in the previous three chapters.

Two sets of practices emerged as especially important. The first was to establish a community-oriented and collective purpose for learning, which is one of the features of a culturally relevant classroom (Ladson-Billings, 1994, p. 60). The second set of practices involved supporting students through a period of destabilization in the school. My analysis indicates that the three elements of critical hope (Duncan-Andrade, 2009), as components of critical pedagogy, explain the importance of these practices. Extending beyond the case to the context helped me understand that these practices were important because they aligned the values of the classroom with the values of other segments of the Ridgevale community. Students thus perceived their experiences in the classroom as consistent with community involvement, which supported the maintenance of cultural competence and the development of students as organic intellectuals.

This chapter begins with a brief consideration of how I came to understand the importance of teaching practices, classroom structures, and classroom routines that can support socially transformative curriculum. Then I provide an analysis of interview and archival data that identifies collective and community power as central to the way key stakeholders in the Ridgevale community understand education. I separately introduce each of the two sets of practices that I have identified as important, following each with an analysis of student interview data that helped me to understand its effectiveness. Finally the chapter concludes with 3 student trajectories through *nepantla* (Aguilar-Valdez et al., 2013; Anzaldúa, 1987) that problematize teaching practices in terms of obedience and resistance in urban science classrooms. Through these student trajectories, I also continue my consideration of the three orientations to science.

Engaging curriculum: Necessary but insufficient

The journal entries from my first year teaching at La Lucha express frustration related to engaging students. When I came to La Lucha, I had three and a half years experience as a high school teacher in the Chicago Public Schools and seven years of experience working or volunteering in urban public schools in some capacity. Looking back now, almost a decade later, I see how inexperienced I still was. But at the time, I was frustrated to feel like a first year teacher all over again. In a journal entry where I reflect on my week at the school in the summer of 2006, I wrote about an incident during the first day of class that I also mentioned in Chapter I. When I gave students a survey that included a question about their understanding of the term “social justice,” a young man expressed disgust with being asked to respond to this question. In my journal, I wrote several questions for myself, including, “How do we interpret this sort of resistance?” and “Does making a social justice point of view the dominant one position it in opposition to some disenfranchised students?” Darder (2002, p. 136) suggests that “rather than perceiving resistance as a pedagogical impediment, teachers can engage with it as a meaningful process in the development of student consciousness.”

Other scholars have noted how teaching science through curriculum organized around local issues of environmental injustice alone is not enough to engage students in meaningful science learning (Dimick, 2012; Settlage & Southerland, 2012). In previous chapters, I suggest that place-based SSI are not equivalent to the Freirean concept of generative themes. Teachers struggling to engage our students in a topic we have chosen because we believe it to be “relevant” should first consider whether we have evidence that this topic is in fact meaningful for students, their families, and their community. Still, in my first few years at La Lucha, I had many experiences teaching units based on topics that I had good reason to believe were generative themes, but which garnered much less success than the aspirin unit and the soil project. The analysis of those shortcomings is beyond the scope of this study, but it is important to acknowledge that the teaching practices examined in this chapter developed over the course of several years as I reflected on my successes and failures in the classroom and learned from the feedback and examples of mentors and colleagues.

When I first arrived at La Lucha, I focused most of my time and energy on designing engaging curricula, without understanding how to establish the classroom structures required to ensure that students were learning. Yang’s (2009) “structured engagement” framework emphasizes the need for teachers to engage youth and create opportunities for youth to engage themselves through curriculum that is meaningful and relevant in the local context while *also providing structure* to support academic achievement. Yang defines structure as “student time and activity [being] highly defined and enforced by the instructor” (p. 54). A reflection that I wrote in the spring of my first full year at La Lucha (dated 4/22/07) laments that my classroom that year was “way too liberal” in terms of how student activity was structured and enforced. The solution that I proposed to myself in that journal entry was the need for an “explicit classroom ethos” coupled with “an intense and relentless commitment to high expectations.” Before delving into the practices, structures, and routines that I developed in response to this self-critique, I present an extension from case to context based on the analysis of the way participants view the strengths of the Ridgevale community.

Collective and Community Power in Ridgevale and at La Lucha

When I asked participants about the strengths of the community, Odette, Cristina, Marisol, Curtis, Jackson, Raquel, and community member Ms. Juarez all used words like “solidarity,” “unity,” or “tight knit” or described neighbors as “relying on” or “looking out” for each other or “sticking together.” Some of these participants were speaking of the community at La Lucha High School in particular, but most were speaking of the West Ridgevale neighborhood where the school is located. For Ms. Epps, La Lucha High School itself is one of the strengths of both West Ridgevale where the school is located and East Ridgevale where she has lived for most of her life. Ms. Epps identified the caring nature of La Lucha High School as creating a level of “connectivity and parent participation” that are the reasons she identifies the school as one of the community’s strengths. Her daughter Jade, highlighted the ability of the community at La Lucha to unite in times of need, which is a trait that Curtis used to describe the West Ridgevale neighborhood. Marisol said that the neighborhood’s strengths mirror the strengths of her own family, in that both units “value family unity over everything.” While there was consensus that unity or solidarity is a defining characteristic of the Ridgevale community and also of the school itself, it is important to avoid romanticizing this togetherness. There are frequent intra-community political debates that Ms. Juarez raised during her interview and that I have been involved with first hand. There are also deep-seated, but not unchallenged, divisions between the Mexican American community in West Ridgevale and the African American community in East Ridgevale. These various tensions are often exacerbated by the prominence of rival street organizations that create more divisions within each neighborhood, especially for youth. Francisco, Curtis, and Ms. Juarez all mentioned the impact of street organizations in their interviews. But none of the participants raised Black-Brown racial tensions explicitly in their interview. When I raised this issue during member checks, all of the participants acknowledged the existence of this issue in the neighborhood, but Curtis and Jade emphasized that in times of need and struggle, Ridgevale community members unite across all of these various divisions.

Another theme that emerged from the interview data was the importance of West Ridgevale being a community composed largely of Mexican immigrants. Curtis and Ms. Avila, both spoke about the prominence of Mexican culture as a source of strength of the community. But, several participants also mentioned immigration status as an obstacle to economic opportunity and political action. That said Cristina, Odette, and Ms. Avila all highlighted the political awareness and activism of community members as another strength of the neighborhood. Indeed La Lucha High School itself is a testament to the strong tradition of political activism and community organizing in Ridgevale. Much of what participants said about the community is echoed by one of the core beliefs set forth by the design team of the school:

> Collective and Community Power
>
> Through collective community power, we commit to a conscious effort to overcome the intended historical obstacles that have been designed to dis-empower and divide our communities, and thereby meet the needs of all members of Ridgevale for continual betterment and progress.

Establishing a community-oriented purpose

The following excerpt from the syllabus of the case study class captures the purpose for learning that I tried to consistently communicate to students. In a justice-centered perspective, learning is something that happens with, for, and in community.

> …the primary goal of this course is not individual success. It is collective success and community empowerment. This means that you are responsible for the success of your classmates and that you are expected to use the power you gain by knowing chemistry to help improve your community. This could be by returning to your community after college to serve as a science teacher or a doctor or it could simply mean leading a laboratory experiment at a local elementary school this year.

I crafted this statement to intentionally push back on dominant notions of learning as individualistic, motivated only by personal financial success, and measured by standardized test performance. This community-oriented purpose for learning was initially communicated through the syllabus and initial course assignments. It was maintained through teaching practices, class structures, and daily routines that complemented the curriculum documented in previous chapters. This statement is aligned with the core beliefs of the school, specifically the belief in collective community power cited above.

Before the close of the previous school year, I called a lunchtime meeting with all of the students who planned to enroll in AP chemistry. During this meeting, I explained the schedule for the 4-day summer session and I also gave students their first assignment, which I called the “funds of knowledge essay”(Gonzalez et al., 1995) because its goal was to bring the forms of knowledge that reside in students’ households into the classroom. Students were assigned to learn and write about a family member who had rich scientific knowledge, even if she or he did not have the education, credentials, or job title typically associated with a scientist. I modeled this assignment for students by telling them the story of my grandfather who had very little formal education and worked at a meat packing plant on the South Side of Chicago. His job involved treating excess fat from slaughtered livestock with a strong base to manufacture soap. My mother has fond memories of her father bringing home glycerin (a byproduct of that reaction) and teaching her what he knew about chemistry. On the first day of the summer session, students met in small groups to share their “funds of knowledge essays” and their personal goals for the class and for their life after high school. This was my first attempt to establish learning as something that happens with, for, and in communities. The “funds of knowledge essay” was an important way to show that our class values the scientific knowledge in students’ families. Sharing these essays along with their goals for the class was an important way to build community within the classroom. Then on the first day of the school year, we read the first page of the course syllabus aloud, including the passage above to establish and emphasize learning as defined by “collective success and community empowerment.”

Start of class ritual.

One of the ways I tried to reinforce our community-oriented purpose throughout the school year was through a beginning of class ritual. Each day when students entered the classroom, the “reaction of the day” was projected on a screen in the front of class. These daily problems are similar to the “do now” or “bell ringer” exercises that are common in classrooms and were written to teach a set of skills valued by the AP chemistry course description (College Board, 2012). These problems consisted of one sentence introducing two chemicals that would react and a short follow-up question (see Chapter V for an example from the monthly reaction quiz). The reaction of the day was often connected to the SSI that we were studying, the canonical chemistry we were studying, or sometimes both. For example, on August 30, the reaction was “Sulfur impurities in coal burn inside [the coal power plant].” And the follow-up question was “What is the oxidation number of sulfur before and after the reaction occurs?” The product of this reaction is sulfur dioxide (SO_2), which ultimately reacts with water in the atmosphere to produce acid rain.

Students were given approximately five minutes to work through the reaction of the day individually or in small groups. I played a song to keep track of this initial time for the reaction of the day. These songs often had lyrics that connected with the theme of the unit we were studying. For example, during our short unit on nuclear chemistry, we started every class with Gil Scott-Heron’s haunting song warning of nuclear disaster, *We Almost Lost Detroit* (Scott-Heron & Jackson, 1977). For the stoichiometry unit, the daily song was a playful composition by DJ Cut Chemist that mixes excerpts from chemistry lectures with samples and break-beats typical of hip-hop and electronic music (MacFadden, 1998). As the song finished each day, one student was selected to model his or her completion of the problem on the board, including a metacognitive explanation of her or his reasoning. The selection of students was random, but rotating, so that every student took a turn before there was a repeat. If the student whose responsibility it was to complete the problem struggled to do so or made a mistake, it was the responsibility of the class to affirm their effort and support or correct them. Once the problem was complete, the student who modeled briefly stated our class purpose, “We are here to develop the knowledge, skills, and habits we need to serve our communities and transform the world.” Then we showed our appreciation for this students’ effort with a solidarity clap, a practice that originated with the United Farm Workers (UFW) strike and Chicano movement of the 1960s and was inspired in my own practice by teachers of Mexican American Studies (de los Rios & Ochoa, 2012, p. 275).

The various components of this start-of-class ritual were borrowed and adapted from colleagues whose practice informed my own over the years and were intended to place the learning of chemistry in the context of other traditions. For example, the class purpose is an adaptation of the purpose established at La Lucha by a former history teacher and assistant principal: “I am here to get the knowledge and skills I need to make a better life for myself and the people I love.” The recitation of the class purpose and solidarity clap was modeled after Curtis Acosta’s teaching practices (Acosta & Mir, 2012), which include recitation of the poem *In Lak’Ech* (Valdez, 1990). But this part of the ritual was also a nod to the struggle that started the school. During that campaign, the hunger strikers and their supporters camped out on the eventual site of the school and called this site “Camp Cesar Chavez” to invoke Chavez’ famous hunger strike during the UFW strike. The inclusion of the solidarity clap in the start of class ritual was an attempt to connect our class with this same legacy of struggle.

Purpose as alternative accountability.

The purpose also became a way to enforce the high expectations I set for students’ time and activity (Yang, 2009). When a student was off task or failed to complete an assignment, rather than referring to their grade, an upcoming test, or threatening punishment, I referred instead to our community-oriented purpose. I tried to emphasize this purpose whenever I redirected students. For example, on the first day of class, I provided students with feedback on their work during the summer session, which I evaluated as sloppy in the use of terms, ideas, and process, rather than penmanship. The following bullet points are excerpted from the slide that I displayed on the screen while I encouraged students to do better work in the stoichiometry unit:

- We are here to get the knowledge, skills, and habits we need to serve our communities and transform the world.
- We can't serve our communities with sloppy work (college access).
- We can't transform the world with sloppy work (study of Hg, Pb in soil from coal example).

In these bullet points, I connect the community service component of our purpose with college access. The connection between community service and college access in these bullet statements refers to the excerpt from the syllabus above that we had read that day in class. Throughout the case study class, I made a point to suggest that students should consider taking on roles in the community that require a college education (like teachers, doctors, social workers) and are often filled by outsiders who do not always have intimate knowledge of or commitment to the community. In these bullet points, I also connect the social transformation component of our purpose with the soil study detailed in Chapter IV. My archives include other presentation slides from different points in the course where I gave the class a pep talk or provided critical feedback using our community-oriented purpose as a framework. For example, I opened the equilibrium unit in a very similar way, but added that students should also use our purpose to hold me accountable when I fall short of their expectations.

Planned and organic opportunities to work together and teach each other.

The case study class included regular structured opportunities for students to work together and teach each other. Most students worked together in small groups to complete the reaction of the day and a student was put in a pedagogical role each time it was her or his turn to model the reaction of the day in the beginning of class ritual. We also frequently engaged in jigsaw activities where students first learned about a particular topic in one small group formation and then taught each other about these topics in new small group formations. For example, Chapter V describes how students taught each other about the various types of chemical reactions this way, and Chapter VI describes a jigsaw of readings about drug development. Each time we would conduct a jigsaw activity, we would discuss effective teaching practices like modeling metacognition, using analogies and examples, and including wait time after asking a question. I discouraged students from simply sharing notes with each other in these jigsaw activities.

Laboratory experiments and group problem solving activities were also a regular part of each unit. For example, as part of their final exam for the first semester, students worked in groups of 2 or 3 to design and carry out a series of experiments to determine the identity of an unknown chemical that poisoned a houseplant that my colleague had brought decorate the laboratory. Each of the 24 laboratory activities we conducted during the course involved students working together, often taking on explicit roles within their small groups. For example, many of our experiments involved using probes connected with computers to make measurements like pH, temperature, or gas pressure. During these experiments, one student would be in charge of the technological components and another would handle the wet chemistry. During paper-and-pencil group problem solving activities, students were sometimes assigned roles like the "analytical chemist" who would be in charge of checking calculations and the "environmental chemist" would be responsible for interpreting the group's answer in terms of the SSI that was used to frame the problem.

Aside from these in-class opportunities to work in small groups and teach each other, students often met in informal groups outside of class to continue their work. The class met during 6th and 8th periods, and 7th period was lunch. Most days, I would stay in the classroom during lunch to offer help and support on homework or laboratory assignments. About once per month, I would convene more formal "co-generative dialogues" with students to elicit student feedback about the course and discuss our progress (Emdin, 2010a; Tobin & Roth, 2005). These conversations would usually focus on the ways we were balancing and integrating various priorities, including preparing for the AP exam or college chemistry courses and addressing issues of social justice. The group of students who consistently attended these dialogues also became the group who was most involved in the soil project. Another overlapping, but different, group of students would consistently seek tutoring from me or would form informal study groups during lunch when there were not more formal conversations. One of these informal study groups met so regularly that they called themselves "the sandwich club."

Internal conflict and uncertainty.

As a young teacher, I was hesitant to introduce structures like those I describe above for several reasons, some better than others. For example, I avoided creating explicit roles for students during group work because I did not perceive that practice to be effective in my experiences as a student. I have mostly gotten over this sort of skepticism as I searched for techniques to provide the sort of structure my early practice sorely lacked. But to this day, some of the practices I describe above still make me uncomfortable. For example, the beginning of class ritual creates internal conflict for two reasons. First the daily recitation of our class purpose makes me wonder whether I was failing to heed Freire’s (1970/2001) repeated w0arnings against relying on slogans. As somebody who abhors reciting the pledge of allegiance in our schools, I worry that I am vulnerable to some of the critiques I might levy against that practice. At the same time, I am conflicted because our class purpose is not a statement of commitment to any particular person or institution, but rather a reminder that we are responsible to serve others and work for a better world in a general sense. Also this daily mantra did not take the place of authentic dialogue, but was merely one strategy to shift the emphasis of conversations about accountability from test scores and grades to community service and social justice. The second internal conflict that I have with the start of class ritual is a discomfort with appropriating the solidarity clap to conclude an exercise that prioritizes learning canonical chemistry. My intention in implementing this practice was to connect learning and academic achievement with the struggle that began the school (which itself was framed as part of a larger, ongoing struggle). But I wonder, despite all that we do in the class to encourage the critique of Western science, whether this is still a disingenuous connection. Despite these ongoing internal conflicts, I saw teachers who I admired implementing similar practices and I hoped that this beginning of class ritual would create the sort of atmosphere I saw in their classrooms. Despite my own discomfort, the data that emerged from my interviews with students pushed me to include these practices here. Whereas the practices described above have been reconstructed from my archival planning documents, the student reflections that follow capture the meanings they have attached to the practices about 18 months after the conclusion of the class.

Student reflections.

Students mentioned the cooperative and community atmosphere of the class more than two dozen times during their nine initial interviews, with seven of the nine student participants commenting on the importance of this characteristic in the case study class. Gabriel cited the community atmosphere of La Lucha High School in general and the case study class in particular as the difference between his success in high school and his struggles in college. In the case study class, he traced this atmosphere to the first day of the summer session when he and his classmates shared their goals with each other in small groups. Cristina, Curtis, and Jade all mentioned that our community-oriented purpose remains an important source of motivation for them in college. For example, in the context of discussing her career goals during her interview, Cristina pulled her course syllabus from the binder of artifacts she brought and began reading the passage from the syllabus that is included above. Cristina's reading of the syllabus was punctuated by an occasional, "Yes!" or "I really like that sentence." She went on to interpret what she had read:

> So, I really feel like the more you know, the more you have to give, right? And that's something I do all the time. This [the syllabus] puts a really good point on you're responsible for, not just your success, but the success of your classmates and you should also be very selfless with the knowledge that you have. So, don't just keep it in here [points to her head with both hands] share it with others and that's really really important. In order to advance just in the classroom setting, for Hilda and Yolanda to get it, I had to help them and for me to get it, they had to help me. It's really just a sharing of the knowledge.

Despite the appreciation she gained for the syllabus during college, Cristina admitted that she did not actually read the syllabus during the case study class (although we did read the introduction she quoted aloud on the first day of class). But her interpretation of this passage makes connections between the way she worked with her classmates for mutual achievement and the community-oriented purpose of learning expressed in the syllabus. Cristina's comments indicate that there are two important implications of the community-oriented purpose to learning. First Cristina emphasizes that it's "really, really important" that students are not satisfied with individual learning but instead also take responsibility for the learning of others. Secondly she notes that this sort of learning is reciprocal and required for everybody to deepen her or his own understandings.

For several students, the beginning of class ritual was an important part of establishing this community-oriented purpose for learning. Five of nine participants (Cristina, Odette, Jade, Curtis, and Francisco) mentioned the start of class ritual as one of the most memorable components of the class. Cristina mentioned the recitation of our class purpose three separate times in our interview, noting that it also still plays a role in her life eighteen months after the conclusion of the class. Jade and Curtis spoke about the lasting impact of this purpose in similar ways. Jade mentioned that she frequently references it in papers for her college classes. At one point during our interview, she spontaneously began to re-enact our beginning of class ritual, including the solidarity clap. She noted that an energetic and fun tone for the class was set by, "motivational songs and reading the mission statement and clapping our hands to it. It was just something like after we clapped our hands, it was like ok, it's time to get to work." In our follow-up interview, Jade noted that her informal study group, "the sandwich club" appropriated the start of class ritual for their meetings. Curtis echoed Jade and Cristina's comments about the ongoing importance of the community-oriented purpose in his academic life and also mentioned the solidarity clap as important to establishing the energy for the class. At the end of Curtis' interview when I asked him whether there was anything he would like to add, or anything that I did not ask about, he said that he thinks about the case study class frequently and specifically mentioned the statement of purpose that concluded the start of class ritual, "So it's like one of the indirect things that the class taught me was purpose – like sometimes there's days when I hate being in school, being in class, and it's like I'm here for a reason, you know?" In describing why they mentioned the beginning of the class ritual as supporting his learning, Curtis and Jade also went beyond its role in establishing purpose and energy. Curtis described what it was like when one student modeled the reaction of the day on the board.

> We would collaborate with the class if it was wrong. Or we would put it on the board and see if something was wrong. But it was never like 'oh you're stupid because you got this wrong.' It was more about helping each other out. And then having the follow-up problems to go a step further, taking students out of their comfort zone to push themselves to answer [the follow up problems]. That was also helpful, like not just to the person [modeling the problem], but to us. Because it was like, oh that's how you do it – like that kind of epiphany.

Jade remembered this supportive atmosphere similarly, noting that at first "everybody was scared…but we all pretty much encouraged each other as one. We pretty much rose together with the class."

Marisol corroborated the supportive and cooperative class atmosphere. When I asked her about components of the class that supported her learning, Marisol recalled, "I know especially in that class, there was a lot of cooperation I noticed compared to any of my other classes. So that was particularly helpful." Marisol elaborated on this cooperation by identifying Curtis and another classmate as being especially supportive of other students. In Chapter IV, I mentioned how Curtis traced his own helpfulness to the soil project, which he said changed his individualistic approach to learning. He explained that working together on the data analysis phase of the soil project helped him to see the value of collaboration in school. Cristina mentioned the peer support that was encouraged through small group activities in class among the aspects of the class that contributed the most to her learning:

> …having support. So I emphasized that a lot of the work was with our group. I really liked that a lot. Even though I did a lot of helping with Hilda and Yolanda. Even though I helped them out a lot, they helped but they helped me a lot too. The questions that would ask me made me would make me think, "Hmm I don't know why, but let me try to find out why." You know just, again it's not just about you and getting your own answers and doing you. It's about everybody – and really participating with everybody and getting involved.

In this quote, Cristina credits frequent small group work with supporting her learning. In describing how her friends' questions would make her think, she implies that part of how group formations supported her learning was by encouraging metacognition. Cristina also mentioned the importance of this trio in supporting her learning when she talked about the work from the course that made her most proud, which was an experiment where students were challenged to design a series of experiments to determine the identity of an unknown compound.

Cristina and her two friends also illustrate the ways that working together were both formal and informal in the case study class. This trio ate lunch in the classroom almost every day. Often times they played cards or socialized over lunch. Other times they focused on studying chemistry. In interviews, Marisol and Jade both mentioned informal lunchtime study groups as important to the formation of classroom community. Jade was part of a study group that called themselves, "the sandwich club." This particular group did not emerge from the case study class. Jade told me that it formed the previous school year, but that she associated their conversations and work during her senior year with the case study class. Curtis actually lamented the lack of organized formal study sessions outside of school hours, but mentioned in his follow-up interview that the classroom where the case study class met was a space where even students who were not in the class felt welcomed. He said that the classroom became a common meeting space for students. Odette credited the more formal lunchtime study sessions and co-generative dialogues with drawing her into involvement with the soil project outside of school.

Culturally relevant purpose.

Establishing and maintaining a community-oriented purpose and approach to learning flies in the face of the values of individualized meritocracy and "learn to earn" that are prevalent in US schools. The community-oriented atmosphere that students describe feeling in our class was aligned with a more holistic *educación* (as opposed to schooling) that values "moral, social, and personal responsibility" and that Valenzuela (1999, p. 23) characterizes as the predominant view in Mexican culture. However the practices I describe here are hardly rare, innovative, or revolutionary in US schools. In fact, relying on routines to start class, small group learning in laboratory settings, and informal study sessions are practices that are I see in virtually every school that I visit when I observe student teachers. As much as I might like to take credit for the galvanization of students into a cohesive unit, I am confident that these practices in isolation were not responsible for the community atmosphere that students attributed to the case study class, nor for the learning that was supported by this atmosphere. Instead a pattern-matching analysis of interview transcripts and my planning documents suggests that the successful community atmosphere was the result of aligning the values of the classroom with those of the larger community. In this way, I did not establish our community-oriented purpose for learning. Rather our class tapped into the way some portions of the larger community view education and the moral, social, and personal responsibility that students already feel for their families and communities. All nine of the student participants expressed some sort of responsibility to their community when describing their future or career goals. While the community-oriented purpose of the case study class may have reinforced this responsibility, my analysis of the way participants described the community suggests that the case study class was not the original source.

While I believe that communicating a community-oriented purpose for and approach to learning is desirable in any high school science classroom, the particular practices, structures, or routines that can accomplish this are highly context dependent. The alignment of this set of practices with the values and beliefs of at least one segment of Ridgevale community in particular is illustrated by the way both community members talked about their hopes for science education. Ms. Juarez, who is from a family of Chilean immigrants that has lived in Ridgevale for decades asserted, “We are people of science and math. And I think that the role is *para mejorar la entera communidad* [to improve the whole community].” While it is not clear exactly who Ms. Juarez means by “we” in this comment, her view of the purpose of science education aligns quite well with the statement of purpose that was part of our start of class ritual: “We are here to build the knowledge, skills, and habits we need to serve our community and transform the world.” Ms. Avila’s ideas about the purposes or goals of science education provide further evidence that the strength of our community-oriented purpose was its connection to the beliefs and values of key stakeholders in the community. When I asked her what she hoped youth at La Lucha would get out of their science classes, Ms. Avila said, “to connect the importance of the two – the relationship between community, science, and…why they’re so vital to everybody’s well-being. That’s what I hope they would get.” Ms. Avila’s response suggests not only that learning science be connected with community, but also that students be asked to consider why science and why community are “vital to everybody’s well being.” Ms. Avila went on to critique the science education at traditional schools, noting that she doubts students at most schools make these connections. It seemed as if she was re-enacting an actual conversation she had with her own school-aged son in her interview:

> Will they get that at other schools? Probably not. They’re just going to get: ‘It was a fun experiment. I got to blow up some stuff today, Mom,’ or ‘Look I got really dirty.’ OK, so what’d you learn?…So I would hope that they would use it for good. For knowledge for self, but also for other people, like you gotta take care of this stuff.

This critique echoes a socio-transformative approach to teaching and learning science that pushes us to move past hands-on, minds-on activities to reflect on the social relevance of learning science (Rodriguez, 1998). Besides critiquing hands-on science learning that does not make deeper connections, in these comments, Ms. Avila re-emphasizes the notion for learning science for “good” and for “other people.” Her closing comments, “you gotta take care of this stuff” once again suggest the social responsibility of *educacíon* as opposed to the individualistic notions of learning as preparation for employment that prevail in US schools.

It is important for me to close this section by acknowledging that the community of Ridgevale is not monolithic. This is obvious when we consider the racial tensions between East and West Ridgevale or the boundaries between the territories of street organizations that I raised earlier. But even within relatively homogenous sections of Ridgevale, people are likely to have diverse beliefs, values, and viewpoints just as they are in any community. For example, there are segments of the community who prioritize individual academic achievement as connected with a belief in the American dream. There have also been many disagreements, divisions, and differences of opinion between the fourteen participants in the hunger strike that founded La Lucha High School. Nonetheless, the three stakeholders I interviewed are representative of a tradition of struggle for equity and justice that exists in Ridgevale locally and in African American and Latin@ communities nationally. The community-oriented purpose for learning in my syllabus and daily ritual matched the way stakeholders talked in interviews about their vision for science education. Students' reflections upon this purpose, in turn, suggests that my classroom structures and rituals were effective because they tapped into or aligned with some of the common beliefs or values in the broader community. In this way, learning chemistry was presented as consistent with students' participation in their communities of origin. This is indicative of the maintenance of cultural competence as defined by culturally relevant pedagogy (Ladson-Billings, 1994) and is further illustrated in the sections that follow.

Responding to Destabilization

Another set of teaching practices that students spoke about as salient in consistent ways is related to the way our class responded to the destabilization of La Lucha High School at the beginning of the school year. Five days before the school year began district administrators fired Ms. Williams, the principal of La Lucha without notice or cause. This firing became the fourth change in administration within ten months at the school after the previous principal suddenly resigned and was replaced by a temporary administrator before Ms. Williams was hired. The Advisory Local School Council selected Ms. Williams in a contentious, but democratic process.

Some members of the council prioritized the previous experience and plan Ms. Williams, who is an African American woman, brought to the school. Other members prioritized the bilingualism and biculturalism of a less experienced Latina candidate. These events and those that ensued are documented more thoroughly by another school stakeholder Stovall (forthcoming). I will include a brief description here to contextualize my data analysis. I relied on media coverage and documents that I produced or collected during these struggles to reconstruct these events and I include a description of my own participation because it is important to the analysis that follows.

Ms. Williams' firing at the beginning of the school year represented a violation of the democratic process by which she was hired and a destabilization of the school as it came at a very inopportune time, less than a week before the first day of school. One of the last minute changes made by the interim principal was to cancel 3 of the 7 Advanced Placement classes offered at the school. Juniors and seniors who had enrolled in those classes were placed in remedial reading courses. My AP chemistry class was not one of the three cut, but the school community was thrown into upheaval by these changes. Teachers and students showed up on the first day of school to find drastic changes to their schedules, which left them unprepared and upset. The cancellation of the number of AP courses had significant implications for individual students as they applied to college and for the way the school was perceived. The numbers of AP courses offered by a school and taken by students are often considered in college admissions decisions (Solorzano & Ornelas, 2004). Moreover, the numbers of students enrolled in AP courses and taking AP exams were included as metrics on the district's own performance policy rubric at the time. Thus the cancellation of AP courses threatened the school's status according to public perception and district policy and also had ramifications for the college admissions chances of La Lucha students. When teachers challenged these decisions by the interim principal, two experienced teachers who had worked at the school since its initial planning stages were also fired without cause. Given the school's history and Chicago Public Schools' infamous record of school closings and privatization by charters (Lipman, 2011), we had little choice but to consider these inexplicable personnel moves as an attack on the very existence of the school.

Many students were enraged about the class cancellations, especially seniors who were preparing for the college application process. Some of them had previously been enrolled in AP courses, but suddenly found themselves in classrooms staffed by substitutes who showed them animated children's films in lieu of actual instruction. On the third day of school, these seniors (several of whom were in the case study class and are also among the participants in this study) organized a sit-in. This first protest garnered widespread participation by students across grade levels and essentially led to the cancellation of the first five class periods for the day. In my own reflection on the event, I noted that out of 81 students in my first three classes, a total of 11 were present in class that morning. This sit-in came to an end when student leaders (including participants in this study) met with the principal and district administrators. These student leaders called for an end to the sit-in after they were promised a follow-up meeting with the principal that included their parents. The case study class was the first class students attended after the sit-in came to an end. I began class by telling students that I was proud of their organizing efforts and promised that I would provide space for them to talk about all of the events and their organizing efforts after class, but that we would proceed with class as planned. This decision, which I repeated several times over the next few weeks, is the focus of the section that follows.

When it became clear that the meeting promised between the interim principal, students, and parents would not materialize, students followed up by organizing another action. They covered their mouths with duct tape and refused to speak in class as a symbolic protest of their lack of voice in the school decision-making process. On that day, I planned for class to be conducted silently, but we moved on with the stoichiometry unit. Outside of school, various school stakeholders including parents, community members and teachers met regularly to support the students' efforts and to organize our own response. Both Ms. Juarez and Ms. Avila became very active in these efforts along with another participant in the original hunger strike. I had been one of two staff representatives on the ALSC who hired Ms. Williams and was a regular participant in these efforts. The ALSC began holding special meetings where student leaders from the case study class were vocal and prominent participants.

Informal meetings of stakeholders at cafes and in homes and backyards also led to more formal community forums at the school and in the neighborhood. My archives include a memo from the assistant principal indicating that this forum would be closed to all stakeholders except for students and parents, but pressure from community members forced the interim principal to open this meeting to the public and the cafeteria was packed that evening. When the assistant principal opened the meeting by using outdated reading scores to justify "a change in direction," I used a live microphone in the back of the cafeteria to interject and correct her presentation with updated numbers that showed a dramatic increase in scores. This strategy had been planned in advance during meetings with various groups of stakeholders. After I spoke, one of the founding hunger strikers used the microphone to take over the meeting. Then series of stakeholders, including students from the case study class, peppered the interim principal and the district administrators who attended with questions that they could not answer.

Before and after the community forum, parents and community members, including all three who participated in this study, were organizing themselves and putting pressure on high-ranking district administrators to meet with them regarding the destabilization of the school. The teachers union became involved in these efforts in defense of the two teachers who were fired, but also in support of the larger community-led push back. After two weeks of insufficient administrative responses to these efforts, on the morning of August 31st, students staged a walkout and rally that led to the cancellation of the case study class later that afternoon. This walkout had almost universal participation among La Lucha students and attracted the attention of several local and even some national media outlets.

These combined efforts led to the reinstatement of the fired teachers, but not of the principal or the cancelled classes. About one week later, contentious negotiations between Mayor Rahm Emmanuel and the Chicago Teachers Union led to the first strike in CPS in 25 years. During the strike, community members, parents, and students continued to put pressure on the district to restore the harms that had been done at La Lucha. The successful CTU strike led to the resignation of the CPS CEO and soon thereafter stakeholders from La Lucha met with the newly appointed CEO who reinstalled Ms. Williams as principal of La Lucha. Upon her return, Ms. Williams was able to restore the previously cancelled AP courses and make corrections to mangled student and teacher class schedules.

Student reflections.

Unfortunately this turnover of administrators at the district and school level is not unusual in urban schools. The principal being reinstated in October marked the end of a 12-month period in which La Lucha had four different principals and five changes in administration, instability that was the result of policies and decisions of the Chicago Public Schools. In the midst of the stoichiometry unit described in the previous chapter, several students in the case study class and I were attending multiple evening meetings per week to support the effort to fight back against the destabilization of the school. The instability and extra organizing work were taking a toll on adults and youth alike and created a tension which interview data indicates students felt and remember. On one hand, it was hard to focus on chemistry and being prepared for class everyday. On the other hand, students were organizing against destabilizing policies that negated their opportunities to learn, so we felt more pressure than usual to take advantage of the opportunities that remained. As I mentioned in recounting these events above, the way I dealt with these tensions was to be involved in the struggle to re-stabilize the school outside of class while pushing forward with the planned curriculum during class.

As he remembered the first month of the case study class in our interview, Jackson empathized with teachers “it can’t be easy to teach in an environment that is very unstable.” Jackson also added his perspective as a student “We were also feeling the effects. The juniors and seniors were getting ourselves [sic] really involved. We were feeling the effects of how unstable everything was.” Marisol identified herself as one of the leaders in the struggle to reinstate Ms. Williams, the fired teachers, and the cancelled classes. Her reflections add specificity to the ways some students experienced the effects of instability that Jackson mentions:

> Academically there was a lot of stress going on, so maybe I was less focused during class when things were occurring. So, yes I was present, so I wouldn’t miss class or anything like that. I would be present, but my mind wouldn’t necessarily be focused on what was on the board or after school time would be spent dealing with other situations [rather] than as much as I would like on my homework. So it took my focus away and my time away from time I should have spent studying.

For Marisol, the organizing efforts to re-stabilize the school were a distraction in terms of both time and her ability to focus on her schoolwork. Odette’s memories of that time add another complication to this tension, the erosion of a previously strong school culture. She recounted how the interim principal and unstable teaching force were unable to uphold the school culture, which led to chaos, especially among the ninth graders who were unfamiliar with the school prior to this instability. She remembered coming to my class after an especially chaotic lunch period where younger students were fighting and she was unable to focus on chemistry. Curtis also remembers having a hard time concentrating during this time:

> It was hectic. It was hard to focus on chemistry. Knowing that one of my other AP classes was taken away also, it kind of made me cherish AP chem and AP Spanish a lot more. Because it was like at any given moment it can be taken away from me, so I need to get all the information and knowledge I can get. It was like I need to take advantage of this opportunity. Because AP psychology was also taken away for the seniors. So it was like, man! What if they were to take chemistry away? Or Spanish?

Curtis' comments reflect the reality for many students in urban schools, the instability of leadership and the volatility of budgets means that the rug of educational opportunities can be pulled from under students' feet at any point in time. It is also important to remember that in the case of La Lucha High School, a hunger strike was necessary to create these opportunities in the first place. But Curtis' comments also suggest this tension between addressing the injustices students were experiencing directly and taking advantage of the educational opportunities that remained.

After much deliberation, I decided to proceed with the stoichiometry unit more-or-less as I had planned it. My analysis of student interviews and artifacts suggests that in this particular set of circumstances, this was a good decision – but this should not be interpreted as a generalizable response to similar circumstances. The data suggests complexity with respect to how teachers, students, and parents navigate the educational destabilization caused by the policies that "deliberately undercut and demean urban schools" (Duncan-Andrade and Morrell, p. 1). All three stakeholders I interviewed for this study became involved in the efforts to reinstate the fired principal and teachers, a decision they attribute, in part, to being inspired by the leadership of the students. When I asked Ms. Juarez about my decision to proceed with the curriculum as planned, she frankly told me:

> I think the biggest mistake is when we try to ignore it and it's happening. Because the conversations are happening anyway. You know – they might be taking away from the class anyway. If it's not aloud, it's in [students'] brains.

Ms. Juarez suggests that whether or not students are vocalizing concern over a community issue outside of class, they are likely to be distracted from class because they are thinking about it. This prediction is corroborated by the recollections of Curtis, Odette, and Marisol above. Jackson and Cristina also indicated in interviews that these events were very stressful for them and detracted from their ability to keep up with homework for the case study class. Ms. Juarez stopped short of characterizing my particular decision to move forward with the stoichiometry curriculum as a mistake. But she does not mince words when she suggests, "the biggest mistake is when we try to ignore it." Herein lies the nuance of my decision to proceed with the curriculum as planned. My decision to proceed with the curriculum as planned did not constitute ignoring the chaos or the struggle for stability because students knew that I was involved in supporting their efforts. Once again teaching practices that were relatively unremarkable (moving forward with academic curriculum as planned) were successful only because they were aligned with the values and priorities of the larger community in which students were raised and presently participating.

Hope as re-stabilizing.

Duncan-Andrade's (2009) critical hope framework, as a theory that is aligned with critical pedagogy and Valenzuela's (1999) notion of authentic care, helps to explain the interactions between the destabilization of the school and my decision to proceed with the curriculum. Duncan-Andrade includes three components of critical hope: audacious, Socratic, and material hope. All three of these components of critical hope are related to counteracting the ways that the dominant discourse of schools (especially as contradicted by school personnel's actions) creates a sense of false hope, which can lead to hopelessness for students.

Seven of the nine students I interviewed brought up the destabilization of the school and the ensuing struggle without specific prompting in their interviews. I raised the topic with an eighth student, Gabriel, after he made several comments that I interpreted as alluding to these events. There was consensus among these eight students that moving forward with the curriculum as planned was the right decision. Their comments provide insight into the complexity of this decision. Marisol noted that I acknowledged the situation in brief and subtle ways and said that she did not perceive our focus on the curriculum as ignoring the struggles for the school. Jade remembered using the first few minutes of class to vent and then getting down to work. Curtis remembered that I set aside time and space after school on the day of the sit-in to debrief. He remembered several seniors, including students who were not in the case study class using the classroom space to continue organizing. Students came to me and other teachers outside of class during that time to seek advice or support related to their struggle. We would see each other at evening meetings. Curtis recalled in our interview that I was the first person to challenge the interim principal's use of outdated school data at a community forum during the second week of school. Cristina remembered this also and said it caused her to worry that I would be the next teacher fired and our class to be the next one cancelled.

All of this suggests that we were able to move forward with the curriculum, in part, because students did not have the impression that I was ignoring the situation. Reflecting on the way we pushed forward with the curriculum, Cristina remembered "I knew that you felt it was important for us to fight." Curtis, Marisol, Jade, and Odette confirmed that they knew I supported and was involved in the efforts to re-stabilize the school. Part of engaging in justice-centered pedagogy is to "practice what you teach" (Picower, 2012) or make a "constructive effort...to diminish the distance between what we say and what we do" (Freire, 1998, p. 63). If we expect our students to engage in struggles for social justice, then we must engage in these sorts of struggles ourselves.

As Duncan-Andrade (2009, p. 188) asserts, "To show the sermon, rather than preach it, is the essence of Socratic hope." We cannot expect students to engage in learning the material we deem important if we ignore the issues they consider to be important. Had I pushed forward with the curriculum as planned while ignoring the struggle, failing to show up at community meetings, or being oblivious to students' struggles, their interpretations of my curricular decision likely would have been very different. This sort of indifference also would have threatened the integrity of the community-oriented purpose for learning that is the focus of the earlier part of this chapter.

Given their sense that I was not ignoring the outside problems, several students described our focus on studying chemistry as providing "a sense of stability" (Jackson) or "some type of consistency" (Odette). Jade told me that her family considered transferring her to another school during that time to ensure that her college application process would not be compromised by the instability. Jade credited the continued rigor of the case study class as one of her primary reasons for deciding to stay at La Lucha. Cristina's comments also corroborate this notion of stability and consistency:

> I actually appreciate that you didn't put that much of an emphasis on connecting the class with what was going on outside. Honestly I think that the class was the most consistent thing that I had going on…It kind of kept me anchored and settled while all the chaos was going on…And I think a lot of students felt the same way. I think we handled it pretty well, as a class.

Cristina's final statement here suggests a sense that we were in this together. It was not that the curriculum provided stability nor did I. Students could have chosen to resist learning that curriculum just as they were resisting much of what was happening in the school at the time. Rather it was that our class implicitly decided that focusing on chemistry for 100 minutes per day was consistent with our involvement in the struggle for the school. The academic success that we were able to achieve despite these circumstances constitutes part of what Duncan-Andrade (2009) refers to as material hope. Jade recalled that her peers who were not in our class were surprised to hear that she and her classmates looked forward to chemistry class and considered it to be a "relief." She described being able to put all of her pent up academic energy into chemistry because it was one of the only classes that had not been seriously disrupted by the schedule changes.

For Odette and Cristina, the decision to push forward with the curriculum was also helped by the fact that they perceived the curriculum as justice-oriented. Odette remembers, "It was just a relief to like go and actually learn something relevant whereas in other classes it was kind of like, let's informally talk about what's going on." Her comments suggest that it was the combination of rigor and relevance that provided her with relief. She had the opportunity to informally discuss the injustices at the school in other spaces and appreciated a space where social justice was linked with more formal learning. Odette and Cristina both described the justice-oriented science curriculum, especially their involvement in the soil project, and the struggle for the school as coming together to reinforce their interest and beliefs in the potential role for science to play in struggles for social justice. The way they both traced their choice of majors and career interests to these concurrent events is discussed further below.

In this particular case, students were fighting was a lack of stability and the cancellation of academically challenging classes. So providing stability and challenging work was exactly what students felt like they needed, despite sometimes having a hard time focusing. In this way, my decision to push forward through the stoichiometry unit was supported by the daily beginning of class ritual, the emphasis on learning as cooperative and collective, and a curriculum that emphasized learning chemistry to fight environmental racism. These practices combined with my own involvement in the struggle the students were fighting allowed us to focus on stoichiometry amidst the chaos often created by outside forces acting on urban schools. This story exemplifies how we must confront inequity in science education as one component of broader social injustice. It also demonstrates how one of the most serious challenges of taking this justice-centered approach is to constantly make difficult decisions about the best way to negotiate the balance between academic rigor and community responsiveness.

As I mentioned when I described two community struggles from my childhood, my goal here is not to romanticize this struggle. Students' educational trajectories were damaged by the destabilization of the school. As student comments above indicate, student learning in the case study class was negatively impacted by these events even though it was one of classes that was not cancelled. Also, the struggle was not without its internal disagreements. For example, Curtis spoke in our interview about how he felt excluded from the initial organizing efforts by twelfth graders who led the struggle and made it “a senior thing.” Ms. Juarez also mentioned in our interview that some teachers misinterpreted her involvement in a negative way. The various stakeholders involved even disagreed about whether the ultimate outcome of organizing efforts should be the reinstatement of Ms. Williams or a new hiring process for principal. However, in the end, stakeholders made compromises and showed unity, thus exhibiting the ability to come together in a time of need that Curtis and Jade mentioned as strengths of the Ridgevale community. For Duncan-Andrade (2009) when educators humbly join with communities like Ridgevale in their painful struggles, this is what constitutes the difference between hokey hope and audacious hope.

Trajectories through *Nepantla*

I began this chapter by trying to complicate the notion of student resistance and by noting that my initial attempts to enact relevant curriculum at La Lucha often fell flat because of insufficient classroom structures. In introducing his methodology for finding classrooms in which structured engagement is successfully implemented, Yang (2009, p. 57) notes that classrooms filled with students who are positioned as “compliant” within the school are less remarkable (and perhaps have less to teach us about structured engagement) than those classrooms that engage those students who are positioned as “resistant.” Among those classrooms likely to be filled with compliant students, Yang mentions Advanced Placement courses, which he notes are often racially tracked.

While the case study class mirrored the racial demographics of the school as a whole, I find myself wondering whether this class was, on average more “compliant” than most classes and what that would mean for the analysis I present here. In recounting a successful walkout at a much larger predominately Mexican American urban school, Valenzuela (1999, p. 52) notes that the success of this student action was largely predicated on the fact that it was led by honors students. Valenzuela argues that the walkout would have been viewed differently and would have been less successful had these relatively privileged students not been involved. The walkout documented in this chapter follows a similar pattern. The most visible leaders were highly successful college-bound, scholarship-earning seniors who were upset by the disruption of their Advanced Placement classes. This similarity further causes me to question the role of student resistance versus student compliance in the case study class and the struggles of that school year.

As I note at the beginning of this chapter, notions of compliance and resistance are complicated by a school that purports to be engaged in counterculture, in challenging oppressive systems. This complexity is manifested in the stories of three students who figure prominently in this chapter and others: Curtis, Odette, and Cristina. In this last section, I combine quotes from their interviews with narratives about their trajectories through school to add richness to my analysis of teaching practices in this chapter and also to the three orientations towards science that I introduced in chapter IV and elaborated in the previous chapter (tourists, concerned scientists, and nepantler@s).

Curtis (tourist in the culture of science).

Curtis' trajectory through school troubles traditional notions of compliance and resistance. In his interview, Curtis told me how he was kicked out of a magnet/gifted program at the end of sixth grade for being involved with a local street organization. He described his affiliation with the Latin Kings as motivated by "intrigue" and a sense of "community" that he shared with his brothers and cousins. In contrast, his status in the gifted program created tension with his older brother who reacted negatively to Curtis smugly doing more advanced math work despite being younger. Curtis' experience of being sent back to his neighborhood elementary school and having his "gifted" label replaced by that of "gang member" made him critical of the way resources were allocated in the school system and the way he was made to feel better than his peers while he was in the gifted program. He remembered experiencing his return to his neighborhood school as a "downgrade" in terms of intellectual challenge and material resources. But he also remembered feeling supported by his family and community members who encouraged him to re-engage with school.

For these reasons, Curtis described himself as coming into La Lucha as committed to following the rules of school, but highly skeptical of the institution. He was especially skeptical that the science curriculum had anything to offer him, recounting in our follow-up interview, "I'm not going to lie, coming in as a freshman I thought science was for those white folks, this is stuff not for us. I thought the other subjects were for us. I came in with a very blindfolded mentality." In our initial interview, Curtis mentioned the aspirin project and the injected relevance of nixtamalization as examples of what he described as "cultural education" that was previously missing from his experiences in school science. When I asked him to elaborate what he meant by "cultural education," Curtis said:

> There's just so many things that my origin has done to contribute, but it's always downplayed and not given credibility. And so the cultural education that I refer to is more like what's not acceptable in American education, like culture. A lot of times, we hide our identities as Latinos, as Mexicans because you feel like you're not abiding to the norm.

In this way, justice-centered science pedagogy supported Curtis as he shifted his orientation towards science. Initially alienated by science, Curtis came to see it as applicable in his other pursuits. As a tourist in the culture of science, Curtis does not feel comfortable living in the *nepantla* between Western science and the other communities in which he participates, but he brings metaphorical souvenirs back and forth between the two. In reflecting upon his participation in the soil project, Curtis explained how the project not only helped him learn science, but also to define social justice more clearly:

> My confidence level, it was also boosted because it's like I participated in a movement – at least that's what I saw it as. This is what social justice is. You know? You do things collectively and you try to make things right and then you share it with everyone else. It's a collective thing. And then it just felt really good.

Again in these comments, we see Curtis connecting the values and practices of the case study class with the values and practices of larger struggles for social justice. Curtis went on to describe how he brought what he learned on the soil project into another community in which he chose to participate, the school basketball team:

> Actually another impact that I remember – this is not anything related, but there's a basketball tournament that was funded by [the company that owned the coal power plants] and they were like put on this shirt [with the company logo]. And I refused to put on the shirt. And I was like, do you know what you're representing? [My coach asked me] what are you talking about? What do you mean? And I told him about the [soil project] research and he was like Oh, OK and he didn't put the shirt on either.

As a tourist in the culture of science, Curtis does not see himself working to change the culture of science itself nor does he science as the primary lever to affect social change. But through his participation in science, Curtis was able to impact the viewpoint of his basketball coach and convince him to partake in a small act of resistance against environmental racism. In this way, tourists in the culture of science can imagine new possibilities for the relationship between science education and social change.

Curtis has continued to dabble in science as a college student. He volunteers as a tutor for struggling students at the local high school in the college town where he lives. He also assists his college classmates with their chemistry courses. He told me in our initial interview about how he posed as a prospective student at his college in order to accompany a friend to her lab to help her with an experiment. He even called me from his college campus just after his initial interview to double check the solution to a non-trivial redox reaction problem he had been working on with his friends for their chemistry class. Curtis continued to show this level of commitment to cooperative learning of chemistry even though he was not enrolled in the class himself. As a result of these ongoing experiences where he feels knowledgeable about chemistry, Curtis decided to enroll in a basic chemistry class for non-majors in his second semester of college. He describes the class as easy and was convinced by the professor to add a minor in chemistry. Given this increased interaction with chemistry, I pressed Curtis in our follow-up interview about whether his trajectory has changed and whether he now considers himself to be part of the culture of science. He insisted that he is still more comfortable and more effective as a tourist.

Odette (*nepantlera*).

In our interview Odette spoke about “being obedient” as one of her personal strengths and one of the reasons she had experienced significant success in school, especially in elementary school. She characterized her education at La Lucha as one that caused her to begin to question the status quo, but was critical of the fact that La Lucha did not initially provide her with any tangible ways to make change. Then she says the struggle to re-stabilize La Lucha after the principal and two teachers were fired without cause changed her point of view by giving her an opportunity to act on her emerging beliefs. She remembered being impressed by a group of mothers, which included her own, when they would speak at the ALSC meetings she attended during that time:

> They would just speak out about politics and all this stuff and I was like whoa! It was just laid out there really raw and really real. It was cool because they didn't have to major in political science to know these things or to notice that they're happening and the motives behind politicians and stuff like that.

She later contrasted this political clarity of the group of mothers who lacked formal education with the obedience that helped her to succeed in school. Odette said that she as she learned from listening to the mothers, she would think to herself about that points they raised, "That's really obvious. But I wasn't able to identify those things because I am so obedient and I just kind of know what I'm taught in class, the way I'm taught in class." Odette's comments here echo Valenzuela's (1999) notion of "subtractive schooling" and Macedo's (1993) notion of "education for stupidification" in that schooling discouraged her from developing critical thinking skills that her mom possessed. In this way, Odette interprets school, with its focus on compliance, as negating some of the cultural resources that existed in her family and community.

Odette described in her interview how her involvement in the struggle at La Lucha that fall, "generalized into a more stop school closings action because I did find myself going to strike in other schools." One of these protests occurred during the second day of high stakes mandated state testing. Odette was the only student in the school to skip these tests and attend the protest. This was an action that ultimately forced her to ask a lawyer to send a cease and desist letter to La Lucha’s principal for harassing her and threatening extralegal punishments related to graduation and grades. Odette was able to access this lawyer’s services because she was involved with an organized group of students at a nearby high school who had planned the protest she attended. During our interview, I indicated to Odette that these are not the actions and experiences of an obedient or compliant student and asked her to reconcile her characterization of herself as obedient with these actions. She did not have much to say at the time, but the day after our interview she sent me an unsolicited email to clarify and elaborate. An excerpt from that email reveals how Odette understands the relationship between structure and engagement in school in a way that is consistent with critical pedagogy, culturally relevant pedagogy, and other critical traditions in education (e.g. Yang, 2009; Apple, 2004):

> Many teachers teach by solely tackling the objectives they need to meet. Education can be oppressive if this way of teaching is being enforced along with not letting students make their own applications or also just not having any applications present in a classroom that reflect life outside of school. In my opinion, this is because it leads to the obedience that makes people more controllable, since they do not question the way things are.

Odette’s comments here assert that a standards-based education that does not problematize students’ reality is oppressive because it does not encourage students to question the status quo or in other words does not support the development of critical consciousness. She implies here that she is no longer willing to tolerate this sort of education in her own life. Besides leading her to become more politically active, Odette also attributes her choice to major in chemistry to the alignment between the community power that she felt by participating in the struggle to re-stabilize the school and the critical consciousness that she developed during the case study class.

The soil project in particular pushed Odette to think in sophisticated ways about the relationship between science and social justice. When I asked her about this relationship, Odette responded:

> I think science in general is a type of action because you do have people developing medicines and stuff like that, but a lot of times – at least how I feel about it, people in those fields don't necessarily think…of themselves as activists. I feel like that is different from someone who goes into the science field with activism in mind because…we do have these doctors and engineers and people who help…make people's lives easier everyday and stuff, but then you also have other people who are fighting like coal power plants and stuff. And that's scientific, but it's also activism. And I feel like in that case, the activism really speaks out more.

Odette's response here captures one component of the difference between a "concerned scientist" orientation and a *nepantler@* orientation. Odette contrasts the notion of science for the greater good with science as tool to engage in activism. I followed up to ask Odette how she viewed her own motivations for declaring a chemistry major and she responded that she intended put her knowledge to use in service of struggles for social justice in communities like Ridgevale. In this way, Odette intends to live in the *nepantla* between Western science and her community's traditions of struggling for equity and justice. To the extent that justice-centered science pedagogy may have supported Odette's path, it did so by aligning learning chemistry with the values of the community, including the political activism of mothers at La Lucha. By deciding to betray her tendency to obey school rules in the face of injustice, Odette participated in sit-ins and walkouts that ultimately allowed her to learn from the critical consciousness of her own mother. Through her experiences in the case study class, Odette began to see how working to change the conventions of Western science and working to apply its tools would position her as participant in the already existing efforts of her community to transform the world into a more just and sustainable place.

Cristina (*nepantlera*).

Cristina came to La Lucha High School having given up on achieving academic success because she had lost hope that she would have a pathway to attend college and ultimately secure a job with high status and high pay. She left a selective enrollment high school after a loss of hope led to her refusal to comply with the demands of her schoolwork, which in turn led to failing grades in several classes, including chemistry. La Lucha High School provided Cristina with a different, less capitalistic and individualistic way to look at learning that was more consistent with her values. In a quote that is included in Chapter V, Cristina attributed rediscovering her academic motivation at La Lucha to this community-oriented purpose "I'm learning this for my community. It's not just for me. It's not just for me to get a good paying job when I graduate. It's for me to help." In this way, Cristina once again saw the value in complying with the demands of school and earned A's and B's at La Lucha and a college credit-earning score of "3" on the AP chemistry exam. Cristina's story illustrates how the broader goals and policies of the US educational system lead students to resist participation in school. A community-oriented purpose allowed Cristina to re-engage because learning was not predicated on individual success as defined by economic opportunity. While Cristina is *Mexicana*, her story resonates with Perry's (2003, p. 12) description of the "indigenous African American educational philosophy" which connects learning with freedom and humanization as opposed to participation in an economic system that systematically excluded African Americans (or undocumented immigrants, in Cristna's case) from high paying jobs.

This purpose initially supported Cristina in decoupling learning and career goals. But she described in her interview how the struggle to re-stabilize the school combined with her participation in the soil study to help her identify what she hopes will become her life's work, being a chemistry teacher in Ridgevale:

> So I was like I'm really liking chemistry and what I'm doing soil sampling wise and it connected really well with what was going on in the school because I was fighting for the school and I was doing the chemistry work too. So making the connections of community and what you like to do or what you like to study is why I'm doing what I'm doing now. Usually when people ask me, without getting into the whole story of it, I say I realized that I liked chemistry and I liked working with my community so I'm just putting them both together.

Again we see in Cristina's comments that the effectiveness of justice-centered science pedagogy is connected to its ability to create some alignment between the learning of canonical science concepts with the ongoing efforts of disenfranchised communities to gain control of their destiny. But even in this alignment, there is a gap between the culture and worldviews of Western science and the culture and worldviews of community members in neighborhoods like Ridgevale. Cristina described in her initial interview how her ongoing work as an organizer with COVER continues to develop her thinking on this topic:

> So I think my job right now is really helping me make connections and not forget about what's outside – don't forget about your community. Don't forget about where you come from. Just because…I feel like a lot of scientists just stay confined to themselves and when they do that, that's when you're more likely to do something bad because you don't know what's going on, you don't know the true costs of it. I also still feel that it's very

> unwelcoming. So science as a whole is unwelcoming to people of color and women. I would love to study and do more on why that is. I guess a lot of it has to do with the history too. Women weren't allowed to have that education back then, and it was just men and men who had the money to, which was mostly white. And that has definitely carried on through generations.

In this quote, Cristina perceives the culture of science to be dangerously disconnected from the realities of communities like Ridgevale and unwelcoming to women of color. Even so, she has chosen to be a chemistry major because, as indicated in earlier comments, she believes that she can be a part of changing the culture of science and believes that science can play a role in making Ridgeway more just and sustainable. Students like Cristina are able to perceive enough alignment between the culture of her community and the culture of science to make navigating the alienating culture of Western science worthwhile. Science *nepantler@s* use their knowledge of both cultures and worldviews to navigate, and even feel comfortable, in the *nepantla,* the spaces in between Western science and *la lucha*.

Conclusion

The preceding section is not meant to imply a causal relationship between teaching practices and student trajectories. There is so much more to these students' stories that my interpretations of their trajectories as they described in interviews certainly did not capture. Also, the last quote from Cristina above illustrates how students' understandings have continued to develop since the end of the case study class. Rather than seeking to make a causal link between teaching practices and student trajectories, I include these brief descriptions of students' paths through school because they problematize the way students are positioned as obedient or resistant in school science settings. In more traditional school settings, despite experiencing initial success, both Curtis and Cristina were positioned as resistant outcasts or failures. Meanwhile Odette's obedience was rewarded with success in school but prevented her from developing the critical consciousness that her mother displayed in community settings. At La Lucha, Curtis and Cristina found a way of participating in the structures of school without sacrificing their integrity while Odette learned to resist those same structures. These transformations did not happen only in the case study class or in isolation. But the extent to which I was able to engage students in learning chemistry was related to the way the purpose of the class was aligned with the values of other communities in which Curtis, Odette, Cristina and other students chose to participate. Still I am left reflecting on students who were framed as resistant even within the context of La Lucha – like the young man who objected to my question about social justice on my first day at the school. I know that not many of these students were enrolled in the case study class. Despite their various negative experiences, Curtis, Odette, and Cristina had all experienced previous success somewhere along their trajectory. This causes me to continue to question whether an AP class, even if students are not excluded by GPA or test scores, is an effective way to resist the inequitable outcomes of science education in US schools. If we seek to create liberatory educational spaces, we have to constantly ask ourselves who is marginalized within those spaces. The evidence presented here indicates that for the students involved in the class, the curriculum and teaching practices were effective, thus illustrating some possibilities for justice-centered science pedagogy. But in order to create more of these possibilities for more students, we must always consider who may have been inadvertently excluded from these opportunities.

Chapter VIII: Revisiting the Catalyst Metaphor

In the opening chapter, I posed three questions to guide this practitioner research study which examined justice-centered science pedagogy in an Advanced Placement chemistry class at an urban neighborhood high school with working class African American and Latin@ students. Within this context, these questions focused on the (1) opportunities and challenges of developing and implementing socially transformative science curriculum, (2) the teaching practices, classroom structures, and routines that supported or impeded the students' development as transformative intellectuals (3) the responses and reflections of students on their experiences with justice-centered pedagogy through their classwork and as they looked back on the class as college students. In the tradition of the extended case method, this final chapter reconstructs the theoretical framework of justice-centered science pedagogy based on the themes that emerged from the study. This reconstructed theory is built not only upon the traditions of culturally relevant and critical pedagogies, but also from empirical evidence and concrete pedagogical examples, thus filling gaps in the science education literature that were identified in Chapter II. Through this reconstructed framework, I respond to the research questions to consider the implications for science teachers, teacher educators, and educational researchers, and also for La Lucha High School and myself.

Reconstructing Justice-Centered Science Pedagogy

Problem-posing versus injected relevance

Four curricular units served as the embedded cases of this single case study. Through an analysis of my planning documents, student work, and student reflections two different approaches to designing socially transformative science curriculum emerged, each with their own opportunities and challenges. The soil project (Chapter IV) and the aspirin unit (Chapter V) constitute “problem-posing [science] education” (Freire, 1970/2001) in that they were organized around socioscientific issues (SSI) that community members and students identify as important in their lives. Meanwhile the stoichiometry and equilibrium units typified an “injected relevance” approach in that they were organized around canonical chemistry concepts, but included regular examples of how these concepts could be applied to understand and solve problems in social contexts to which students could relate.

The challenges and opportunities of problem-posing science education.

The first challenge of a problem-posing approach in school science is selecting SSI that are relevant to the community and also provide a context within which to learn canonical content. While this study fell short of developing a systematic approach to this selection process, it demonstrated that any such process (whether formalized or not) requires substantial political clarity, community engagement, and content knowledge on the part of the teacher. In order to find issues that reside at the intersection of community concerns and canonical science understandings, teachers have to understand both of these components deeply in their own right, but they also have to be able to see how these concerns and understandings fit into the larger sociopolitical contexts from which they arise. Within the context of teaching working class students of color in US urban settings, this implies understanding the ways health and environmental problems are shaped by white supremacy, capitalism, and patriarchy. It also implies critiquing Western science as Eurocentric, androcentric and elitist while still recognizing the agency of organized groups of ordinary people to wield the power of Western science to intervene in health and environmental concerns they face (Brown & Mutegi, 2010; Corburn, 2005). Furthermore, it is important for justice-centered science teachers to view science as contested space and to seek to understand the many contributions of peoples from outside of dominant groups in order to act as science teacher *nepantler@s* (Aguilar-Valdez et al, 2013).

This study highlighted some of the opportunities created by problem-posing science education to engage students of various orientations towards science. Student learning, as analyzed using standards documents and socio-transformative constructivism (sTc, Rodriguez, 1998), demonstrated all three strands of culturally relevant pedagogy, in interconnected ways. In the soil project, students were able to contribute to their community's understanding of the impact of two local coal power plants. The students who presented at family science night bridged content knowledge and cultural competence to translate scientific jargon and methodology into a summary of their study that was meaningful to their parents and neighbors. Students also developed critical consciousness about environmental racism as they examined the distribution of heavy metal pollution across a city divided by race and class. At least two of the nine participants used their participation as a pathway into community involvement and parlayed their academic achievement into increased participation in the culture of science with the intention of changing it. Justice-centered science pedagogy asserts that urban youth are powerful producers of scientific knowledge and culture who are capable of serving their communities and transforming the world through collective action that is informed by scientific understandings.

In the aspirin unit, students relied on scholarly sources and experimental data to demonstrate academic achievement in writing that made interdisciplinary connections between ethnic studies, anthropology, and synthetic chemistry. They had the opportunity to synthesize and analyze a chemical that significantly impacted modern medicine while developing critical consciousness about the relationships between the development of pharmaceuticals, illegal street drugs, and the knowledge of indigenous peoples. Students constructed arguments that affirmed the cultural wisdom of their ancestors and in their homes and used this affirmation as motivation to learn the techniques of synthetic chemistry. Justice-centered science pedagogy asserts that rather than simply competing for class time or curricular space, the three criteria for culturally relevant pedagogy (academic achievement, critical consciousness, and cultural competence) work together to engage students of various orientations as they appreciate, appropriate, critique, and change Western science.

The challenges and opportunities of injected relevance.

The challenge of injected relevance lies in creating authentic activities that provide opportunities for students to reflect on the sociocultural relevance of the science they are learning and to consider whose voices matter as they apply canonical science skills to discrete examples of SSI (Rodriguez, 1998). Organizing curriculum around the concepts and skills that are highly valued within scientific disciplines may push teachers to dictate the social relevance of these concepts rather than spending time to explore their applicability with their students. Injecting relevance without providing explicit opportunities for students to produce or critique scientific knowledge in social contexts falls short of the ideals of justice-centered science pedagogy. This study suggests that injected relevance is likely to be experienced differently by students with different orientations towards science. “Science *nepantler@s*,” who seem to have internalized an sTc approach to learning, may engage in reflexivity and metacognition on their own (Rodriguez, 1998). Meanwhile “concerned scientists” may divorce canonical concepts from their embedded social contexts for efficiency. “Tourists in the culture of science” can easily become travel weary while dwelling for long stretches in canonical content that is not immersed in a relevant context. Nevertheless, an injected relevance approach provides a mechanism for developing and implementing socially transformative science curriculum in school contexts where time and resources are at a premium or accountability measures restrict curricular freedom.

Navigating the standards dilemma.

As the NGSS are adopted and implemented in several states that led their development and others who sign on, science teachers are going to be forced to grapple with performance expectations that are highly specific in the way that they link disciplinary core ideas, science and engineering practices, and cross-cutting concepts. These performance expectations will become especially problematic if (or when) they become attached to a high stakes standardized test. Meanwhile the proliferation of the PARCC exam, which assesses the CCSS, puts additional pressure on science teachers to address the CCSS for reading and writing in science and technical subjects. The analysis of curriculum and student artifacts in this study suggests that these two standards documents add complexity to both problem-posing and injected relevance approaches.

The specificity of the NGSS performance expectations creates additional challenges for science educators implementing a problem-posing approach. Real problems (SSI) facing the community are necessarily interdisciplinary in nature and thus are likely to draw on diverse sets of skills and conceptual understandings that can be difficult for a teacher to predict. If science educators are given the autonomy to "manipulate the [function and vision of the NGSS] to meet the needs of all learners," (Gallard, Mensah, & Pitts, 2014, p. 1) then problem-posing units can rely on unbraiding and re-braiding the three strands of a given performance expectation. Since the NGSS have been designed to encourage online interaction with the performance expectations, the website could embed a tool that allows teachers to reconfigure their own customized performance expectations. This sort of tool would allow teachers to select new combinations by choosing an applicable disciplinary core idea, science and engineering practice, and cross-cutting concept to fit the SSI that are relevant in their contexts. Unfortunately if the performance expectations of the NGSS as they are currently written become written in the stone of standardized tests, then they will constitute a significant barrier to problem-posing science education.

Because an injected relevance approach and the NGSS both place the conceptual understanding of Western science at the center of the science curriculum, they are better aligned than the NGSS and a problem-posing approach. Given this alignment, the NGSS may function to remind teachers “what matters” with respect to these canonical understandings as they inject relevance into their curriculum. Still my analysis in Chapter VI indicates that even with this alignment, the NGSS performance expectations are still unnecessarily narrow and specific. For example, the performance expectation that deals with chemical equilibrium assumes that maximizing the products of an equilibrium reaction is always the best outcome. This represents a view of chemistry that not only prioritizes canonical science knowledge, but also takes an industrial and capitalistic viewpoint where maximizing product (and thus profits) in the manufacture or synthesis of a chemical is always the ideal outcome. Another problem presented by the injected relevance approach, at least as constituted in the case study class, is that it is not likely to provide opportunities for the “range of writing” required by the CCSS (National Governors Association, 2010). Still considering the CCSS may prompt teachers to create more opportunities within injected relevance units for the components of sTc (authentic activity, reflexivity, metacognition, and dialogic conversations) through reading and writing activities that were lacking in my stoichiometry and equilibrium units (Rodriguez, 1998). Ultimately the way the NGSS are assessed and implemented will determine whether these standards documents provide focus and guidance versus simply creating limitations and distractions for teachers who wish to engage in justice-centered science pedagogy.

Context-specific practices, routines, and structures.

Justice-centered science pedagogy resists the notion of "best practices," instead acknowledging that all teaching is context-specific and what works in one setting may not in another. In the context of the case study class, two sets of practices, structures, and routines emerged as important to support the implementation of socially transformative science curricula. Their impact can be understood as providing our classroom with a sense of "critical hope" through its three components: audacious hope, Socratic hope, and material hope (Duncan-Andrade, 2009). The first set of classroom structures and routines consistently communicated a community-oriented purpose and approach to learning. By supporting a collaborative environment in the classroom and pushing back against individualistic "learn to earn" rhetoric, these routines and structures provided a sense of "audacious hope" for students who had been framed as failures or outcasts in other academic contexts. The second set of practices involved responding to the destabilization of the school community by pushing forward with the planned curriculum inside the classroom while being involved in the student and parent-led pushback against this destabilization outside of the classroom. Our class created a sense of "Socratic hope" by working in coordinated ways to fight unjust educational policies that threatened our school. The solidarity created by these efforts combined with the sense of community established by the first set of practices. This combination allowed us to focus on a challenging chemistry curriculum that was the source of "material hope" for many students as they prepared for the college application process.

The success of these teaching practices did not occur in isolation from the curriculum or the community. For example, it is important to note that the decision to move forward with the planned curriculum during the destabilization of the school was a decision that responded to this particular set of circumstances. Often during a time of crisis in the school community, it would be inappropriate and ineffective to continue with the curriculum as planned because such a decision would constitute ignoring students' realities and suffering (Duncan-Andrade, 2009). It is also important to acknowledge the alignment between counterhegemonic teaching practices and socially transformative curriculum. Our community-oriented purpose resonated with students, in part, because the soil project provided an example of what it means to learn for community service or transformation. In fact, the alignment of the struggle to re-stabilize the school coincided with the soil project in such a way as to inspire two participants (Cristina and Odette) to pursue chemistry majors in college. The relatively mundane teaching practices and classroom structures and routines were effective not because they were innovative, nor were they universal "best practices." Instead these practices were effective in creating a learning environment with values, beliefs, and goals that were consistent with those of other communities in which students participated. While the Ridgevale community and La Lucha High School certainly have a unique history of organizing for social justice, all dispossessed and disenfranchised communities resist their subjugation in some way. Justice-centered science pedagogy seeks to align the values, beliefs, and goals of science classrooms with the elements of the surrounding community that are engaged in struggles for social justice.

Implications for Science Education as a Catalyst for Change

In the second chapter, I extended the common metaphor "catalyst for change" by relying on the chemical function of a catalyst to conclude that if science education is to operate as a catalyst for social change, it must meet Ladson-Billings' (1995) three criteria for culturally relevant pedagogy. Science education as a catalyst for change must support academic achievement, cultural competence, and critical consciousness in order to facilitate social change under less harsh conditions than would otherwise be required. By providing an alternate pathway for social change, science education as a catalyst must also allow marginalized youth, as agents of change, to be more selective about the outcomes of their efforts than they otherwise would be.

In justice-centered science pedagogy, youth become these agents of change by developing into transformative intellectuals who build on community strengths and leverage scientific knowledge to struggle against injustice while also constructing new possibilities for just and sustainable communities (Gramsci, 1971/2014; Romero, 2014). Youth in the case study class took on the role of transformative intellectuals through the curriculum as they presented the findings of the soil project at family science night. But they also did so on their own as they organized and spoke out against the destabilization of the school. Participants' orientations towards science coupled with their continued participation in science and community provides evidence of their ongoing development as transformative intellectuals.

In Chapter II, I note that justice-centered pedagogy recognizes the need for the development of critical scientific literacy (Roth & Calabrese Barton, 2004) in marginalized communities, while it also asserts that we must provide access to the STEM pipeline for students from these communities who desire such pathways. Patterns that emerged from the data have added nuance to this assertion. I categorize participants' orientations towards science into three categories, which I have called (1) tourists in the culture of science, (2) concerned scientists, and (3) science *nepanter@s* (Aguilar-Valdez at al, 2013). Among the participants, "tourists in the culture of science" was the largest group, which is what I would expect among most groups of students whose science education took a justice-centered approach. Tourists in the culture of science are community members who value scientific literacy, but who are not interested in access to the STEM pipeline. Tourists appropriate Western science practices and concepts when they become useful in a community context.

Concerned scientists and science *nepantler@s* both seek access to the STEM pipeline. Concerned scientists pursue a career in science because they are fascinated by scientific concepts and experiments, but also for broadly defined humanistic reasons. Science *nepantler@s* thrive in the *nepantla* or spaces in between struggles for social justice, students' cultures, and the practice of Western science. In the short term, *nepantler@s* build bridges that tourists and concerned scientists cross as they move back and forth between these worlds. But in the long-term *nepantler@s* seek to change the culture of Western science and put their scientific knowledge to use, not for broad humanitarian reasons, but to solve specific problems in dispossessed and disenfranchised communities. Tourists in the culture of science and *nepantler@s* are both orientations that are consistent with transformative intellectualism. The difference between transformative intellectuals with these two orientations lies in whether science is central or peripheral to their understandings and interventions in the world. Concerned scientists are intellectuals, but whether they are "organic" (in that they continue to represent the class or community from which they come) or "transformative" (in that they use their status and knowledge as an intellectual to support struggles for social justice) depends on how exactly they navigate the problematic aspects of Western science culture.

The potential for youth to take on the role of transformative intellectuals can be understood in comments from the stakeholders that I interviewed. Ms. Epps, Ms. Juarez, and Ms. Avila all attributed their own involvement in the struggle to re-stabilize La Lucha High School that fall, at least in part, to the influence of the youth. They were inspired by the courage and conviction the young people showed in organizing the sit-in and walkout. But Ms. Juarez was also careful to emphasize that the role of the youth in achieving social justice is not just about resisting injustice. When I asked her to define social justice, Ms. Juarez responded:

> Number one – like the first thing that comes to me is fighting for things when we see injustices, right? But it's also about creating solutions and having autonomy having a voice. Right? Social justice is not just about fighting, right? It's like how do we continue to live to create? To have a community that is flourishing, to have a community that doesn't oppress others. Right? And how do we live it? It's not just about a march and a protest. It's also about how do we create? And find our own solutions.

Ms. Juarez highlights that transformative intellectuals must not only fight back against injustices, but also construct more just and sustainable communities. Justice-centered science pedagogy envisions students of the three orientations described above working together to address SSI that impact people differently across the lines of race, class and gender. Some of these SSI, for example global warming, food and water shortages, or epidemic disease may ultimately threaten the well-being and survival, not just of marginalized communities, but of all of humankind. In this way, the work of these transformative intellectuals is indeed necessary to "serve our communities and transform the world." For their part, tourists in the culture of science constitute the grassroots proliferation of critical scientific literacy. Concerned scientists engage in research that will inform technical solutions. And science *nepantler@s* bridge the worlds of science experts and grassroots struggles for social justice.

Implications for science teachers.

This study implies three implications for science teachers. First, justice-centered science pedagogy calls on teachers to engage deeply with the communities where we teach to continually develop our political, cultural, and content-area understandings. Secondly, problem-posing and injected relevance approaches can help us to navigate the tensions between developing curricula that is standards-based and relevant to students in their local contexts. And finally, science teachers must participate in the grassroots organization of teachers as a political force that is allied with youth, parents, and communities to transform larger injustices that inevitably reinforce the inequities within science education.

Be a teacher-student.

Science teachers must continue to develop our own community, classical, and critical knowledge (Gutstein, 2006, 2012) in order to develop curricula that are organized around SSI that matter in our specific local contexts. Examples from the curricula presented in Chapters IV - VI illustrate how this approach supported the development of my practice over several years. Developing an understanding of community knowledge in Ridgevale was critical to the development of both problem-posing and injected relevance units. Reaching out to COVER when I was first hired to teach at La Lucha allowed me to gradually build relationships that facilitated the soil project more than six years later. A youth volunteer at COVER also introduced me to the problems caused by uranium mining on Navajo lands, which led to several examples of injected relevance throughout the case study class. Regularly visiting and shopping at *botanicas* (stores in Mexican communities that sell herbs, tinctures, and teas) along the main commercial strip in the West Ridgevale community inspired me to read about the traditional medicinal knowledge of the indigenous peoples of Mexico (Ortiz de Montellano, 1975). Science teachers, especially those teaching in a community that is different from the one where they were raised, must spend significant amounts of time engaging with the communities where they teach. This includes ordinary forms of participation like grocery shopping or attending school athletic events. But it also includes becoming familiar with and humbly participating in grassroots political struggles, like the struggle to shut down the coal power plant in Ridgevale.

In order to design the curriculum described in this study, I also continued to learn classical chemistry, well beyond what I learned while earning a B.A. in chemistry. At the start of the soil project described in Chapter IV, I was unfamiliar with the inductively coupled plasma atomic emission-spectrometer (ICP-AES) that was used to analyze our soil samples for lead and mercury concentrations. My reflections on the aspirin unit in Chapter V indicate that I should allow students to develop their own procedures for extracting salicin from willow bark, because the procedure I found was not effective. Taking a justice-centered approach requires us to relearn and “re-cognize” (Freire, 1970/2001) the science content in which we have studied to be experts. The need for us to relearn our science disciplines is intensified by the fact that most science teachers have learned our discipline in reductionist isolation rather than in ways that are contextualized by SSI.

The narrow but demanding scope of college science curricula also means that developing political clarity requires science teachers to take seriously the study of history, sociology, and ethnic studies. Of particular importance in this study is the development of a critical analysis of white supremacy, capitalism, and patriarchy as totalizing hegemonic forces (Stovall, 2006a). For example, studying the work of indigenous and African American scholars helped me to understand the ways Western science benefitted from and contributed to colonization (Bang et al., 2013; Brown & Mutegi, 2010; Smith, 1999). Developing political clarity also requires us to move beyond studying towards praxis as we participate in grassroots political efforts. A group of politically active teachers with whom I was engaged introduced me to COVER. Participating in this organization, in turn, helped me to deepen my understandings of environmental racism to include issues like access to public transportation and green space as part of the struggle for environmental justice. These various forms of learning and engagement are likely to facilitate the identification of SSI that are relevant in local contexts. But science teachers should also consider more systematic explorations of student or community concerns and interests to identify generative themes (O'Cadiz et al., 1998). Some possibilities for this sort of work are included in the section below where I address implications for La Lucha High School below.

Use injected relevance and problem-posing approaches to navigate standards.

The findings of this study suggest that science teachers can use an injected relevance approach to encourage students to consider the sociocultural relevance of science content knowledge and to problematize its construction. This injected relevance should include explicit opportunities for students to discuss, debate, and write about the relationships between science content knowledge and the social contexts in which it is produced and applied. Science teachers should also consider how to push examples of injected relevance towards the development of problem-posing units. To illustrate this practice, I describe how two examples of injected relevance from Chapter VI could be reimagined as a problem problem-posing unit.

The issue of toxic uranium mining on Navajo lands was used as an example of injected relevance in the equilibrium unit analyzed in Chapter VI. In Chicago, much of our electricity was generated at nuclear power plants outside of the city. The Illinois Hispanic Chamber of Commerce is currently running radio advertisements in support of Illinois’ nuclear power plants. A problem-posing unit could investigate whether this organization is representing the best interest of Latin@s in Illinois by teaching the chemistry captured by NGSS HS-PS1-8: "Develop models to illustrate the changes in the composition of the nucleus of the atom and the energy released during the processes of fission, fusion, and radioactive decay" (NGSS Lead States, 2013).

Another example of injected relevance from the case study class that could become the basis for a problem-posing unit is the nixtamalization of corn. This process continues to be investigated by scientists and engineers (Ruiz-Gutiérrez et al., 2010) and could be the basis for a unit where students designed and optimized a nixtamalization process. For Mexican American students this unit would provide an opportunity to build on the contributions of their ancestors and investigate the politics of corn production post-NAFTA while partially addressing the chemistry captured by NGSS 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." (NGSS Lead States, 2013).

I hope that these examples, along with those described in Chapters IV and V, inspire teachers to design problem-posing units that address problems that are generative in their contexts. I must emphasize that this is the work of teachers, not professional curriculum developers. Justice-centered science pedagogy rejects corporate curricula that have been designed for "generic" students. This does not mean that textbooks cannot be used as reference materials, but they should not be used in isolation or without providing students with tools to critique the perspective of the authors. Justice-centered science pedagogy also rejects the notion that teachers in other contexts could simply import the soil study, the aspirin unit, or other examples of problem-posing curricula. Curriculum development, from a justice-centered perspective, is a local process that teachers undertake with their students and communities.

The examples of possible problem-posing units that I propose above continue to highlight the tensions between this approach and the NGSS. In order to truly study nuclear power and uranium mining as SSI, we would have to examine the biological and environmental impacts of radiation and how these impacts are unevenly distributed across lines of race and class. It is not enough to model the physical processes that are the focus of the relevant performance expectation. Likewise a unit on nixtamalization would seek to optimize a process that is both chemical and biological as the alkaline solution under investigation would be used to modify corn. This is a different focus than the one captured by the NGSS performance expectation, which highlights maximizing chemical products at equilibrium. If teachers are given the flexibility to design our own performance expectations from the three strands of the NGSS, these tensions will be minimized and teachers will be supported to develop problem-posing curriculum. However if we are held accountable to these performance expectations as they are written, we will have a hard time navigating these tensions.

Get organized.

This brings me to the final implication for teachers that I will discuss: the imperative for us to be an organized political force working to build sustainable and just local schools and communities. We must work in organized ways with communities and against corporate school reform and other neoliberal and racist projects (Kumashiro, 2012; Lipman, 2011; Sokolower, 2013). Our work cannot be only in the classroom. If our teaching is about social justice, then we must “practice what we teach” (Picower, 2012). The case study class was interrupted for seven days by the first teachers strike in Chicago in 25 years. While I did not have the space to discuss it at length here, the strike contributed to our levels of stress, but also to the energy that emerged from the struggle to re-stabilize La Lucha High School that fall. Justice-centered pedagogy will not be possible in the long term if teachers do not lead the struggle to transform our public schools. We must unequivocally reject schools' historical roles as reproducers of social inequality (which will only be re-entrenched by corporate school reform) while we work with communities to reimagine schools that are constructed in their self-determined best interests and in their images.

Implications for teacher educators.

Corporate school reform efforts are also pushing further into teacher education. These reforms include the expansion of high stakes assessment profiteering and the creation of teacher education institutions affiliated with charter school networks rather than colleges of education (Au, 2013; Stitzlein & West, 2014). In this context, teacher educators must acknowledge that new approaches to teacher education are required while also being clear that this innovation should not be associated with taking short cuts, privatization, or attacks on unions or the intellectual work of teaching. In order for more new science teachers to take a justice-centered approach, the findings of this study imply three important considerations for teacher educators: (1) build networks for new teachers that provide increased access to community knowledge and scientific expertise, (2) include sociopolitical considerations in science teacher education curricula, and (3) increase the representation of African American and Latin@ teachers.

Educate community science teachers.

In my second year as a teacher at a predominately African American magnet high school, I planned a unit that was very similar to the soil project that is the topic of Chapter IV. This unit was framed in terms of the problem of childhood lead poisoning caused by deteriorating lead paint and automobile exhaust (rather than focusing on coal power plants). Students volunteered on Saturday morning and afterschool. With the help of a chemistry professor from a local university (neither of those mentioned in this study), I designed a digestion process that we could conduct in our school labs. But when it came time to analyze the digested samples, I was unable to coordinate the use of university instruments with this professor. The soil project documented in Chapter IV was possible because it took place within the context of a larger study conducted by a community college professor and because we were given access to university labs and equipment by a sympathetic faculty member at a different institution. Furthermore, COVER organizers put me in touch with these university scientists. My original attempt at executing this type of project fell short because at the time, I did not have this type of network that included community organizations and university scientists. As teacher educators, we need to think about how we can push beyond the traditional triad of university supervisor, cooperating teacher, and pre-service teacher to educate “community (science) teachers” (Murrell, 2001). Building networks that include university scientists will provide new teachers with access to content expertise and equipment that is often required to truly address SSI. Building networks that include grassroots community organizations will help new teachers identify and understand SSI in their local contexts.

Science teacher education is political.

The second implication of this study for teacher education is the explicit inclusion of sociopolitical issues in science teacher education. My analysis of the soil study and aspirin unit highlights the importance of my own political clarity in designing those units. In Chapter I, I trace my understandings of educational inequity and environmental racism to my childhood experiences as part of a politicized family in a marginalized neighborhood. Science teacher education programs must push teacher candidates to consider the sociopolitical context of their work, especially considering that many science teachers do not enter our programs with these sorts of experiences.

The need for more African American and Latin@ science teachers.

The final implication of this study for teacher education is the importance of recruiting more African American and Latin@ science teachers. Chapters IV - VI document how a critical understanding of race and racism was central to the development of both problem-posing and injected relevance units. Chapter VII documents teaching practices that were informed by the values and beliefs of students' communities. Within this context, justice-centered science pedagogy values "the voices and narrative of people of color as sources of critique of the dominant social order which purposely devalues them" (Ladson-Billings, 1998 as cited in Stovall, 2006a, p. 256). Given my own white privilege and conflicted Latino identity discussed in chapter I, I do not include my own voice here. I write and speak in solidarity and as an ally. These voices and narratives of people of color must be present in science classrooms as embodied by teachers, not just students. In a district whose students are 40% African American and 46% Latin@, the Chicago Public Schools have been executing a systematic purge of African American teachers through school closings and other misguided policies. From the time I began teaching in the Chicago Public Schools in 2003 until the time I resigned in 2014, the percentage of African American teachers in CPS fell from 37.7% to 23.4% (Smith, 2013). This drop, which actually began several years earlier, represents a loss of more than 3,100 Black teachers. Meanwhile over the same timeframe, the percentage of Latin@ teachers grew slightly from 12.8% to 15.1%. This growth did not nearly keep pace with the increase in Latin@ student population which went from 36.8 – 45.6% during that time (Smith, 2013). This local data is indicative of national trends (Epstein, 2005; Irizarry & Donaldson, 2012). If these troubling trends are not reversed, the goals of justice-centered science pedagogy are likely to be warped and co-opted due to the absence of African American and Latin@ voices and narratives among science teachers.

Implications for educational researchers

The goal of this study was to examine possibilities for secondary school science that is capable of responding to inequity in science education as one piece of larger systematic oppression. The results of this study imply at least three related lines of research to further our understandings in this realm: (1) additional case studies and cross-case analysis of justice-centered science pedagogy, (2) research focusing on the education of justice-centered science teachers, (3) Youth Participatory Action Research (YPAR) in the natural sciences.

Justice-centered science pedagogy: case studies, cross-case analysis, teacher education

I undertook this study for my dissertation research in large part because I could not find any examples in the existing literature that examined the effective practice of an experienced secondary science teacher enacting culturally relevant or critical pedagogy. I hope that this study provides lessons learned and context-specific possibilities for my fellow secondary science teachers. However, in order to truly understand science education as a response to larger issues of oppression, we need more such case studies in a wide variety of contexts. These various case studies may take the form of teacher research or could involve partnerships between university researchers and science teachers. Cochran-Smith and Lytle (2009) lament that the teacher research movement has not had much success in aggregating findings across studies. To that point, cross-case analyses (Yin, 2009) of science teachers enacting justice-centered science pedagogy in different contexts would contribute a great deal to our understanding of how to address the seemingly intractable problem of inequity in science education. A second, but closely related, line of research would examine the preparation of justice-centered science teachers within the teacher education context described in the previous section.

YPAR in the natural sciences.

When I describe the soil project to researchers, they often label it Youth Participatory Action Research or YPAR (Cammarota & Fine, 2008). YPAR blurs the lines between research and pedagogy as it has been applied in numerous US urban contexts as strategy to address educational inequity (Cammarota & Romero, 2009; Duncan-Andrade & Morrell, 2008; Morrell, 2004). The soil project shares many of the features of YPAR in that young people investigated a real problem in their community (coal power plant pollution) and then chose to take some action (family science night) upon which they later reflected. But, I hesitate to apply this label to the soil project because the youth did not participate in the initial formulation of the question and the design of the study.

Most YPAR is associated with social science. YPAR that applies the tools, instruments, and methods of the natural sciences is difficult for various reasons. Most of these reasons somehow boil down to the cost and sophistication of the equipment required to conduct authentic scientific investigations in “real world” settings. For example, COVER and the US EPA recently discovered alarming levels of soil contamination involving polyaromatic hydrocarbons (PAHs) in the soil of a brownfield in the Ridgevale neighborhood. Several colleagues and I tried to support youth at La Lucha High School who wanted to undertake their own investigation of PAH contamination in the neighborhood. But even with university contacts, we were not able to access instruments that could measure PAHs. While the soil project may not constitute YPAR itself, the success documented in Chapter IV suggests that YPAR that applies the tools of the natural sciences to urban environmental and health problems is possible. This line of research is promising in terms of its ability to build the capacity of communities to solve the problems caused by environmental racism, but it could also contribute much to the literature in urban science education. Pursuing this line of research will require collaboration between youth, university science educators, university scientists, secondary science teachers, and local community organizations.

Implications for La Lucha.

While a catalyst remains unchanged at the end of the chemical reaction that it facilitates, the same cannot be said for science education. I point out this limit of the "catalyst for social change" metaphor because one of the primary goals of undertaking this project was to inform the work of my colleagues in the science department at La Lucha High School. My goal in this short section is to make suggestions for the continued improvement and reinvention of science education at La Lucha. Even within the same physical context, reinvention is required as time passes and people and circumstances change. My suggestions here emerge from the findings of this study, but are also influenced by my tacit understandings of the La Lucha science curriculum as a whole. In some ways, the case study class is representative of our approach as a department. But obviously my idiosyncrasies and those of the particular group of students and the AP chemistry curriculum also shaped the case study class.

My recommendations to the science department at La Lucha High School include the continued development and redevelopment of problem-posing units. To that end, I recommend that some sort of data-collection process be integrated into the spring semester of each core class in the science department. This process could include surveys or class-wide focus groups whose purpose is to identify the SSI that are generative for the students. The data from these surveys could be used to redesign or make changes to units in students' current class and also to plan for the class they will enter in the following year.

My second recommendation is to build in more opportunities during science electives (like AP courses) for students to reflect, in writing on the sociocultural relevance of the curriculum and on their own metacognitive processes. In other words, injected relevance should be informed to a greater extent by sTc (Rodriguez, 1998) in order to constitute what might eb called "infused relevance." While science *nepantler@s* (Aguilar-Valdez et al, 2013) are likely to engage in this sort of reflection on their own, building formal reflections into the curriculum will engage more students in an sTc approach to learning. My final recommendation is to provide more rich opportunities for students to engage in thinking about the contributions of their ancestors to Western science or their own empirical understandings of the world. One powerful way to accomplish this might be to design interdisciplinary projects with the English or social studies departments that problematize and investigate the relationships between the meteoric rise of Western science and technology with the colonization of Africa and the Americas. I submit these three recommendations with humility and in admiration of the exceptional ways in which my colleagues at La Lucha High School are already enacting justice-centered science pedagogy.

Personal implications.

The conclusion of this study leaves me in a strange place personally and professionally. I am inspired to jump back into the work this project analyzes. I have now had a two-year hiatus from being a high school science teacher. I miss it dearly and I know there is important work to be done. I am confident that the lessons that I have learned from this study will make me a better high school science teacher. I am inspired to improve my approach to injected relevance while I also see possibilities for problem-posing units to emerge from SSI that were previously taught in this way. Science *nepantleras* Odette and Cristina have provided me with other ideas for problem-posing units during this project. Odette completed a case study for a college course on the pesticides that were at issue during the 1965 United Farmworkers strike that I imagine as a problem-posing unit that begins by problematizing the origins of the produce we eat. Cristina conducted an undergraduate research project to examine the scientific funds of knowledge of Ridgevale community members and COVER volunteers. Her findings, which include the use of medicinal teas and strategies for the reuse of disposable household items, could also be the basis for problem-posing units in high school science classes.

As eager as I am to return to the secondary science classroom, I also take seriously the implications for educational researchers and teacher educators outlined above. Working as a teacher educator while completing this project was synergistic. The lessons I learned from analyzing my own teaching through practitioner research became activities in my chemistry teaching methods course and my practitioner research course. Sharing this research project with other educational researchers inspired new directions for this sort of work and underscored the importance for more justice-centered research in science education. In the coming years, I hope to find ways to follow in the footsteps of my mentors who have blurred the lines of theory and practice and who have carved out spaces for teacher educators and educational researchers to stay grounded as community teachers. Regardless of the particular role I take, this project has reinforced for me the idea that justice-centered science pedagogy can and should play an important role in ongoing struggles to eradicate oppression and build communities that are more just and sustainable.

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APPENDICES

APPENDIX A: IRB APPROVAL LETTER

UNIVERSITY OF ILLINOIS
AT CHICAGO

Office for the Protection of Research Subjects (OPRS)
Office of the Vice Chancellor for Research (MC 672)
203 Administrative Office Building
1737 West Polk Street
Chicago, Illinois 60612-7227

Approval Notice

Initial Review (Response To Modifications)

September 23, 2014

Daniel Morales-Doyle

Curriculum and Instruction

3620 W 64th Place

M/C 147

Chicago, IL 60612

Phone: (773) 655-6044

RE: **Protocol # 2014-0816**

“Justice-Centered Science Pedagogy”

Dear Mr. Morales-Doyle:

Your Initial Review application (Response To Modifications) was reviewed and approved by the Expedited review process on September 22, 2014. You may now begin your research.

Please note the following information about your approved research protocol:

APPENDIX A (continued)

Protocol Approval Period: September 22, 2014 - September 22, 2015

Approved Subject Enrollment #: 50

Additional Determinations for Research Involving Minors: These determinations have not been made for this study since it has not been approved for enrollment of minors.

Performance Sites: UIC, "La Lucha" High School

Sponsor: None

Research Protocol:

a) Justice-Centered Science Pedagogy; Version 2; 09/17/2014

Recruitment Material:

a) Recruitment Script; Version 2; 09/17/2014

Informed Consents:

a) Consent Document; Version 2; 09/17/2014
b) A waiver of informed consent has been granted for recruitment purposes only under 45 CFR 46.116(d) (minimal risk; release of contact information for recruitment purposes; signed consent will be obtained at enrollment)

Your research meets the criteria for expedited review as defined in 45 CFR 46.110(b)(1) under the following specific categories:
(5) Research involving materials (data, documents, records, or specimens) that have been collected, or will be collected solely for non-research purposes (such as medical treatment or diagnosis),

(6) Collection of data from voice, video, digital, or image recordings made for research purposes., (7) Research on individual or group characteristics or behavior (including but not limited to research on perception, cognition, motivation, identity, language, communication, cultural beliefs or practices and social behavior) or research employing survey, interview, oral history, focus group, program evaluation, human factors evaluation, or quality assurance methodologies.

Please note the Review History of this submission:

Receipt Date	Submission Type	Review Process	Review Date	Review Action
08/25/2014	Initial Review	Expedited	08/28/2014	Modifications Required
09/17/2014	Response To Modifications	Expedited	09/22/2014	Approved

APPENDIX A (continued)

Please remember to:

→ Use your **research protocol number** (2014-0816) on any documents or correspondence with the IRB concerning your research protocol.
→ Review and comply with all requirements on the enclosure,

"UIC Investigator Responsibilities, Protection of Human Research Subjects"
(http://tigger.uic.edu/depts/ovcr/research/protocolreview/irb/policies/0924.pdf)

Please note that the UIC IRB has the prerogative and authority to ask further questions, seek additional information, require further modifications, or monitor the conduct of your research and the consent process.

Please be aware that if the scope of work in the grant/project changes, the protocol must be amended and approved by the UIC IRB before the initiation of the change.

We wish you the best as you conduct your research. If you have any questions or need further help, please contact OPRS at (312) 996-1711 or me at (312) 996-2014. Please send any correspondence about this protocol to OPRS at 203 AOB, M/C 672.

Sincerely,

Sandra Costello

Assistant Director, IRB # 2

Office for the Protection of Research Subjects

Enclosures:

1. **UIC Investigator Responsibilities, Protection of Human Research Subjects**
2. **Informed Consent Document:**
    a) Consent Document; Version 2; 09/17/2014
3. **Recruiting Material:**
    a) Recruitment Script; Version 2; 09/17/2014

cc: Kimberly Lawless, Curriculum and Instruction, M/C 147
David Stovall (faculty advisor), Educational Policy Studies, M/C 14

APPENDIX B: INTERVIEW PROTOCOLS

Interview Questions – Alumni

Initial Statement: This interview is intended to capture your understandings about this class and related issues like science education, community involvement, and social justice. This is not an evaluation of me as a good or bad teacher, but an investigation into the practices that I used and how they align with these other concerns. This study will help me become a better teacher and may also help other science teachers improve their practice, so please be as honest as possible. You may choose not to answer any particular question and you may choose to end this interview at any time.

Strengths, Needs, Concerns, Aspirations (Personal, Family, Community):

Tell me a little bit about who you are.

What do you see as some of your major strengths as a person?

> Where did you develop these strengths?
>
> Who helped you develop them?

Tell me about your family and community.

> What do you see as some of the major strengths of your family or community?
>
> Do you think you'll live in this community after college?
>
> What do you see as some of the major problems or obstacles you and your family or community face?
>
> What are some of the solutions to overcoming those obstacles?
>
> Describe any ways that you feel like you have been involved in your community in terms of building its strengths or dealing with its problems.

What do you imagine yourself doing in ten years?

What do you expect to be happening with this community in ten years?

What do you see as your role in shaping the future of this community?

How would you describe yourself as a student? As a science student?

The course:

Why did you decide to take AP chemistry? What did you hope to get out of the course?

What other AP or advanced courses did you take? Can you talk about the experience of taking AP courses? Why was it important to you to take AP courses, in general?

APPENDIX B (continued)

How well do you think the course met your needs and supported you in accomplishing your goals?

> What aspects of the course were helpful in terms of supporting you as you worked towards those goals?

How would you evaluate the balance we tried to strike between social justice curriculum and preparing for college chemistry and the AP exam?

How well did the course align with or compare to your other courses in and out of the science department?

What are your most memorable experiences from the course?

[Present curriculum map, including major topics & assessments, and student work to aid in memory]

What work are you most proud of from the course? What about this particular assignment or project made you proud?

What assignment, unit, or topic caused you the most difficulty during the course? Why?

What assignment or project do you feel like you learned the most from in this course?

> What did you learn?
>
> What about the project facilitated your learning?

What kind of knowledge, skills, or habits do you feel like you concretely developed or improved in this class?

What types of activities or assignments in general were:

- most engaging or fascinating?
- most useful/instructive?
- least useful/instructive?
- most frustrating, irrelevant, or boring?

Views on science and science education:

What do you think is the role of science in our society?

How would you describe the culture of science and scientists?

Do you consider yourself to be part of the culture of science?

Do you see places where your home/community/youth culture and the culture of science conflict or align?

APPENDIX B (continued)

How do you think this class dealt with these alignments or conflicts?

Why do you think the state or city boards of education require you to study science in school?

How do you feel about these reasons for studying science? How well do they align with your reasons for studying science?

Social Justice:

What does social justice mean to you?

What does environmental justice mean to you?

What does social justice have to do with education?

What does social justice have to do with science education?

Post-course community involvement, academics, and science experiences

In what ways, if at all, are you involved in your community or in social justice organizations now? Why are you involved? Or why aren't you involved in these sorts of things?

In what ways, if at all, do you use science knowledge or skills in your everyday life, now that you have graduated from high school?

Are you currently enrolled in college? If so, where?

Why did you choose that school?

What is your major?

Why did you choose that major?

What science classes, if any, have you taken since AP chemistry (in HS or college)?

What have been your experiences in science courses since taking AP chemistry?

Have you felt prepared?

How did this course compare with subsequent science courses?

What career path do you intend to follow?

What influenced you to choose that career path?

What do you hope to accomplish in your career?

Questions for those alumni who were involved with the soil study outside of class:

APPENDIX B (continued)

Why did you choose to collect soil samples outside of school, attend meetings related to the project, and and organize and present at our family science night?

Describe your experience collecting soil samples in the community.

Describe your experience interacting with the chemists from the university.

Describe your experience conducting an experiment in a university laboratory.

Describe your experience presenting the results of your study to the community.

What impact, if any, did these experiences have on you?

> What impact do you think this study had on you as a student, in terms of your academic path or success?
>
> Do you think this study and your presentation of the results made an impact in the community? If so, how? If not, why not?

What did you learn about chemistry during this project?

What did you learn about your community during this project?

What did you learn about social justice during this project?

APPENDIX B (continued)

Interview Questions – Community Members

Strengths, Needs, Concerns, Aspirations (Personal, Family, Community):

Tell me about your community.

> What do you see as some of the major strengths of your community?
>
> What do you see as some of the major problems or obstacles you and your family or community face?
>
> What do you think are some of the solutions to overcoming those obstacles?
>
> Describe some of the ways that you have been involved in your community in terms of building its strengths or dealing with its problems.
>
> How would you describe your involvement with my AP chemistry class? Why did you choose to get involved?

What do you expect to be happening with this community in ten years?

What do you see as your role in shaping the future of this community?

Views on science and science education:

What do you think is the role of science in our society?

What role do you think science plays in your community?

Why do you think the state or city boards of education require students to study science in school? How do you feel about these reasons?

What do you hope that youth in your community get out of their science classes? What kind of science education do you think should be available to young people in your community?

> To what extent do you see this class as aligned with this vision or not? Explain what you mean.

Were you able to attend the family science night where the students presented their results?

For community members who attended science night:

Why did you choose to attend this event?

Describe what you saw, did, and heard at this event.

Do you think this event made an impact on the community? If so, how? If not, why not?

APPENDIX B (continued)

Social Justice:

What does social justice mean to you?

What does environmental justice mean to you?

What does social justice have to do with education?

What does social justice have to do with science education?

APPENDIX B (continued)

Interview Questions – Parents

Strengths, Needs, Concerns, Aspirations (Personal, Family, Community):

Tell me a little bit about your son/daughter.

What are some of her/his strengths?

What are your hopes and dreams for her/him?

How has her/his schooling or education supported or hindered those hopes/dreams?

Tell me about your community.

What do you see as some of the major strengths of your community?

What do you see as some of the major problems or obstacles your community faces?

What are some of the solutions to overcoming those obstacles?

What should be the role of schools or education in the community?

Describe how you have been involved in your community in terms of building its strengths or dealing with its problems.

What do you expect to be happening with this community in ten years?

What do you see as your role in shaping the future of this community?

Views on science and science education:

What do you think is the role of science in our society?

What do you think is the role of science in your community?

Why do you think the state or city boards of education require students to study science in school?

What do you hope that your son/daughter gets out of their science classes?

Do you think he or she accomplished these goals?

What kind of science education do you think should be available to your children and other young people in your community?

To what extent do you think this class met these expectations? Explain what you mean.

For parents whose children participated in the soil project outside of class:

Did your son/daughter tell you about the soil study s/he participated in?

APPENDIX B (continued)

If so, what did s/he say?

What impact, if any, do you think this project had on her/him?

Were you able to attend the family science night where the students presented their results?

If so, what did you think about that night and your son/daughter's involvement?

Do you think it made an impact on the community? If so, how? If not, why not?

Do you think it made an impact on your son/daughter? If so, how? If not, why not?

Social Justice:

What does social justice mean to you?

What does social justice have to do with education?

What does social justice have to do with science education?

APPENDIX C: PAIRS OF LETTERS TO THE GOVERNOR

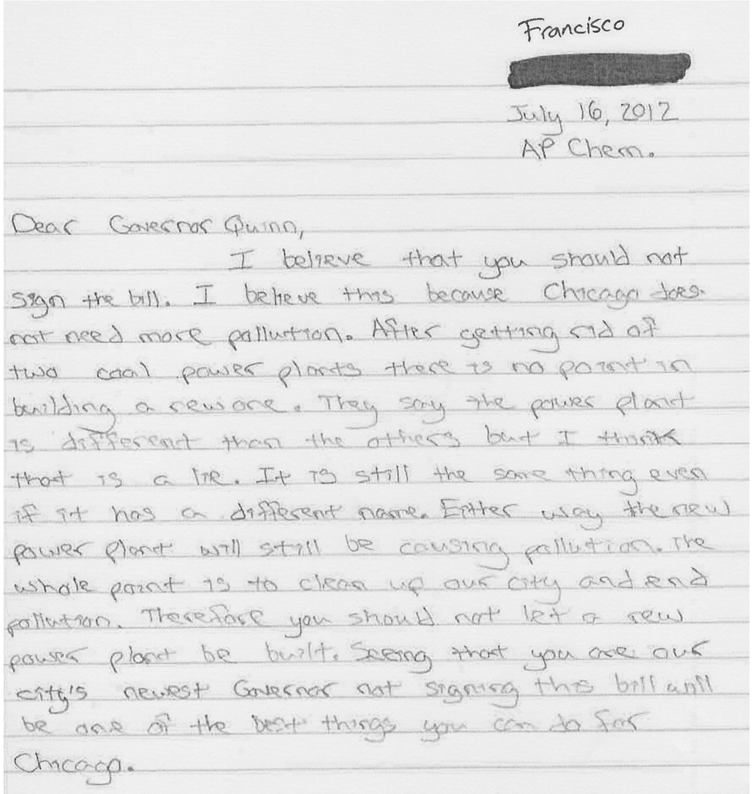
Cristina's initial letter to Governor Quinn (dated 7/16/12, transcribed because scanned copy of original was illegible):

"My name is Cristina Castro and I'm a senior at La Lucha High School. I live on the ____ block of ____, not too far from the _____ Power Plant. I used to go to school on _____ and _____ and everyday on my way home, I would see the dark smoke clouds [the plant] would expel everyday. I'm against coal power plants and believe that this new one to be build on 2015 is a bad idea. The bill that has been presented to you should be vetoed because the community has the right to cleaner air. I believe it is unjust to allow this to happen because the community doesn't deserve it.

Cristina's second letter to Governor Quinn: (dated 7/19/12, transcribed because scanned copy of original was illegible):

"For the past fifteen years, I've been living in the ___ block of ____, which is not too far from the ____ power plant. I, along with my community, are first witnesses to what the coal power plant has done. I am aware that there are plans to build a coal gasification plant on the southeast side of Chicago. The coal power plant here on the West Side provided jobs for people that didn't live within the community. Even though the southeast side needs jobs, will the jobs be provided to people in the community that need jobs? This plant should be reconsidered because coal is impure. If the emissions are buried underground, they can leak and get into the water supply which can make the water acidic and that's not good for consumption. I ask you as a witness to please veto the bill."

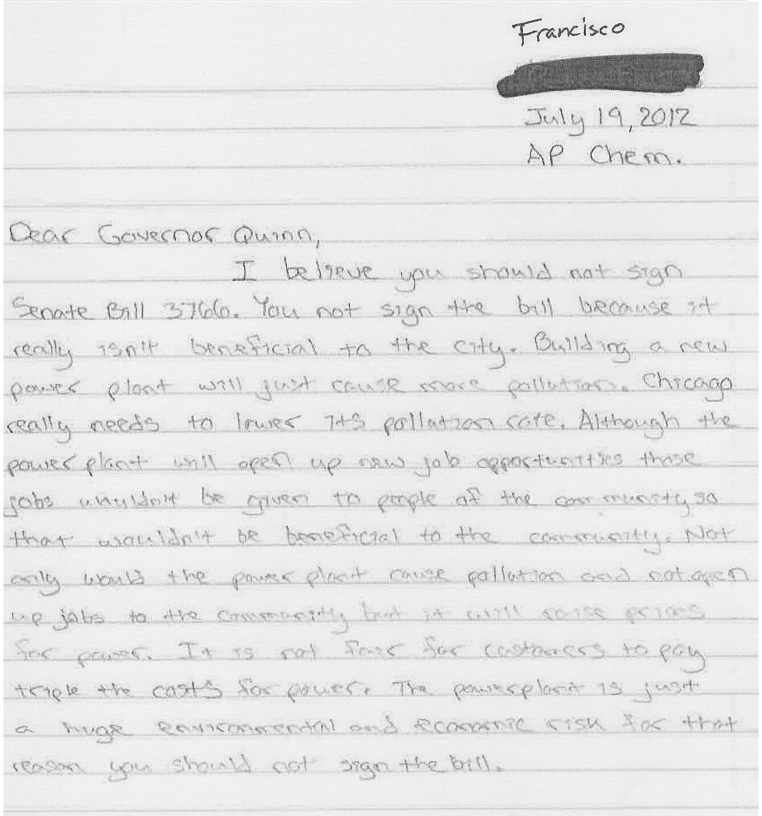
APPENDIX C (continued)



Francisco
[redacted]
July 16, 2012
AP Chem.

Dear Governor Quinn,

I believe that you should not sign the bill. I believe this because Chicago does not need more pollution. After getting rid of two coal power plants there is no point in building a new one. They say the power plant is different than the others but I think that is a lie. It is still the same thing even if it has a different name. Either way the new power plant will still be causing pollution. The whole point is to clean up our city and end pollution. Therefore you should not let a new power plant be built. Seeing that you are our city's newest Governor not signing this bill will be one of the best things you can do for Chicago.

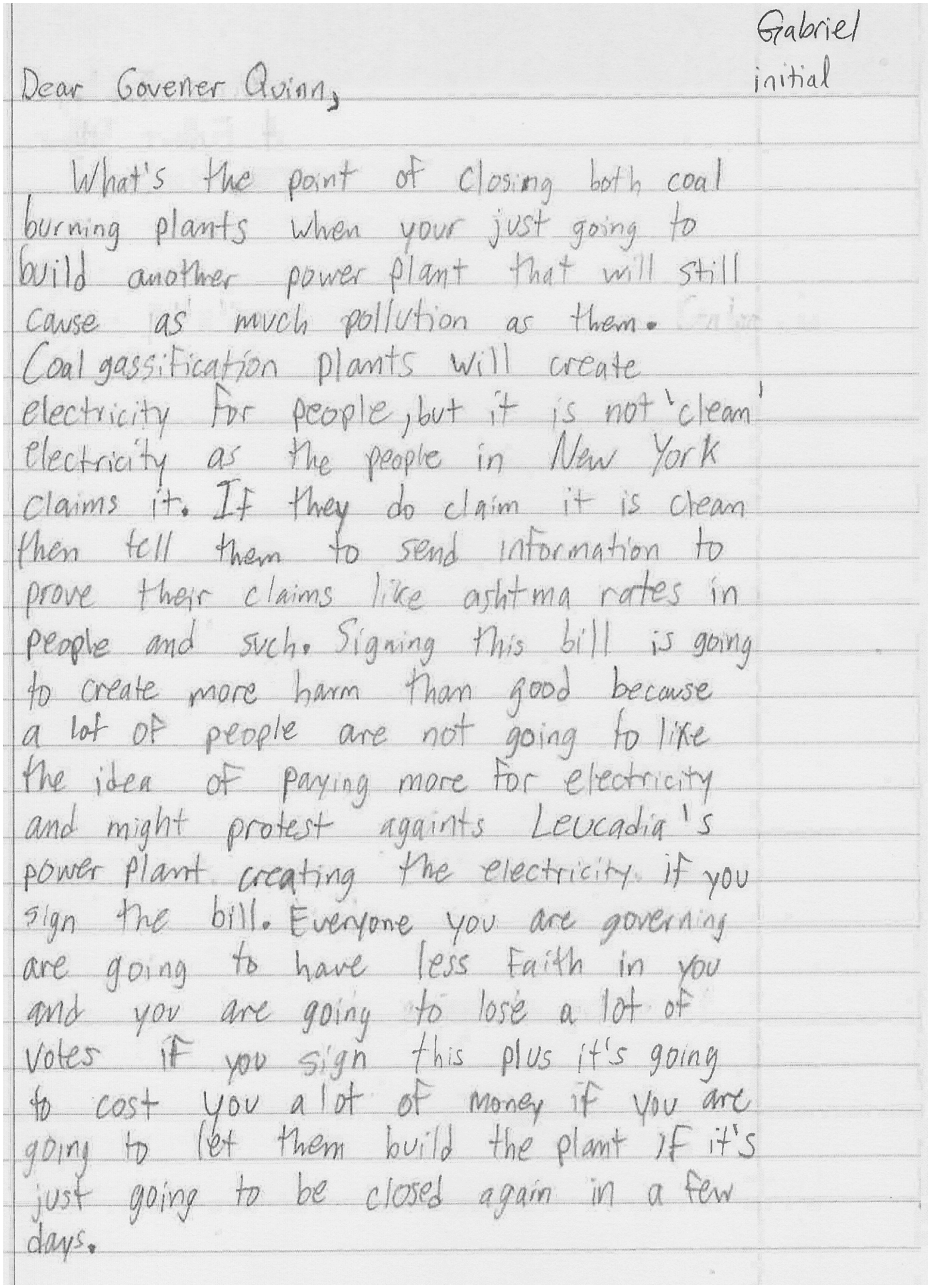


Francisco
[redacted]
July 19, 2012
AP Chem.

Dear Governor Quinn,

I believe you should not sign Senate Bill 3766. You not sign the bill because it really isn't beneficial to the city. Building a new power plant will just cause more pollution. Chicago really needs to lower its pollution rate. Although the power plant will open up new job opportunities those jobs wouldn't be given to people of the community so that wouldn't be beneficial to the community. Not only would the power plant cause pollution and not open up jobs to the community but it will raise prices for power. It is not fair for costumers to pay triple the costs for power. The powerplant is just a huge environmental and economic risk for that reason you should not sign the bill.

APPENDIX C (continued)

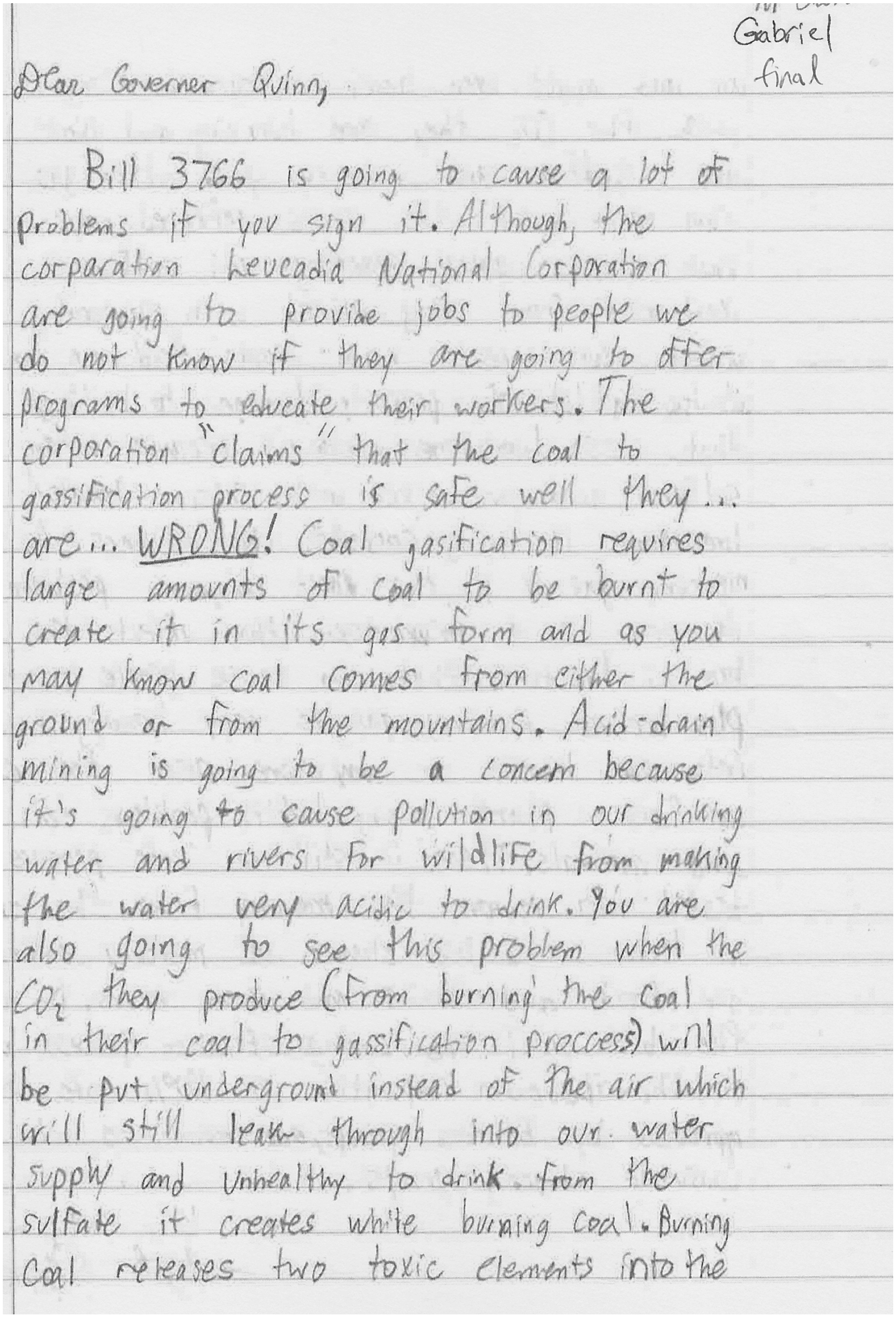


Gabriel
initial

Dear Govener Quinn,

What's the point of closing both coal burning plants when your just going to build another power plant that will still cause as much pollution as them. Coal gassification plants will create electricity for people, but it is not 'clean' electricity as the people in New York claims it. If they do claim it is clean then tell them to send information to prove their claims like ashtma rates in people and such. Signing this bill is going to create more harm than good because a lot of people are not going to like the idea of paying more for electricity and might protest againts Leucadia's power plant creating the electricity if you sign the bill. Everyone you are governing are going to have less Faith in you and you are going to lose a lot of votes if you sign this plus it's going to cost you a lot of money if you are going to let them build the plant if it's just going to be closed again in a few days.

APPENDIX C (continued)



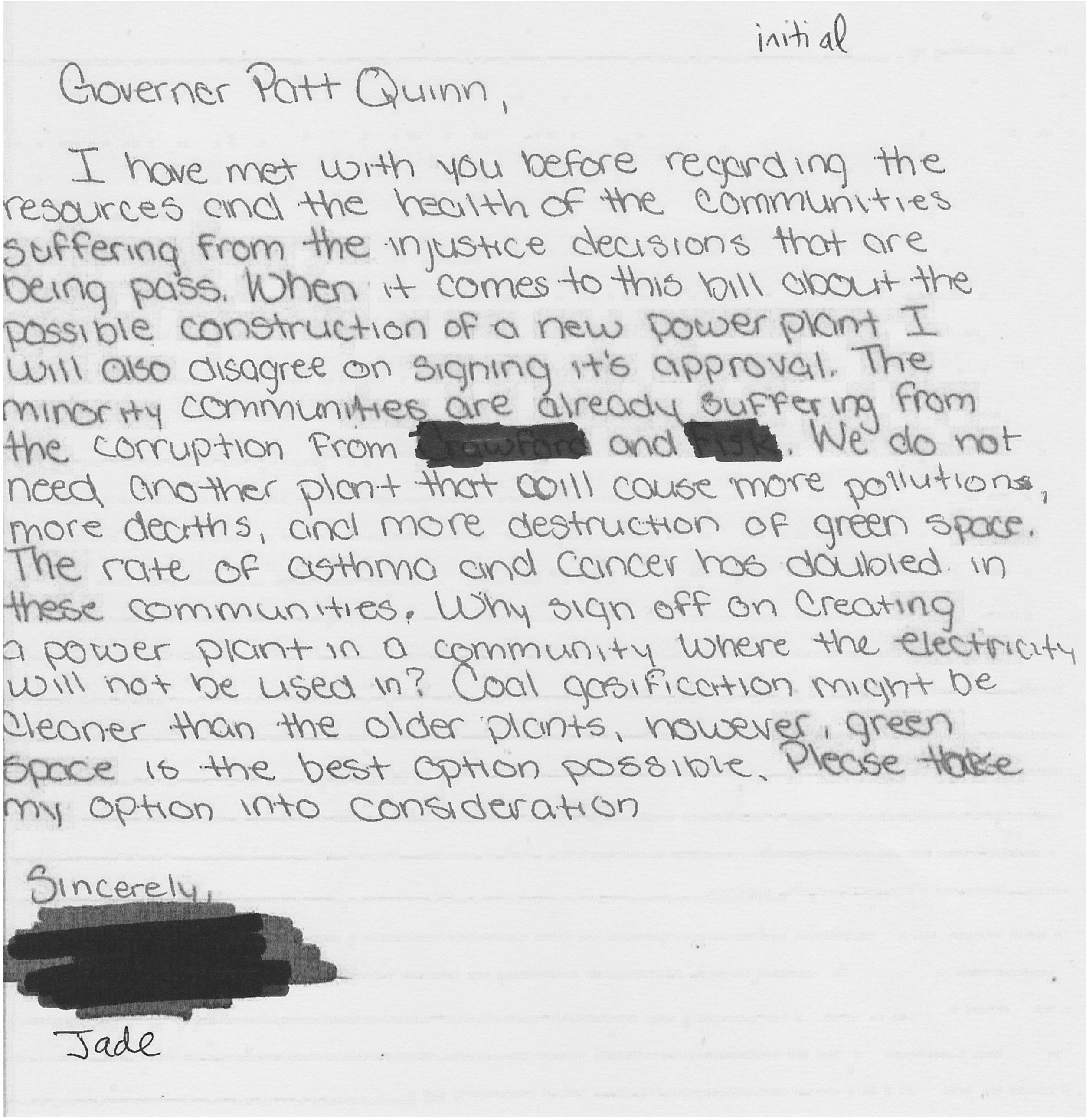
Gabriel
final

Dear Governer Quinn,

Bill 3766 is going to cause a lot of problems if you sign it. Although, the corparation Leucadia National Corporation are going to provide jobs to people we do not know if they are going to offer programs to educate their workers. The corporation "claims" that the coal to gassification process is safe well they... are... <u>WRONG</u>! Coal gasification requires large amounts of coal to be burnt to create it in its gas form and as you may know coal comes from either the ground or from the mountains. Acid-drain mining is going to be a concern because it's going to cause pollution in our drinking water and rivers for wildlife from making the water very acidic to drink. You are also going to see this problem when the CO_2 they produce (from burning the coal in their coal to gassification proccess) will be put underground instead of the air which will still leak through into our water supply and unhealthy to drink. from the sulfate it creates white burning coal. Burning Coal releases two toxic elements into the

APPENDIX C (continued)

Jade (initial)



initial

Governer Patt Quinn,

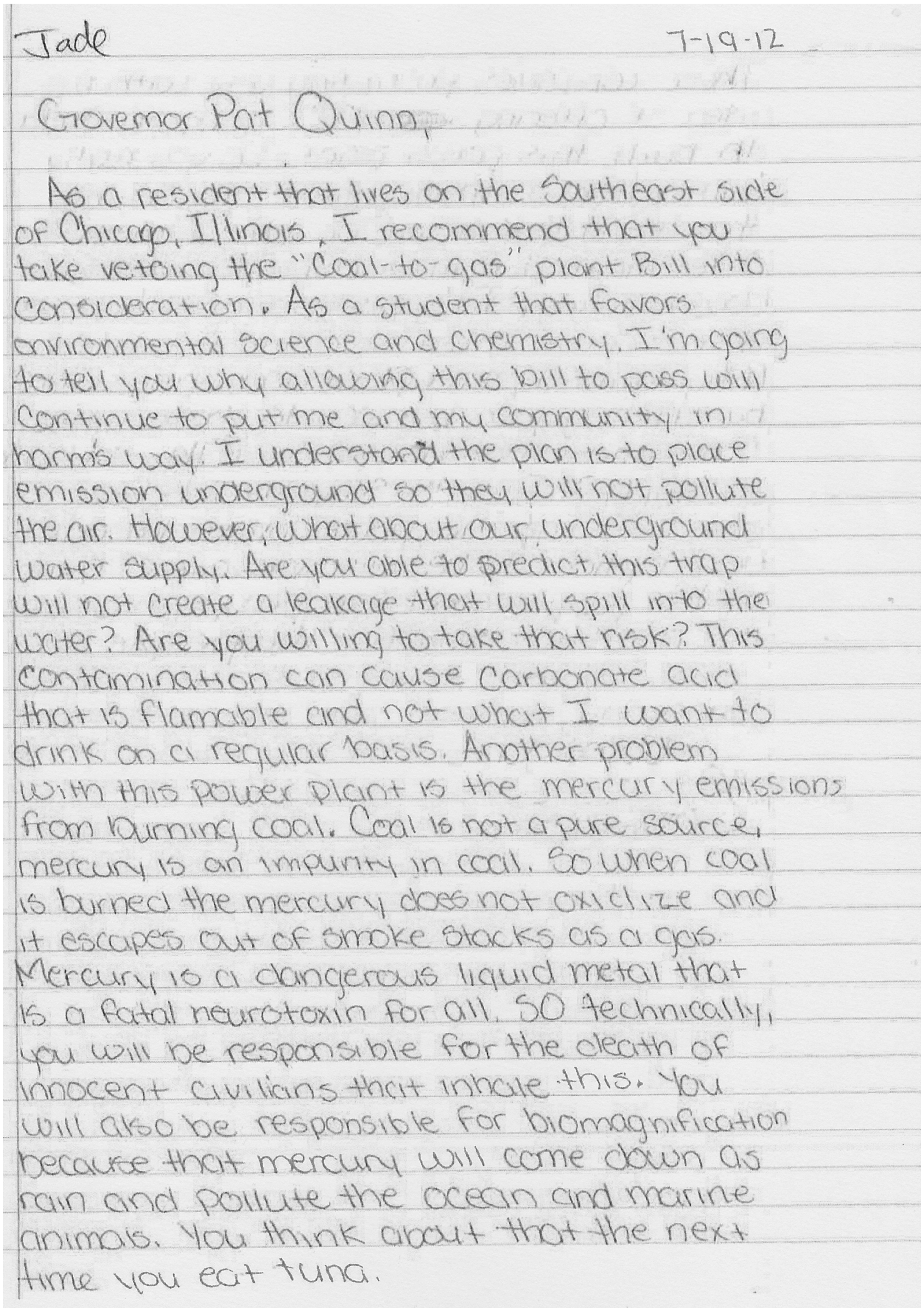
I have met with you before regarding the resources and the health of the communities suffering from the injustice decisions that are being pass. When it comes to this bill about the possible construction of a new power plant I will also disagree on signing it's approval. The minority communities are already suffering from the corruption from [redacted] and [redacted]. We do not need another plant that will cause more pollutions, more deaths, and more destruction of green space. The rate of asthma and cancer has doubled in these communities. Why sign off on Creating a power plant in a community where the electricity will not be used in? Coal gasification might be cleaner than the older plants, however, green space is the best option possible. Please take my option into consideration

Sincerely,

[redacted]

Jade

APPENDIX C (continued)



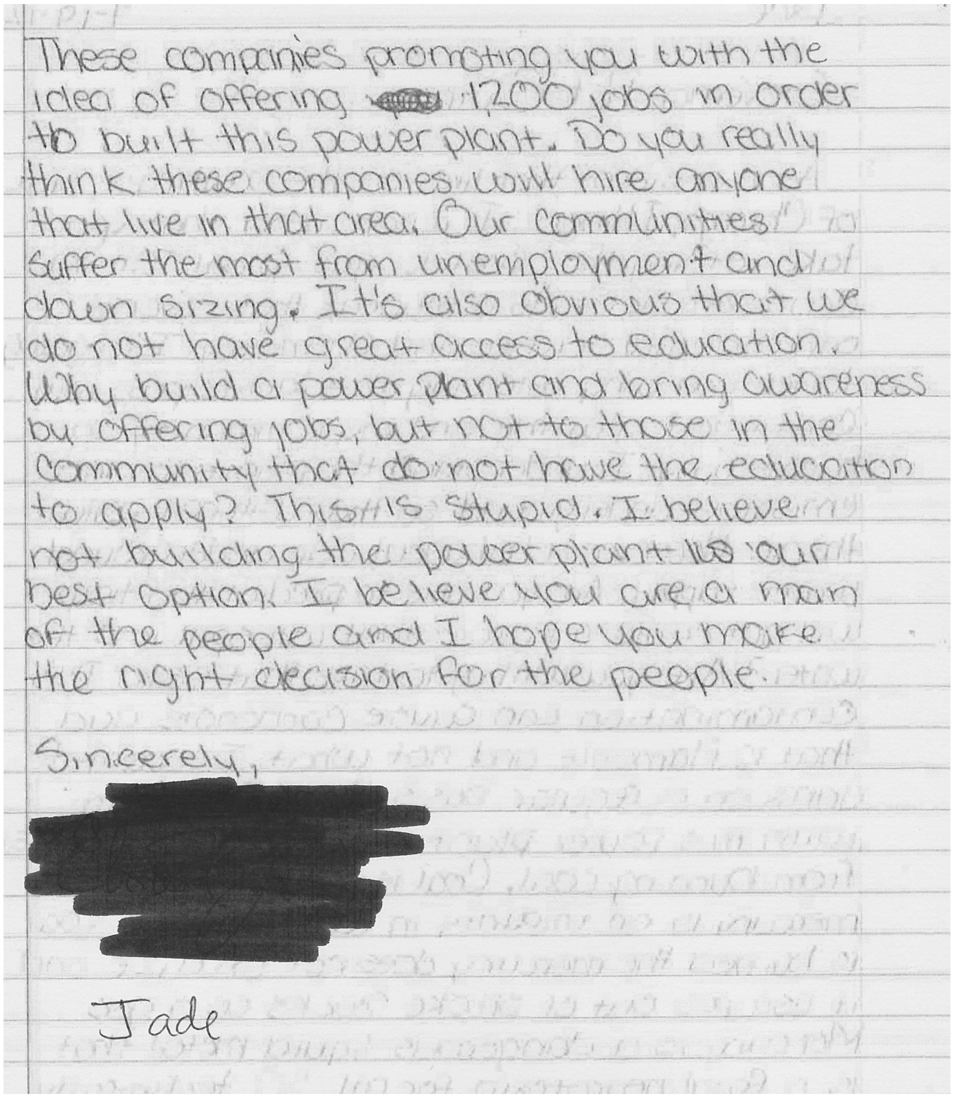
Jade 7-19-12

Grovemor Pat Quinn,

As a resident that lives on the Southeast side of Chicago, Illinois, I recommend that you take vetoing the "Coal-to-gas" plant Bill into consideration. As a student that favors environmental science and chemistry, I'm going to tell you why allowing this bill to pass will continue to put me and my community in harm's way. I understand the plan is to place emission underground so they will not pollute the air. However, what about our underground water supply. Are you able to predict this trap will not create a leakage that will spill into the water? Are you willing to take that risk? This contamination can cause carbonate acid that is flamable and not what I want to drink on a regular basis. Another problem with this power plant is the mercury emissions from burning coal. Coal is not a pure source, mercury is an impurity in coal. So when coal is burned the mercury does not oxidize and it escapes out of smoke stacks as a gas. Mercury is a dangerous liquid metal that is a fatal neurotoxin for all. SO technically, you will be responsible for the death of innocent civilians that inhale this. You will also be responsible for biomagnification because that mercury will come down as rain and pollute the ocean and marine animals. You think about that the next time you eat tuna.

APPENDIX C (continued)

Jade (final, continued)



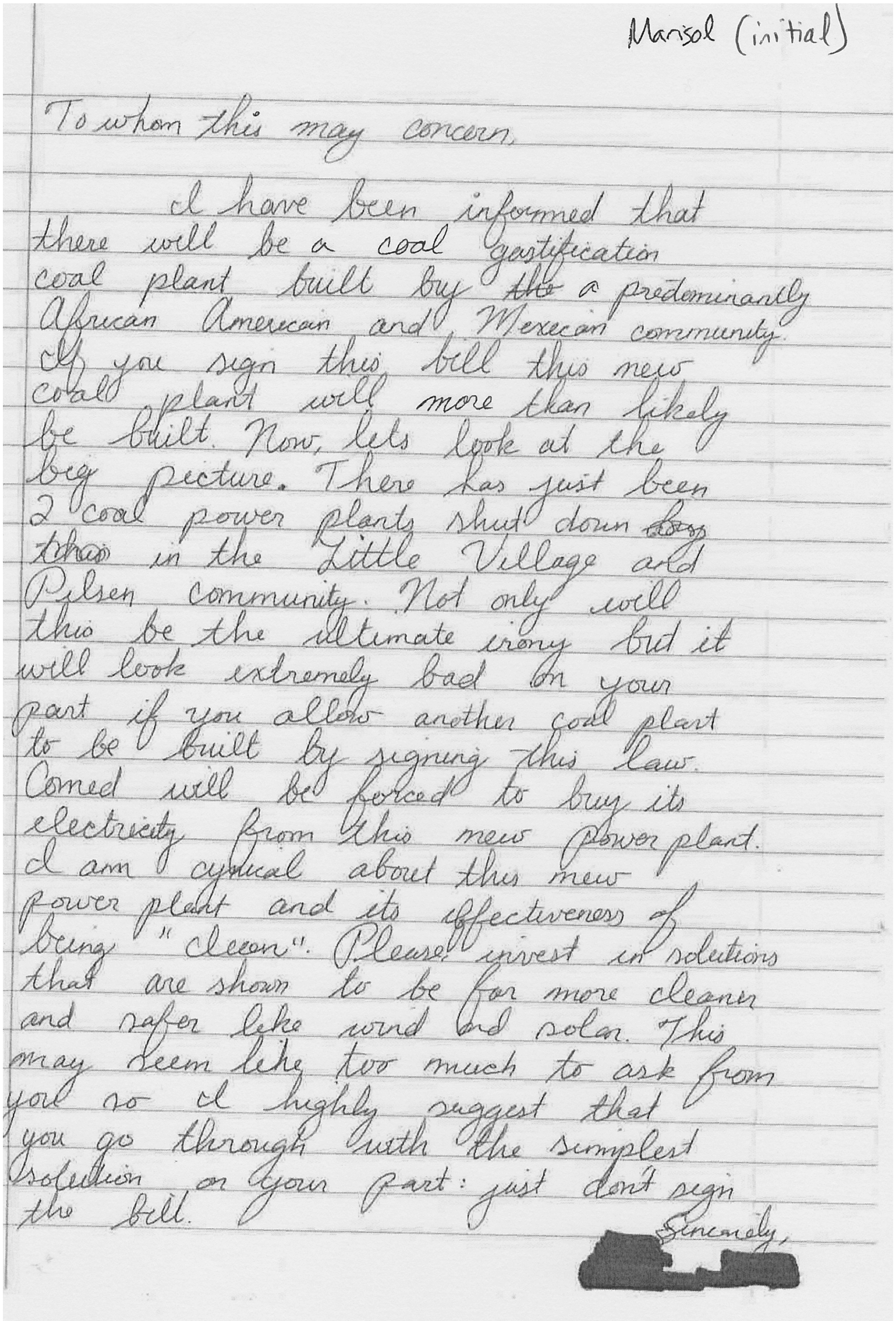
These companies promoting you with the idea of offering 1,200 jobs in order to built this power plant. Do you really think these companies will hire anyone that live in that area. Our communities" suffer the most from unemployment and down sizing. It's also obvious that we do not have great access to education. Why build a power plant and bring awareness by offering jobs, but not to those in the community that do not have the education to apply? This is stupid. I believe not building the power plant is our best option. I believe you are a man of the people and I hope you make the right decision for the people.

Sincerely,

[redacted]

Jade

APPENDIX C (continued)



Marisol (initial)

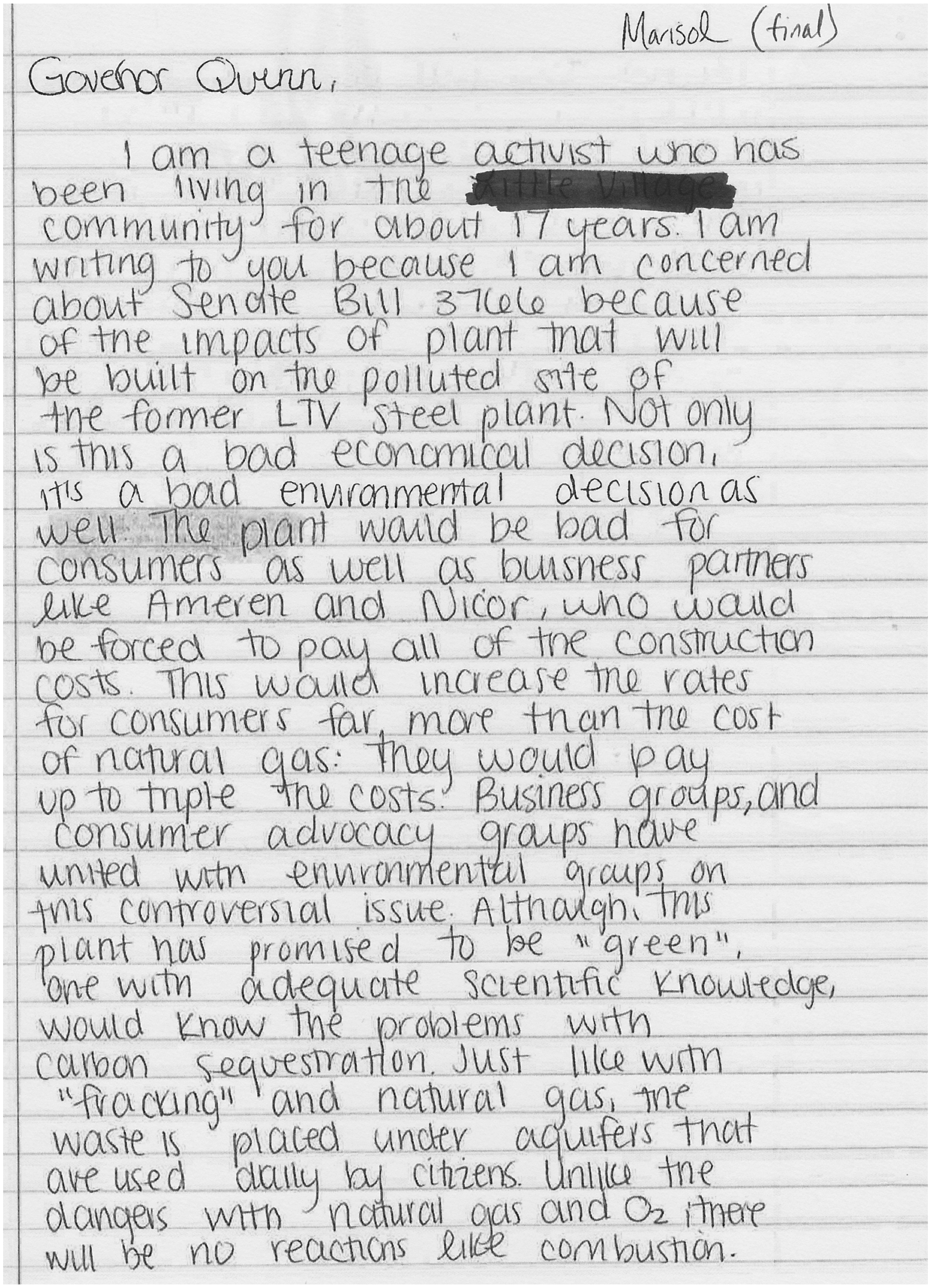
To whom this may concern,

I have been informed that there will be a coal gastification coal plant built by ~~the~~ a predominantly African Amerecan and Mexecan community. If you sign this bill this new coal plant will more than likely be built. Now, lets look at the big picture. There has just been 2 coal power plants shut down ~~by~~ ~~thas~~ in the Little Village and Pilsen community. Not only will this be the ultimate irony but it will look extremely bad on your part if you allow another coal plant to be built by signing this law. Comed will be forced to buy its electricity from this new power plant. I am cynical about this new power plant and its effectiveness of being "clean". Please invest in solutions that are shown to be for more cleaner and safer like wind and solar. This may seem like too much to ask from you so I highly suggest that you go through with the simplest solution on your part: just don't sign the bill.

Sincerely,

[redacted]

APPENDIX C (continued)



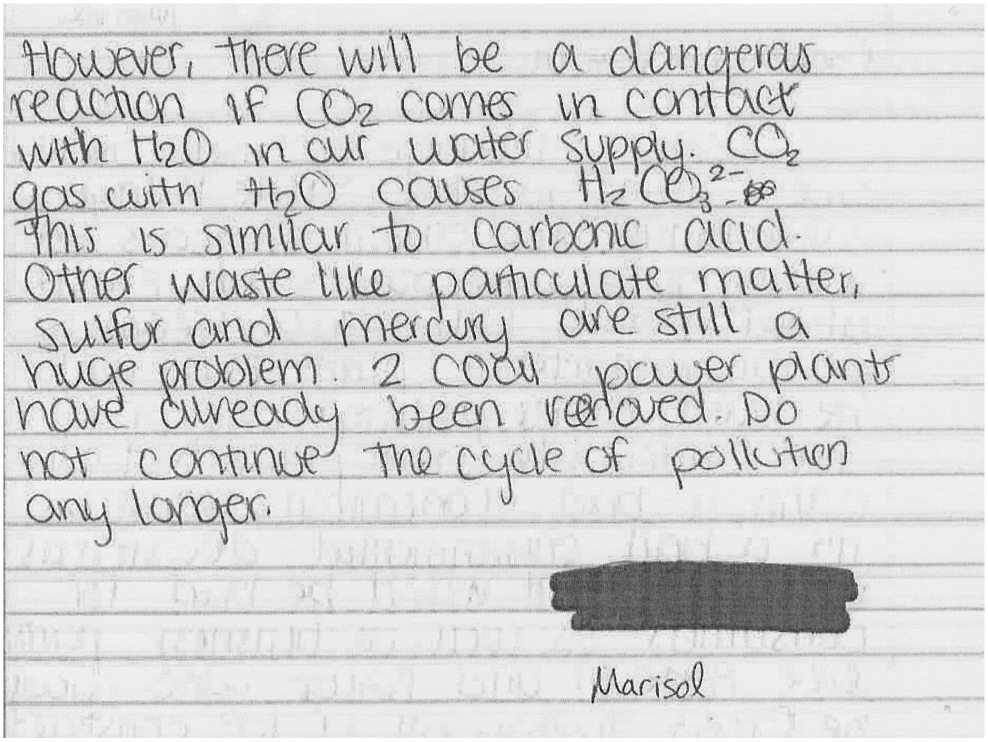
Marisol (final)

Govenor Quinn,

I am a teenage activist who has been living in the [redacted] community for about 17 years. I am writing to you because I am concerned about Senate Bill 3766 because of the impacts of plant that will be built on the polluted site of the former LTV steel plant. Not only is this a bad economical decision, it's a bad environmental decision as well. The plant would be bad for consumers as well as busness partners like Ameren and Nicor, who would be forced to pay all of the construction costs. This would increase the rates for consumers far more than the cost of natural gas: They would pay up to triple the costs. Business groups, and consumer advocacy groups have united with environmental groups on this controversial issue. Although, this plant has promised to be "green", one with adequate scientific knowledge, would know the problems with carbon sequestration. Just like with "fracking" and natural gas, the waste is placed under aquifers that are used daily by citizens. Unlike the dangers with natural gas and O_2, there will be no reactions like combustion.

APPENDIX C (continued)

Marisol (final, continued)

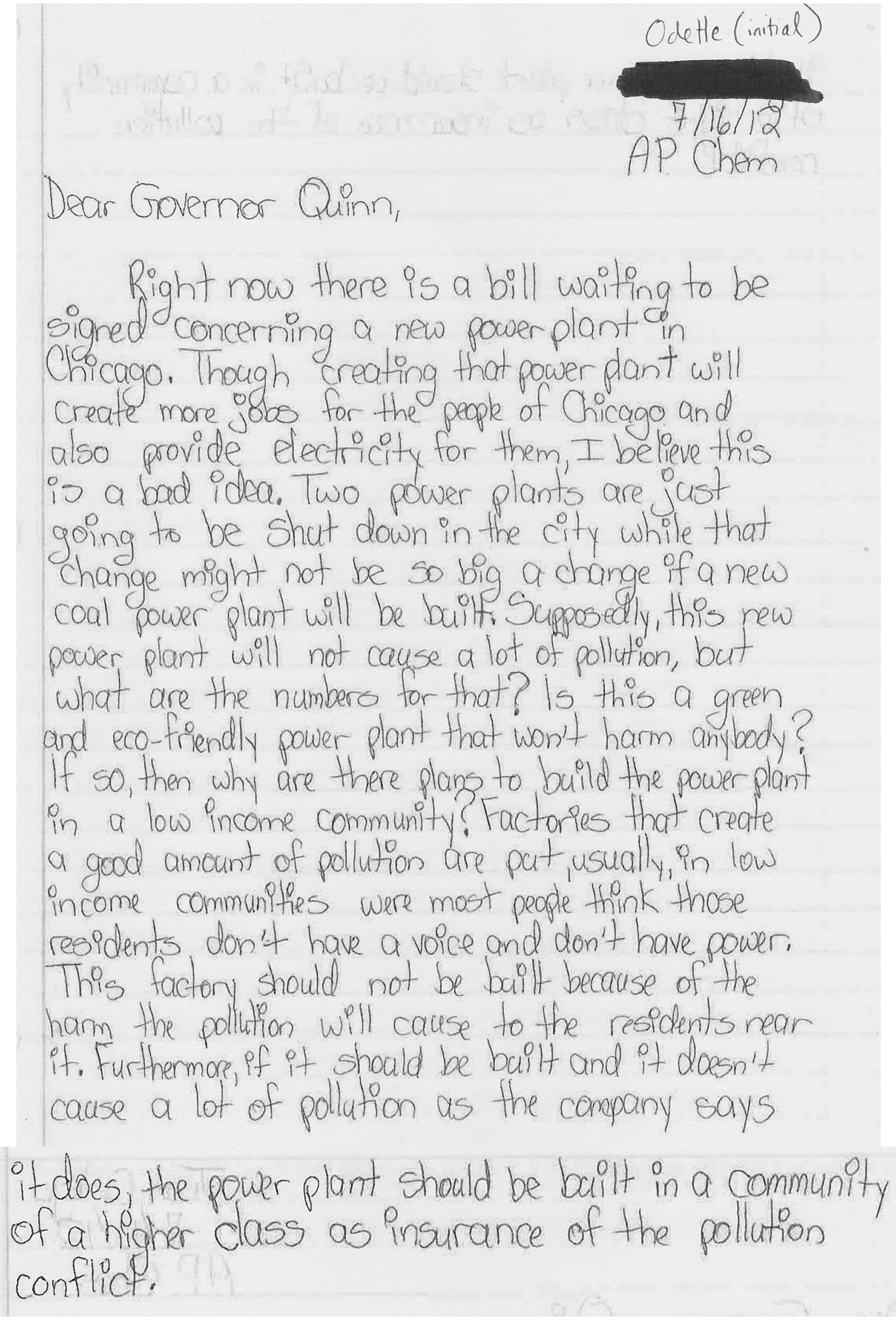


However, there will be a dangerous reaction if CO_2 comes in contact with H_2O in our water supply. CO_2 gas with H_2O causes $H_2CO_3^{2-}$ This is similar to carbonic acid. Other waste like particulate matter, sulfur and mercury are still a huge problem. 2 coal power plants have already been removed. Do not continue the cycle of pollution any longer.

[redacted]

Marisol

APPENDIX C (continued)



Odette (initial)

[redacted]

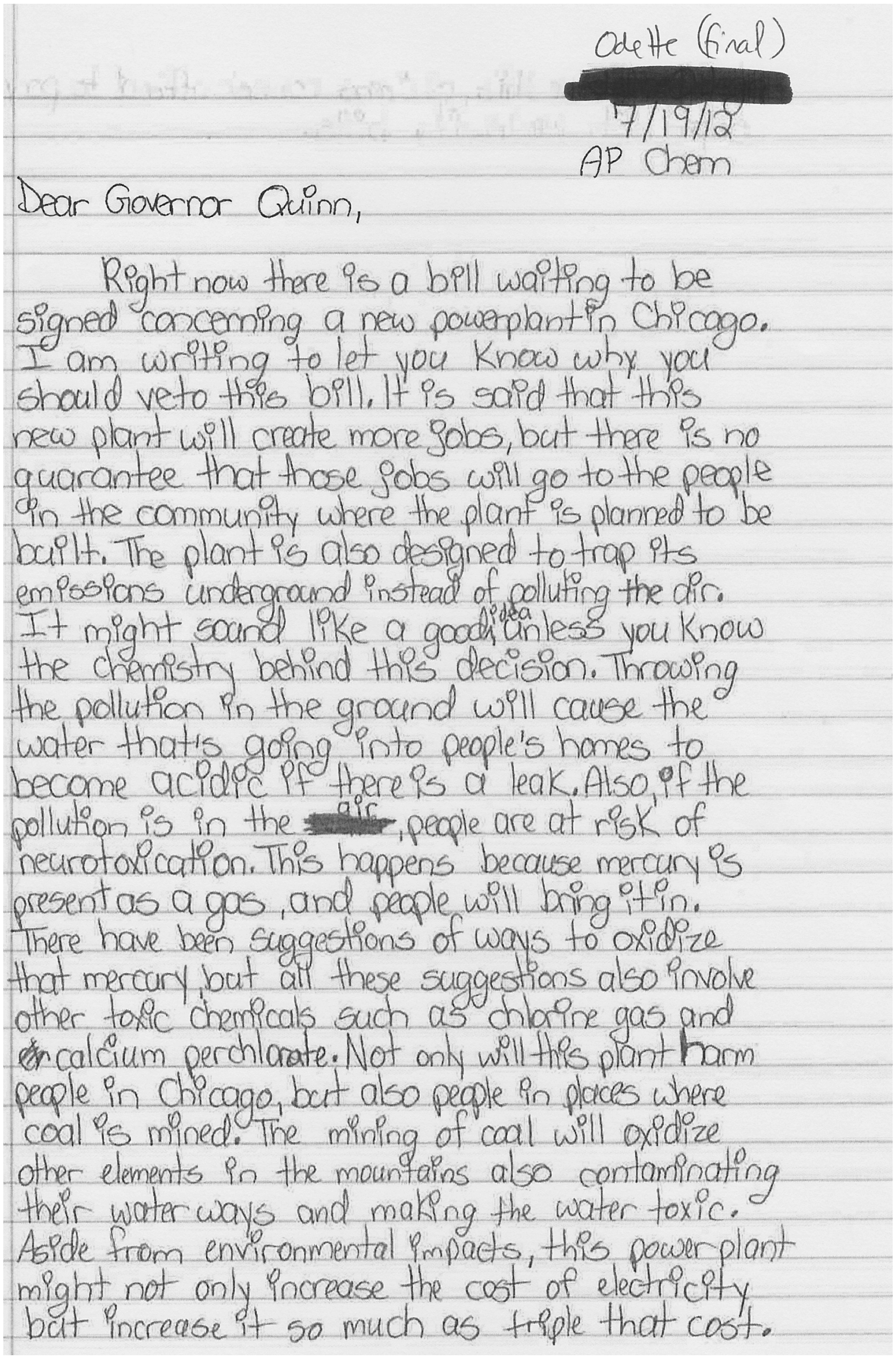
7/16/12

AP Chem

Dear Governor Quinn,

Right now there is a bill waiting to be signed concerning a new power plant in Chicago. Though creating that power plant will create more jobs for the people of Chicago and also provide electricity for them, I believe this is a bad idea. Two power plants are just going to be shut down in the city while that change might not be so big a change if a new coal power plant will be built. Supposedly, this new power plant will not cause a lot of pollution, but what are the numbers for that? Is this a green and eco-friendly power plant that won't harm anybody? If so, then why are there plans to build the power plant in a low income community? Factories that create a good amount of pollution are put, usually, in low income communities were most people think those residents don't have a voice and don't have power. This factory should not be built because of the harm the pollution will cause to the residents near it. Furthermore, if it should be built and it doesn't cause a lot of pollution as the company says it does, the power plant should be built in a community of a higher class as insurance of the pollution conflict.

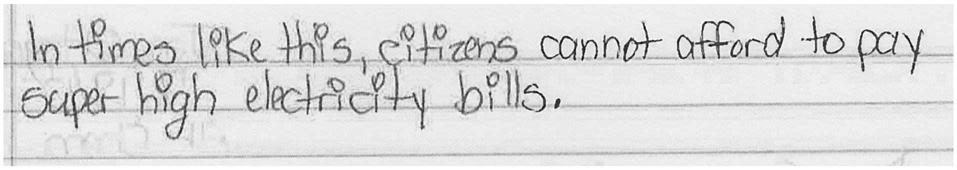
APPENDIX C (continued)



Odette (final)
[redacted]
7/19/12
AP Chem

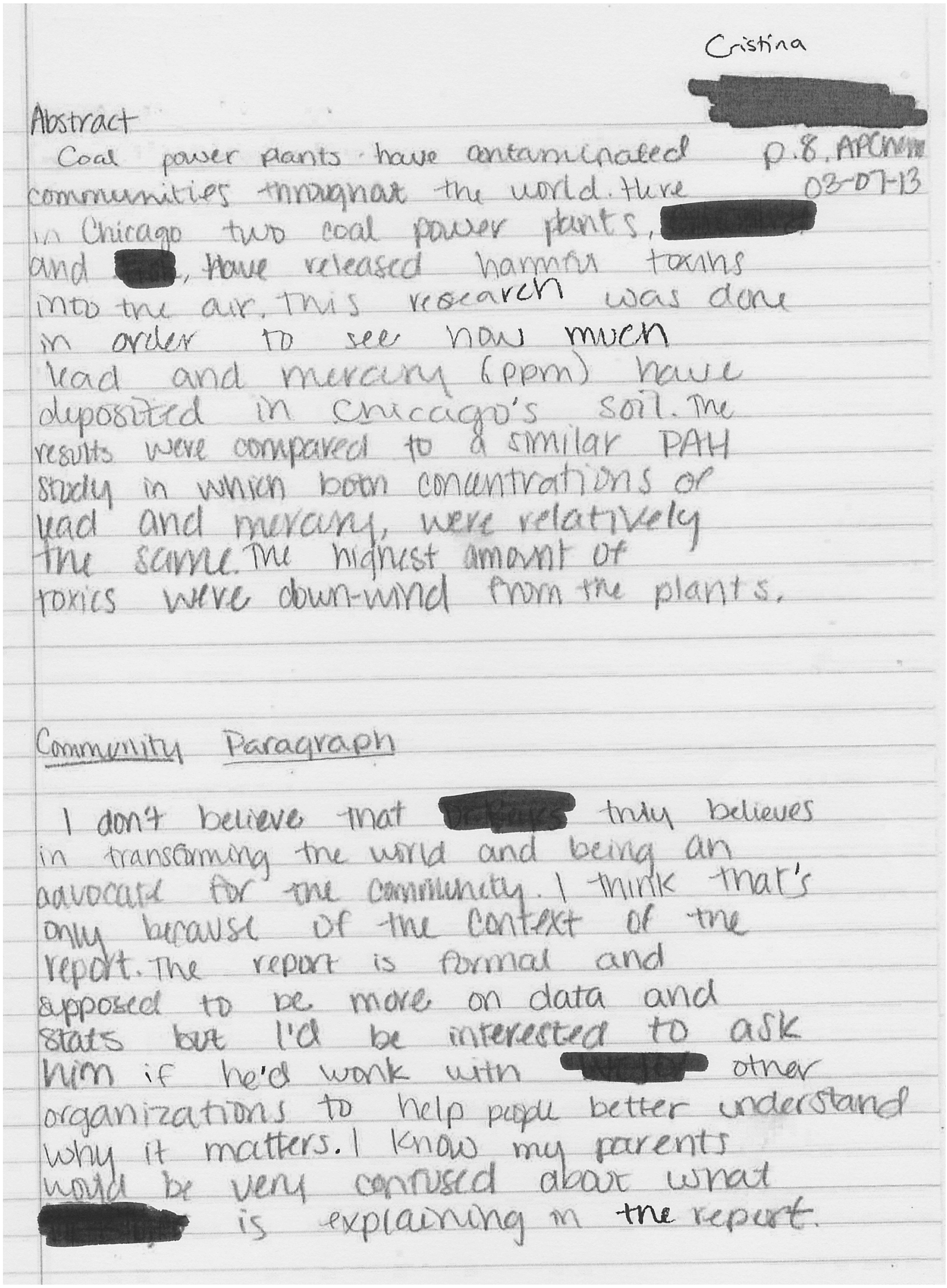
Dear Governor Quinn,

Right now there is a bill waiting to be signed concerning a new powerplant in Chicago. I am writing to let you know why you should veto this bill. It is said that this new plant will create more jobs, but there is no guarantee that those jobs will go to the people in the community where the plant is planned to be built. The plant is also designed to trap its emissions underground instead of polluting the air. It might sound like a good idea unless you know the chemistry behind this decision. Throwing the pollution in the ground will cause the water that's going into people's homes to become acidic if there is a leak. Also, if the pollution is in the air, people are at risk of neurotoxication. This happens because mercury is present as a gas, and people will bring it in. There have been suggestions of ways to oxidize that mercury, but all these suggestions also involve other toxic chemicals such as chlorine gas and calcium perchlorate. Not only will this plant harm people in Chicago, but also people in places where coal is mined. The mining of coal will oxidize other elements in the mountains also contaminating their water ways and making the water toxic. Aside from environmental impacts, this power plant might not only increase the cost of electricity but increase it so much as triple that cost.



In times like this, citizens cannot afford to pay super high electricity bills.

APPENDIX D: ABSTRACT AND REFLECTIONS ON HERNANDEZ STUDY



Cristina

[redacted]

p.8, APCh[redacted]

03-07-13

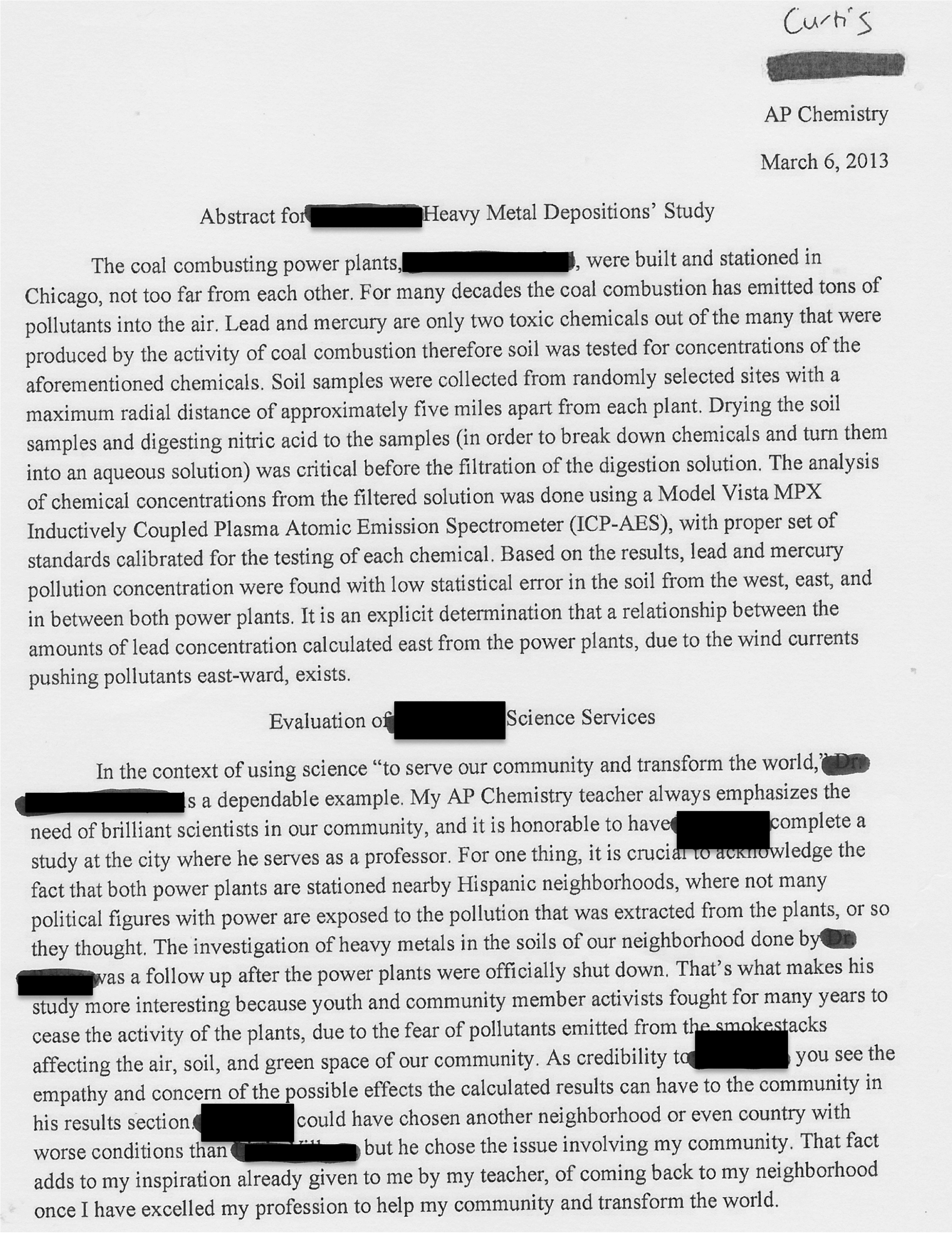
Abstract

Coal power plants have contaminated communities throughout the world. There in Chicago two coal power plants, [redacted] and [redacted], Have released harmful toxins into the air. This research was done in order to see how much lead and mercury (ppm) have deposited in Chicago's soil. The results were compared to a similar PAH study in which both concentrations of lead and mercury, were relatively the same. The highest amount of toxics were down-wind from the plants.

Community Paragraph

I don't believe that [redacted] truly believes in transforming the world and being an advocate for the community. I think that's only because of the context of the report. The report is formal and supposed to be more on data and stats but I'd be interested to ask him if he'd work with [redacted] other organizations to help people better understand why it matters. I know my parents would be very confused about what [redacted] is explaining in the report.

APPENDIX D (continued)



Curtis [redacted]

AP Chemistry

March 6, 2013

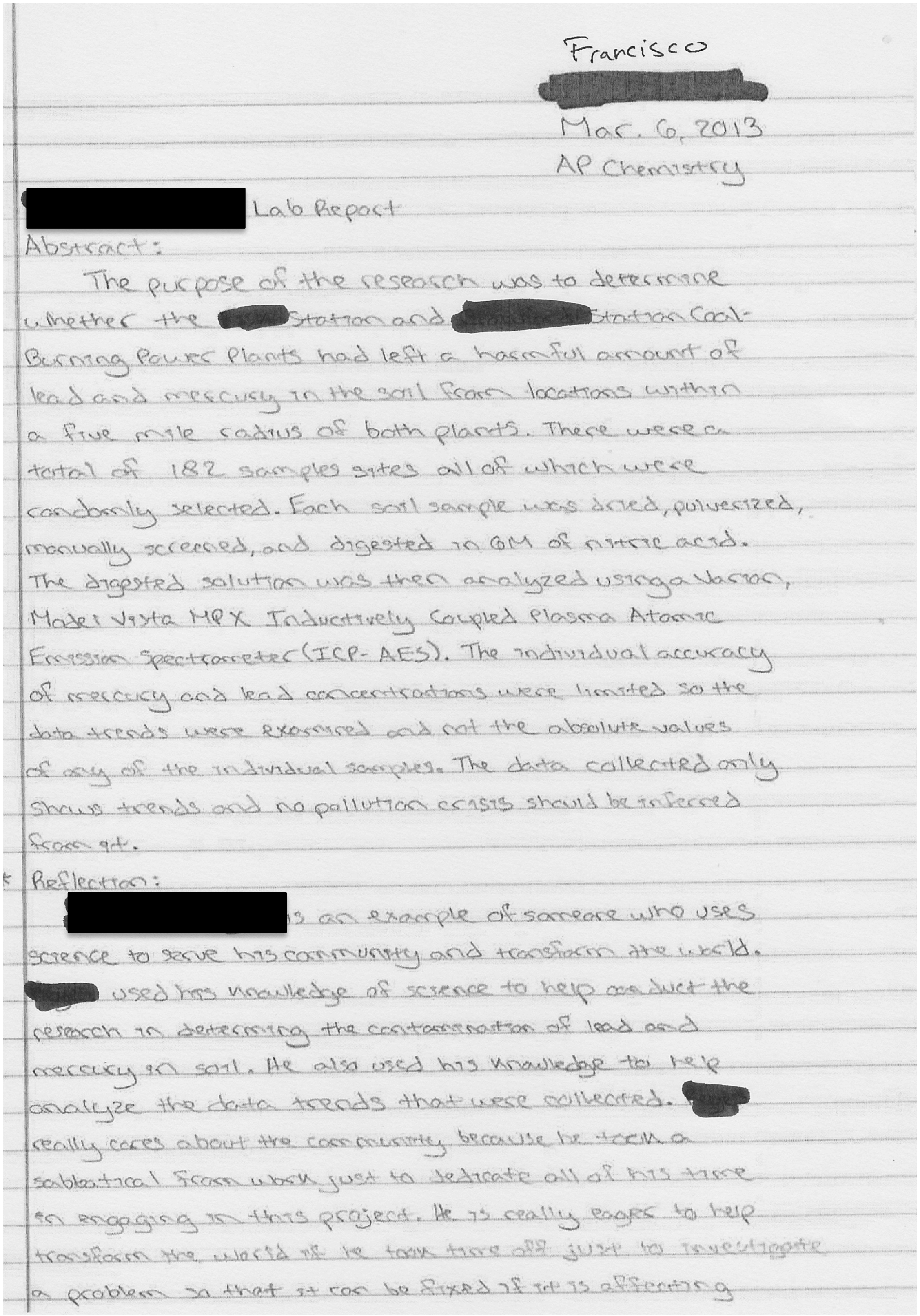
Abstract for [redacted] Heavy Metal Depositions' Study

The coal combusting power plants, [redacted], were built and stationed in Chicago, not too far from each other. For many decades the coal combustion has emitted tons of pollutants into the air. Lead and mercury are only two toxic chemicals out of the many that were produced by the activity of coal combustion therefore soil was tested for concentrations of the aforementioned chemicals. Soil samples were collected from randomly selected sites with a maximum radial distance of approximately five miles apart from each plant. Drying the soil samples and digesting nitric acid to the samples (in order to break down chemicals and turn them into an aqueous solution) was critical before the filtration of the digestion solution. The analysis of chemical concentrations from the filtered solution was done using a Model Vista MPX Inductively Coupled Plasma Atomic Emission Spectrometer (ICP-AES), with proper set of standards calibrated for the testing of each chemical. Based on the results, lead and mercury pollution concentration were found with low statistical error in the soil from the west, east, and in between both power plants. It is an explicit determination that a relationship between the amounts of lead concentration calculated east from the power plants, due to the wind currents pushing pollutants east-ward, exists.

Evaluation of [redacted] Science Services

In the context of using science "to serve our community and transform the world," [redacted]s a dependable example. My AP Chemistry teacher always emphasizes the need of brilliant scientists in our community, and it is honorable to have [redacted] complete a study at the city where he serves as a professor. For one thing, it is crucial to acknowledge the fact that both power plants are stationed nearby Hispanic neighborhoods, where not many political figures with power are exposed to the pollution that was extracted from the plants, or so they thought. The investigation of heavy metals in the soils of our neighborhood done by [redacted] was a follow up after the power plants were officially shut down. That's what makes his study more interesting because youth and community member activists fought for many years to cease the activity of the plants, due to the fear of pollutants emitted from the smokestacks affecting the air, soil, and green space of our community. As credibility to [redacted] you see the empathy and concern of the possible effects the calculated results can have to the community in his results section [redacted] could have chosen another neighborhood or even country with worse conditions than [redacted] but he chose the issue involving my community. That fact adds to my inspiration already given to me by my teacher, of coming back to my neighborhood once I have excelled my profession to help my community and transform the world.

APPENDIX D (continued)



Francisco
[redacted]
Mar. 6, 2013
AP Chemistry

[redacted] Lab Report

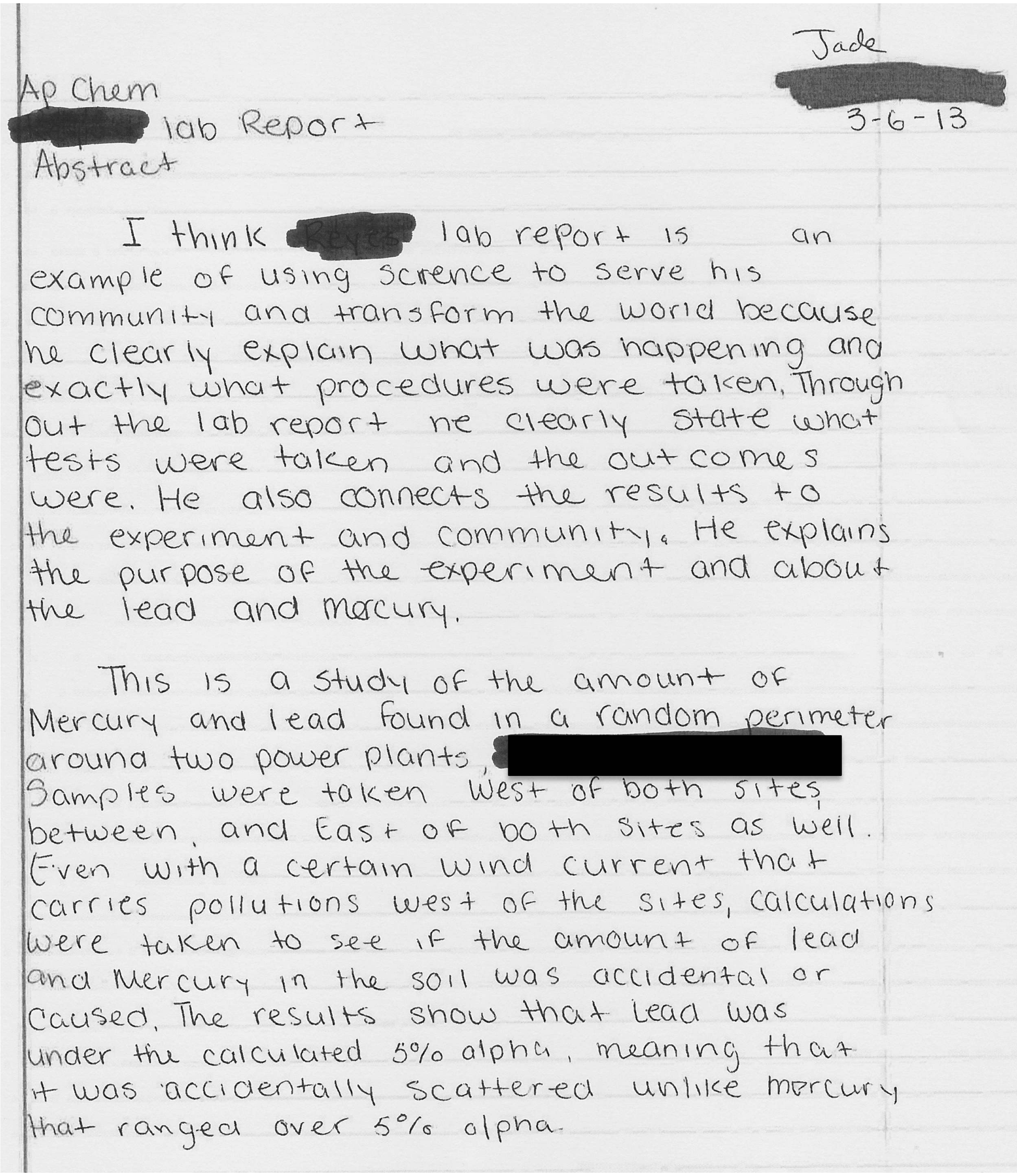
Abstract:

The purpose of the research was to determine whether the [redacted] Station and [redacted] Station Coal-Burning Power Plants had left a harmful amount of lead and mercury in the soil from locations within a five mile radius of both plants. There were a total of 182 samples sites all of which were randomly selected. Each soil sample was dried, pulverized, manually screened, and digested in 6M of nitric acid. The digested solution was then analyzed using a Varian, Model Vista MPX Inductively Coupled Plasma Atomic Emission Spectrometer (ICP-AES). The individual accuracy of mercury and lead concentrations were limited so the data trends were examined and not the absolute values of any of the individual samples. The data collected only shows trends and no pollution crisis should be inferred from it.

* Reflection:

[redacted] is an example of someone who uses science to serve his community and transform the world. [redacted] used his knowledge of science to help conduct the research in determing the contamination of lead and mercury in soil. He also used his knowledge to help analyze the data trends that were collected. [redacted] really cares about the community because he took a sabbatical from work just to dedicate all of his time in engaging in this project. He is really eager to help transform the world if he took time off just to investigate a problem so that it can be fixed if it is affecting

APPENDIX D (continued)

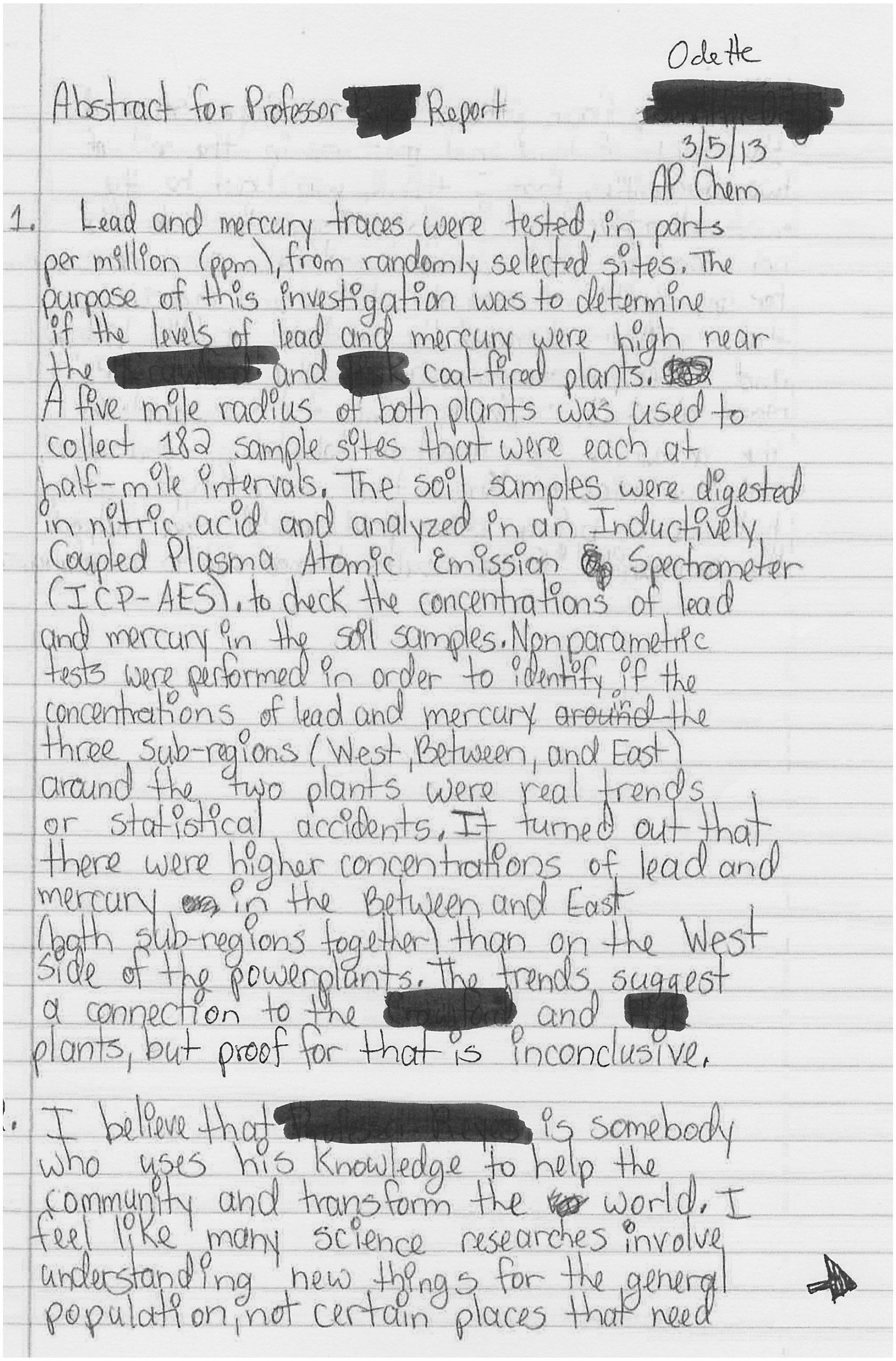


Jade
[redacted]
3-6-13

Ap Chem
[redacted] lab Report
Abstract

I think [redacted] lab report is an example of using science to serve his community and transform the world because he clearly explain what was happening and exactly what procedures were taken. Through out the lab report he clearly state what tests were taken and the outcomes were. He also connects the results to the experiment and community. He explains the purpose of the experiment and about the lead and mercury.

This is a study of the amount of Mercury and lead found in a random perimeter around two power plants, [redacted] Samples were taken West of both sites, between, and East of both sites as well. Even with a certain wind current that carries pollutions west of the sites, calculations were taken to see if the amount of lead and Mercury in the soil was accidental or caused. The results show that lead was under the calculated 5% alpha, meaning that it was accidentally scattered unlike mercury that ranged over 5% alpha.



Odette

Abstract for Professor [redacted] Report

[redacted]

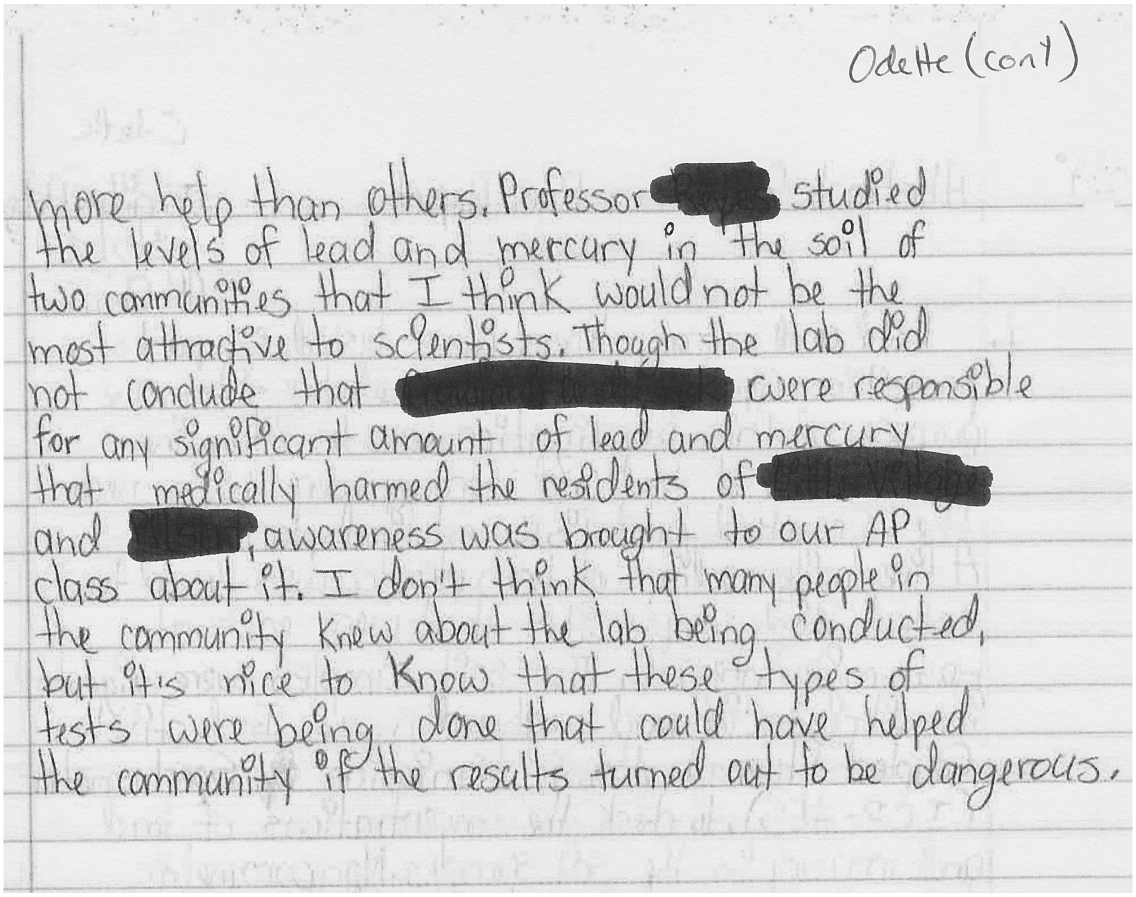
3/5/13

AP Chem

1. Lead and mercury traces were tested, in parts per million (ppm), from randomly selected sites. The purpose of this investigation was to determine if the levels of lead and mercury were high near the [redacted] and [redacted] coal-fired plants. A five mile radius of both plants was used to collect 182 sample sites that were each at half-mile intervals. The soil samples were digested in nitric acid and analyzed in an Inductively Coupled Plasma Atomic Emission Spectrometer (ICP-AES), to check the concentrations of lead and mercury in the soil samples. Nonparametric tests were performed in order to identify if the concentrations of lead and mercury ~~around~~ in the three Sub-regions (West, Between, and East) around the two plants were real trends or statistical accidents. It turned out that there were higher concentrations of lead and mercury in the Between and East (both sub-regions together) than on the West Side of the powerplants. The trends suggest a connection to the [redacted] and [redacted] plants, but proof for that is inconclusive.

2. I believe that [redacted] is somebody who uses his Knowledge to help the community and transform the world. I feel like many science researches involve understanding new things for the general population, not certain places that need

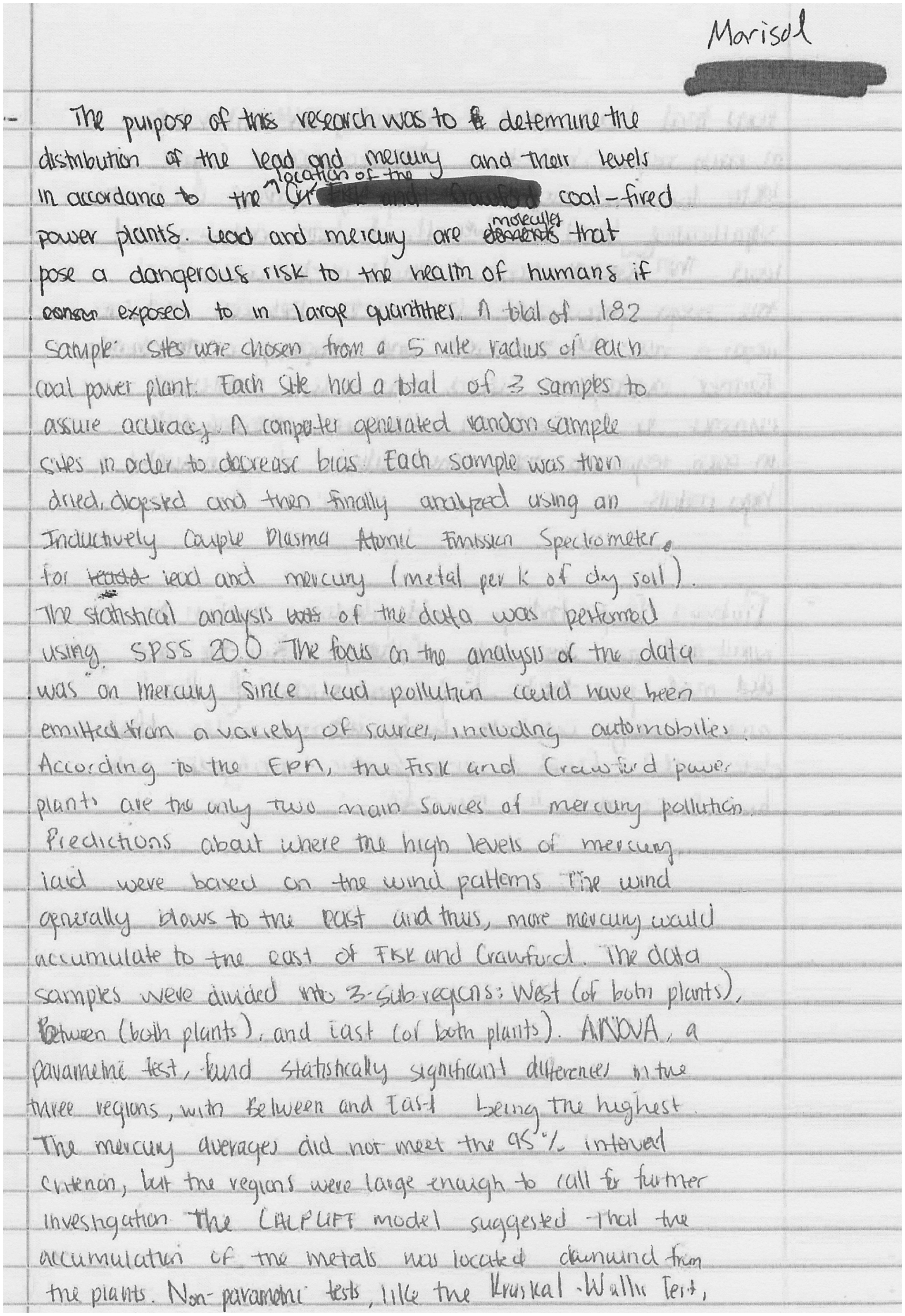
APPENDIX D (continued)



Odette (cont)

more help than others. Professor [redacted] studied the levels of lead and mercury in the soil of two communities that I think would not be the most attractive to scientists. Though the lab did not conclude that [redacted] were responsible for any significant amount of lead and mercury that medically harmed the residents of [redacted] and [redacted], awareness was brought to our AP class about it. I don't think that many people in the community knew about the lab being conducted, but it's nice to know that these types of tests were being done that could have helped the community if the results turned out to be dangerous.

APPENDIX D (continued)

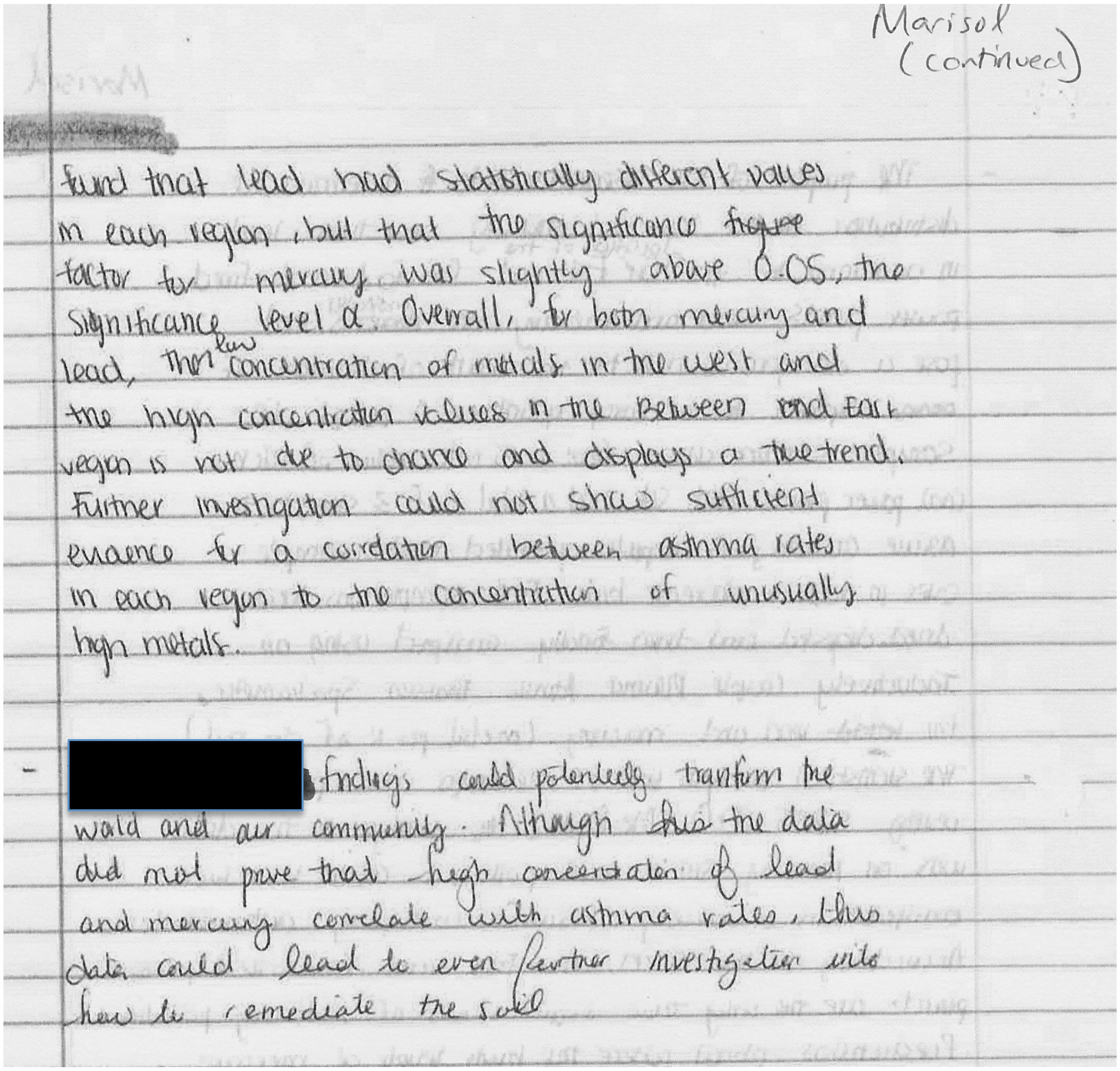


Marisol

[redacted]

The purpose of this research was to ~~&~~ determine the distribution of the lead and mercury and their levels in accordance to the location of the ~~Cit~~ [redacted] coal-fired power plants. Lead and mercury are ~~elements~~ molecules that pose a dangerous risk to the health of humans if ~~consum~~ exposed to in large quantities. A total of 182 sample sites were chosen from a 5 mile radius of each coal power plant. Each site had a total of 3 samples to assure accuracy. A computer generated random sample sites in order to decrease bias. Each sample was then dried, digested and then finally analyzed using an Inductively Couple Plasma Atomic Emission Spectrometer for ~~lead~~ lead and mercury (metal per k of dry soil). The statistical analysis ~~was~~ of the data was performed using SPSS 20.0 The focus on the analysis of the data was on mercury since lead pollution could have been emitted from a variety of sources, including automobiles. According to the EPA, the Fisk and Crawford power plants are the only two main sources of mercury pollution. Predictions about where the high levels of mercury laid were based on the wind patterns. The wind generally blows to the east and thus, more mercury would accumulate to the east of Fisk and Crawford. The data samples were divided into 3-sub-regions: West (of both plants), Between (both plants), and East (of both plants). ANOVA, a parametric test, found statistically significant differences in the three regions, with Between and East being the highest. The mercury averages did not meet the 95% interval criterion, but the regions were large enough to call for further investigation. The CALPUFF model suggested that the accumulation of the metals was located downwind from the plants. Non-parametric tests, like the Kruskal-Wallis Test,

APPENDIX D (continued)



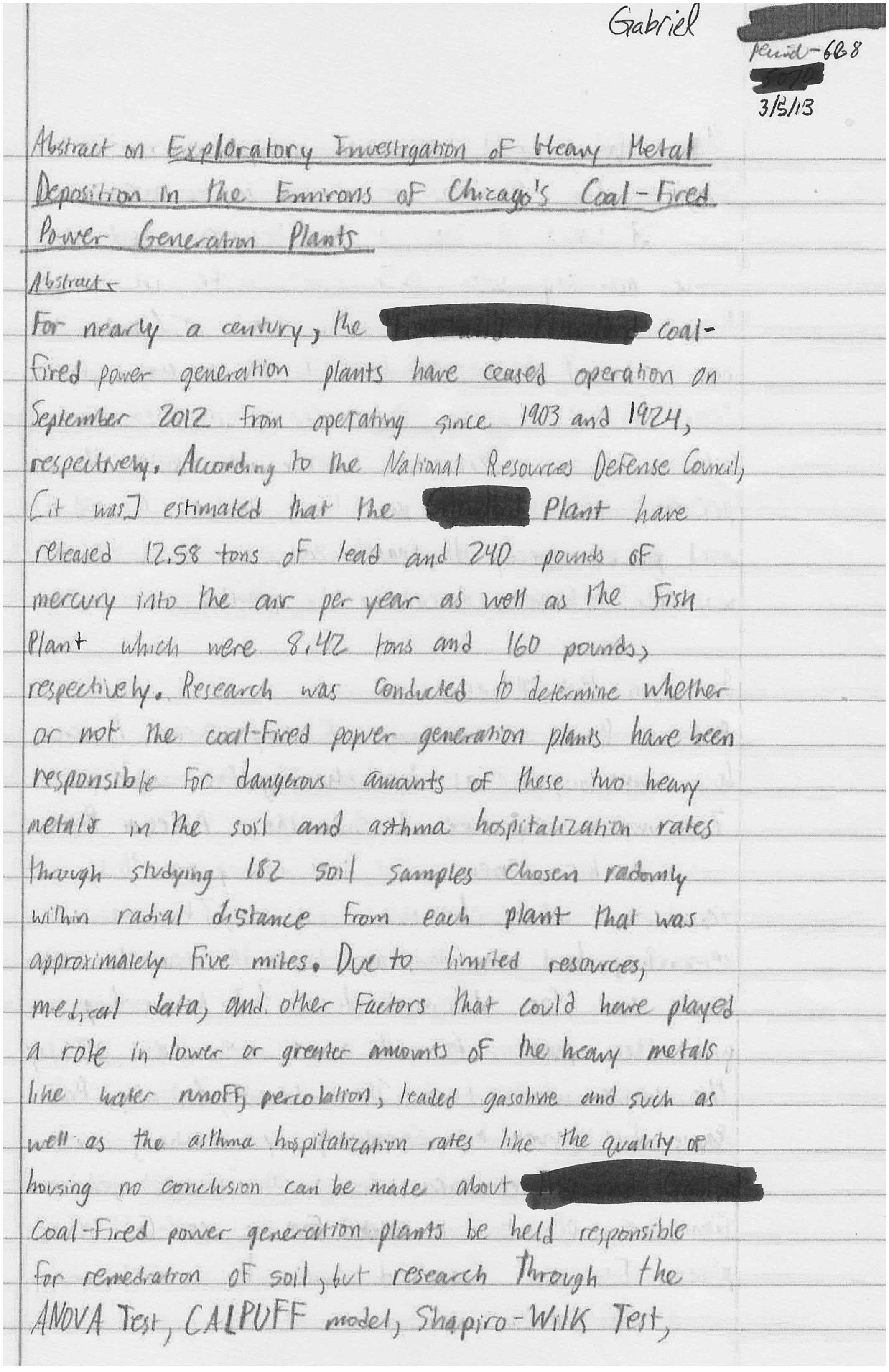
Marisol
(continued)

[redacted]

fund that lead had statistically different values in each region, but that the significance ~~figure~~ factor for mercury was slightly above 0.05, the significance level α. Overall, for both mercury and lead, then low concentration of metals in the west and the high concentration values in the Between and East region is not due to chance and displays a true trend. Further investigation could not show sufficient evidence for a correlation between asthma rates in each region to the concentration of unusually high metals.

[redacted] findings could potentially tranform the world and our community. Although ~~this~~ the data did not prove that high concentration of lead and mercury correlate with asthma rates, this data could lead to even further investigation into how to remediate the soil

APPENDIX D (continued)



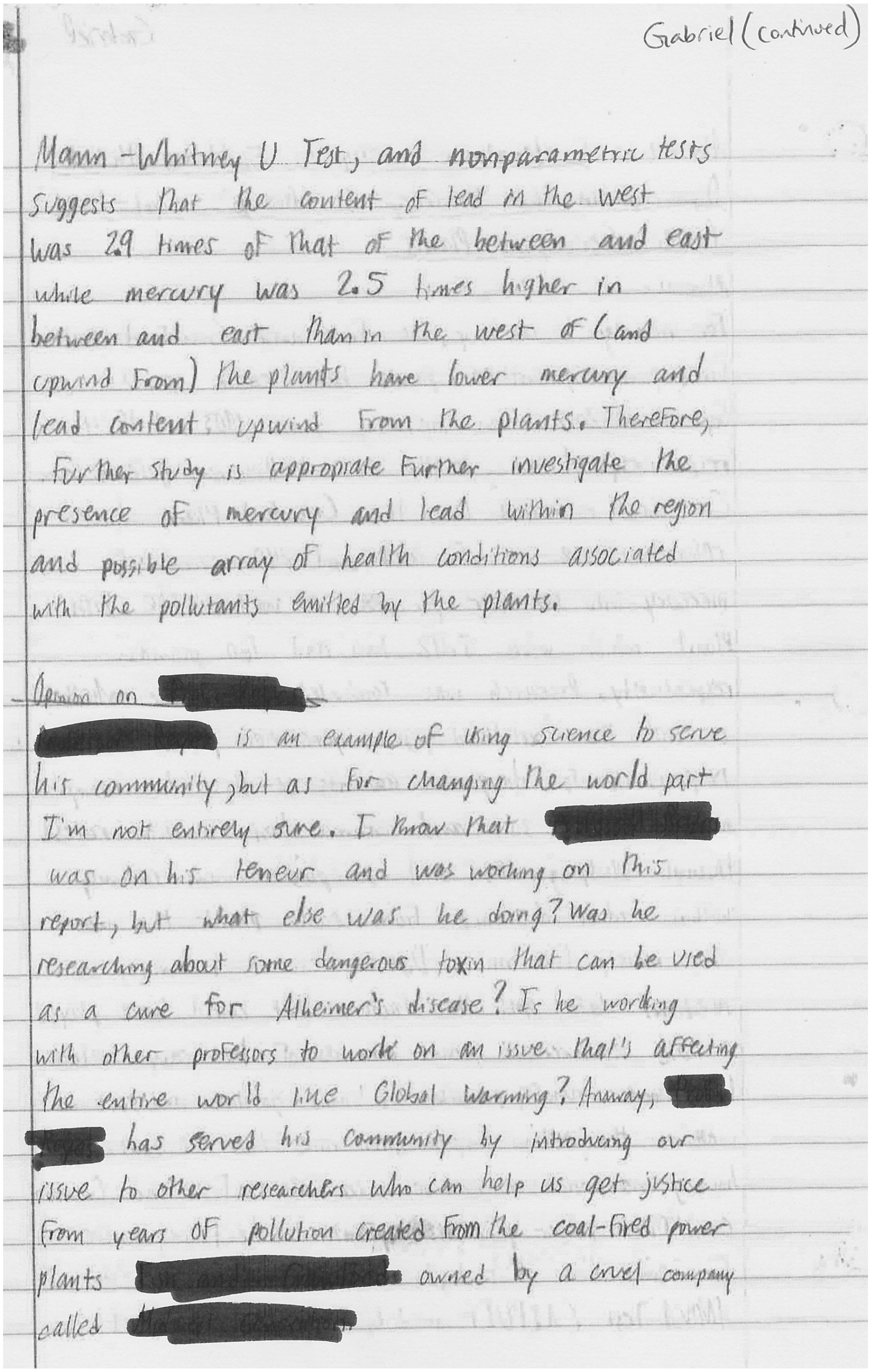
Gabriel [redacted]
Period-6&8
[redacted]
3/5/13

Abstract on Exploratory Investigation of Heavy Metal Deposition in the Environs of Chicago's Coal-Fired Power Generation Plants

Abstract:

For nearly a century, the [redacted] coal-fired power generation plants have ceased operation on September 2012 from operating since 1903 and 1924, respectively. According to the National Resources Defense Council, [it was] estimated that the [redacted] Plant have released 12.58 tons of lead and 240 pounds of mercury into the air per year as well as the Fisk Plant which were 8.42 tons and 160 pounds, respectively. Research was conducted to determine whether or not the coal-fired power generation plants have been responsible for dangerous amounts of these two heavy metals in the soil and asthma hospitalization rates through studying 182 soil samples chosen radomly within radial distance from each plant that was approximately five miles. Due to limited resources, medical data, and other factors that could have played a role in lower or greater amounts of the heavy metals like water runoff, percolation, leaded gasoline and such as well as the asthma hospitalization rates like the quality of housing no conclusion can be made about [redacted] Coal-Fired power generation plants be held responsible for remedration of soil, but research through the ANOVA Test, CALPUFF model, Shapiro-Wilk Test,

APPENDIX D (continued)



Gabriel (continued)

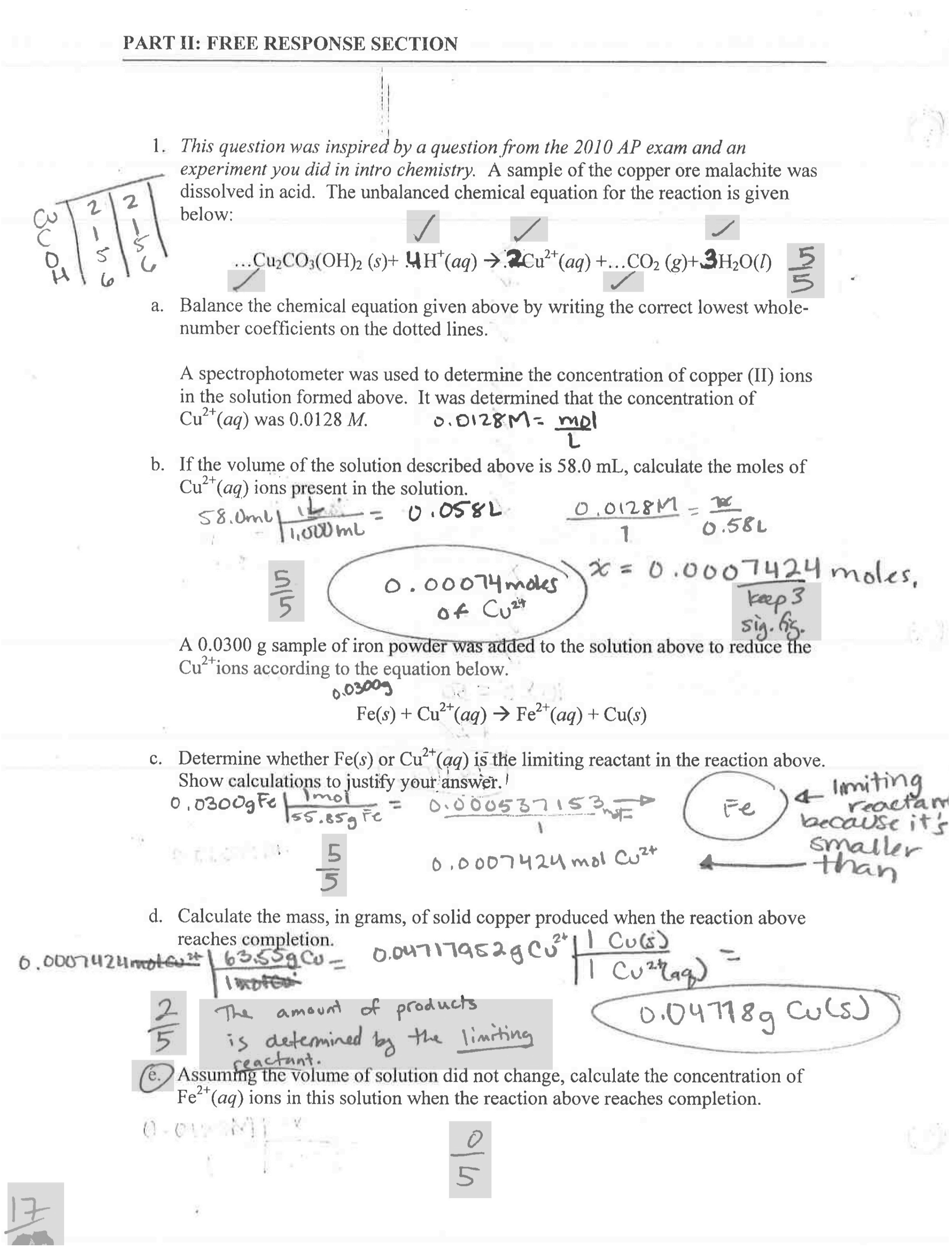
Mann-Whitney U Test, and nonparametric tests suggests that the content of lead in the west was 2.9 times of that of the between and east while mercury was 2.5 times higher in between and east than in the west of (and upwind from) the plants have lower mercury and lead content, upwind from the plants. Therefore, Further study is appropriate Further investigate the presence of mercury and lead within the region and possible array of health conditions associated with the pollutants emitted by the plants.

Opinion on [redacted]

[redacted] is an example of using science to serve his community, but as for changing the world part I'm not entirely sure. I know that [redacted] was on his teneur and was working on this report, but what else was he doing? Was he researching about some dangerous toxin that can be used as a cure for Alheimer's disease? Is he working with other professors to work on an issue that's affecting the entire world like Global Warming? Anyway, [redacted] has served his community by introducing our issue to other researchers who can help us get justice from years of pollution created from the coal-fired power plants [redacted] owned by a cruel company called [redacted]

APPENDIX E: STOICHIOMETRY EXAM PROBLEM 1

Cristina:



PART II: FREE RESPONSE SECTION

1. *This question was inspired by a question from the 2010 AP exam and an experiment you did in intro chemistry.* A sample of the copper ore malachite was dissolved in acid. The unbalanced chemical equation for the reaction is given below:

Cu	2	2
C	1	1
O	5	5
H	6	6

✓ ✓ ✓ ✓ ✓

$\ldots Cu_2CO_3(OH)_2\ (s) + 4H^+(aq) \rightarrow 2Cu^{2+}(aq) + \ldots CO_2\ (g) + 3H_2O(l)$ $\frac{5}{5}$

a. Balance the chemical equation given above by writing the correct lowest whole-number coefficients on the dotted lines.

A spectrophotometer was used to determine the concentration of copper (II) ions in the solution formed above. It was determined that the concentration of $Cu^{2+}(aq)$ was 0.0128 *M*. $0.0128M = \frac{mol}{L}$

b. If the volume of the solution described above is 58.0 mL, calculate the moles of $Cu^{2+}(aq)$ ions present in the solution.

$58.0mL \left| \frac{1L}{1{,}000mL} \right. = 0.058L$ $\frac{0.0128M}{1} = \frac{x}{0.58L}$

$\frac{5}{5}$ 0.00074 moles of Cu^{2+} $x = 0.0007424$ moles, keep 3 sig. fig.

A 0.0300 g sample of iron powder was added to the solution above to reduce the Cu^{2+} ions according to the equation below.

0.0300g

$Fe(s) + Cu^{2+}(aq) \rightarrow Fe^{2+}(aq) + Cu(s)$

c. Determine whether $Fe(s)$ or $Cu^{2+}(aq)$ is the limiting reactant in the reaction above. Show calculations to justify your answer.

$0.0300g\,Fe \left| \frac{1mol}{55.85g\,Fe} \right. = \frac{0.000537153\ mol\ Fe}{1} \rightarrow$ Fe ← limiting reactant because it's smaller than

$\frac{5}{5}$ 0.0007424 mol Cu^{2+} ←

d. Calculate the mass, in grams, of solid copper produced when the reaction above reaches completion.

$0.0007424 \cancel{mol\,Cu^{2+}} \left| \frac{63.55g\,Cu}{1 \cancel{mol\,Cu}} \right. = 0.04717952g\,Cu^{2+} \left| \frac{1\ Cu(s)}{1\ Cu^{2+}(aq)} \right. =$

$\frac{2}{5}$ The amount of products is determined by the limiting reactant. 0.04718g Cu(s)

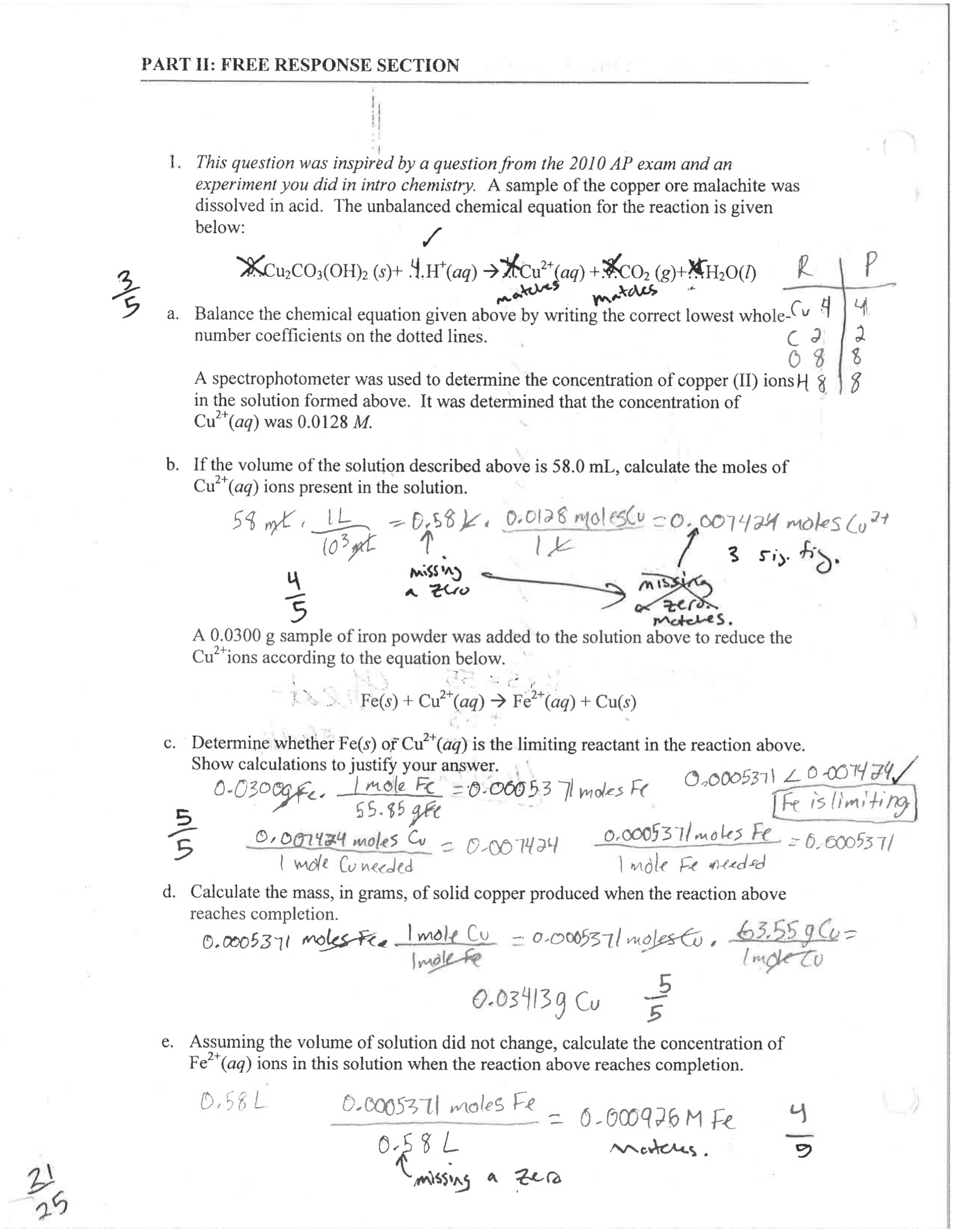
e. Assuming the volume of solution did not change, calculate the concentration of $Fe^{2+}(aq)$ ions in this solution when the reaction above reaches completion.

$\frac{0}{5}$

17/[redacted]

APPENDIX E (continued)

Curtis:



PART II: FREE RESPONSE SECTION

1. *This question was inspired by a question from the 2010 AP exam and an experiment you did in intro chemistry.* A sample of the copper ore malachite was dissolved in acid. The unbalanced chemical equation for the reaction is given below:

✓

$$\cancel{\ldots}Cu_2CO_3(OH)_2\ (s) + 4\ H^+(aq) \rightarrow \cancel{\ldots}Cu^{2+}(aq) + \cancel{\ldots}CO_2\ (g) + \cancel{\ldots}H_2O(l)$$

matches matches

	R	P
Cu	4	4
C	2	2
O	8	8
H	8	8

3/5

a. Balance the chemical equation given above by writing the correct lowest whole-number coefficients on the dotted lines.

A spectrophotometer was used to determine the concentration of copper (II) ions in the solution formed above. It was determined that the concentration of $Cu^{2+}(aq)$ was 0.0128 *M*.

b. If the volume of the solution described above is 58.0 mL, calculate the moles of $Cu^{2+}(aq)$ ions present in the solution.

$$58\ \cancel{mL} \cdot \frac{1L}{10^3\ \cancel{mL}} = 0.58\ \cancel{L} \cdot \frac{0.0128\ moles\ Cu}{1\ \cancel{L}} = 0.007424\ moles\ Cu^{2+}$$

missing a zero

~~missing a zero.~~ matches.

3 sig. fig.

4/5

A 0.0300 g sample of iron powder was added to the solution above to reduce the Cu^{2+} ions according to the equation below.

$$Fe(s) + Cu^{2+}(aq) \rightarrow Fe^{2+}(aq) + Cu(s)$$

c. Determine whether Fe(*s*) or $Cu^{2+}(aq)$ is the limiting reactant in the reaction above. Show calculations to justify your answer.

$$0.0300\ \cancel{g\ Fe} \cdot \frac{1\ mole\ Fe}{55.85\ \cancel{g\ Fe}} = 0.0005371\ moles\ Fe$$

$$0.0005371 < 0.007474 ✓$$

$$\boxed{Fe\ is\ limiting}$$

5/5

$$\frac{0.007424\ moles\ Cu}{1\ mole\ Cu\ needed} = 0.007424 \qquad \frac{0.0005371\ moles\ Fe}{1\ mole\ Fe\ needed} = 0.0005371$$

d. Calculate the mass, in grams, of solid copper produced when the reaction above reaches completion.

$$0.0005371\ \cancel{moles\ Fe} \cdot \frac{1\ mole\ Cu}{1\ \cancel{mole\ Fe}} = 0.0005371\ \cancel{moles\ Cu} \cdot \frac{63.55\ g\ Cu}{1\ \cancel{mole\ Cu}} =$$

$$0.03413\ g\ Cu$$

5/5

e. Assuming the volume of solution did not change, calculate the concentration of $Fe^{2+}(aq)$ ions in this solution when the reaction above reaches completion.

0.58 L

$$\frac{0.0005371\ moles\ Fe}{0.58\ L} = 0.000926\ M\ Fe$$

missing a zero

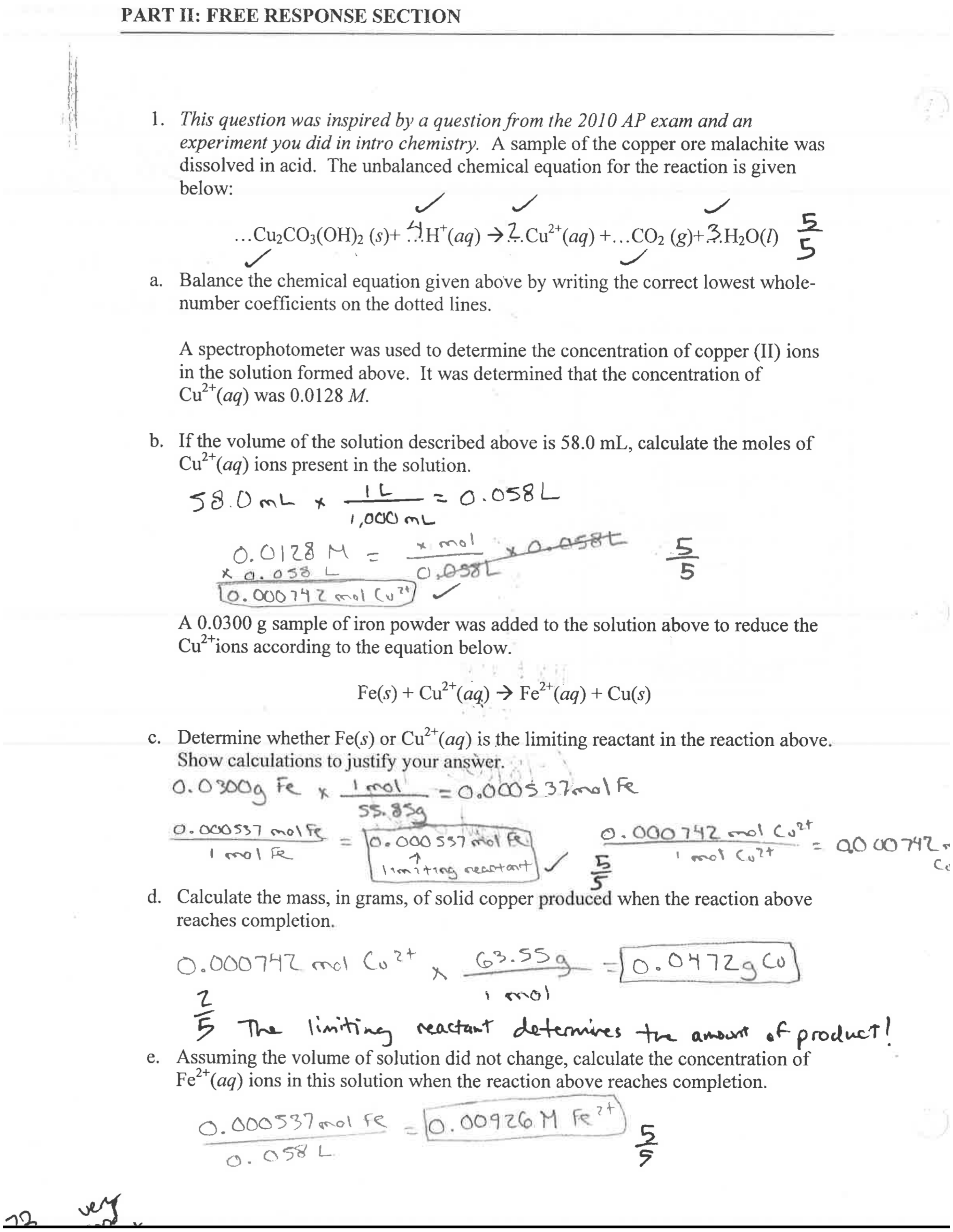
matches.

4/5

21/25

APPENDIX E (continued)

Francisco:



PART II: FREE RESPONSE SECTION

1. *This question was inspired by a question from the 2010 AP exam and an experiment you did in intro chemistry.* A sample of the copper ore malachite was dissolved in acid. The unbalanced chemical equation for the reaction is given below:

$$\ldots Cu_2CO_3(OH)_2\,(s) + 4\,H^+(aq) \rightarrow 2\,Cu^{2+}(aq) + \ldots CO_2\,(g) + 3\,H_2O(l) \qquad \frac{5}{5}$$

a. Balance the chemical equation given above by writing the correct lowest whole-number coefficients on the dotted lines.

A spectrophotometer was used to determine the concentration of copper (II) ions in the solution formed above. It was determined that the concentration of $Cu^{2+}(aq)$ was 0.0128 *M*.

b. If the volume of the solution described above is 58.0 mL, calculate the moles of $Cu^{2+}(aq)$ ions present in the solution.

$$58.0\text{ mL} \times \frac{1\text{ L}}{1{,}000\text{ mL}} = 0.058\text{ L}$$

$$0.0128\text{ M} = \frac{x\text{ mol}}{0.058\text{ L}} \; \cancel{\times 0.058\text{ L}} \qquad \frac{5}{5}$$

$$\times\, 0.058\text{ L}$$

$$\boxed{0.000742\text{ mol }Cu^{2+}}\ ✓$$

A 0.0300 g sample of iron powder was added to the solution above to reduce the Cu^{2+}ions according to the equation below.

$$Fe(s) + Cu^{2+}(aq) \rightarrow Fe^{2+}(aq) + Cu(s)$$

c. Determine whether Fe(*s*) or $Cu^{2+}(aq)$ is the limiting reactant in the reaction above. Show calculations to justify your answer.

$$0.0300\text{g Fe} \times \frac{1\text{ mol}}{55.85\text{g}} = 0.000537\text{ mol Fe}$$

$$\frac{0.000537\text{ mol Fe}}{1\text{ mol Fe}} = \boxed{\begin{array}{c}0.000537\text{ mol Fe}\\ \uparrow\\ \text{limiting reactant}\end{array}}\ ✓ \quad \frac{5}{5} \qquad \frac{0.000742\text{ mol }Cu^{2+}}{1\text{ mol }Cu^{2+}} = 0.000742$$

d. Calculate the mass, in grams, of solid copper produced when the reaction above reaches completion.

$$0.000742\text{ mol }Cu^{2+} \times \frac{63.55\text{g}}{1\text{ mol}} = \boxed{0.0472\text{g Cu}}$$

$\frac{2}{5}$ The limiting reactant determines the amount of product!

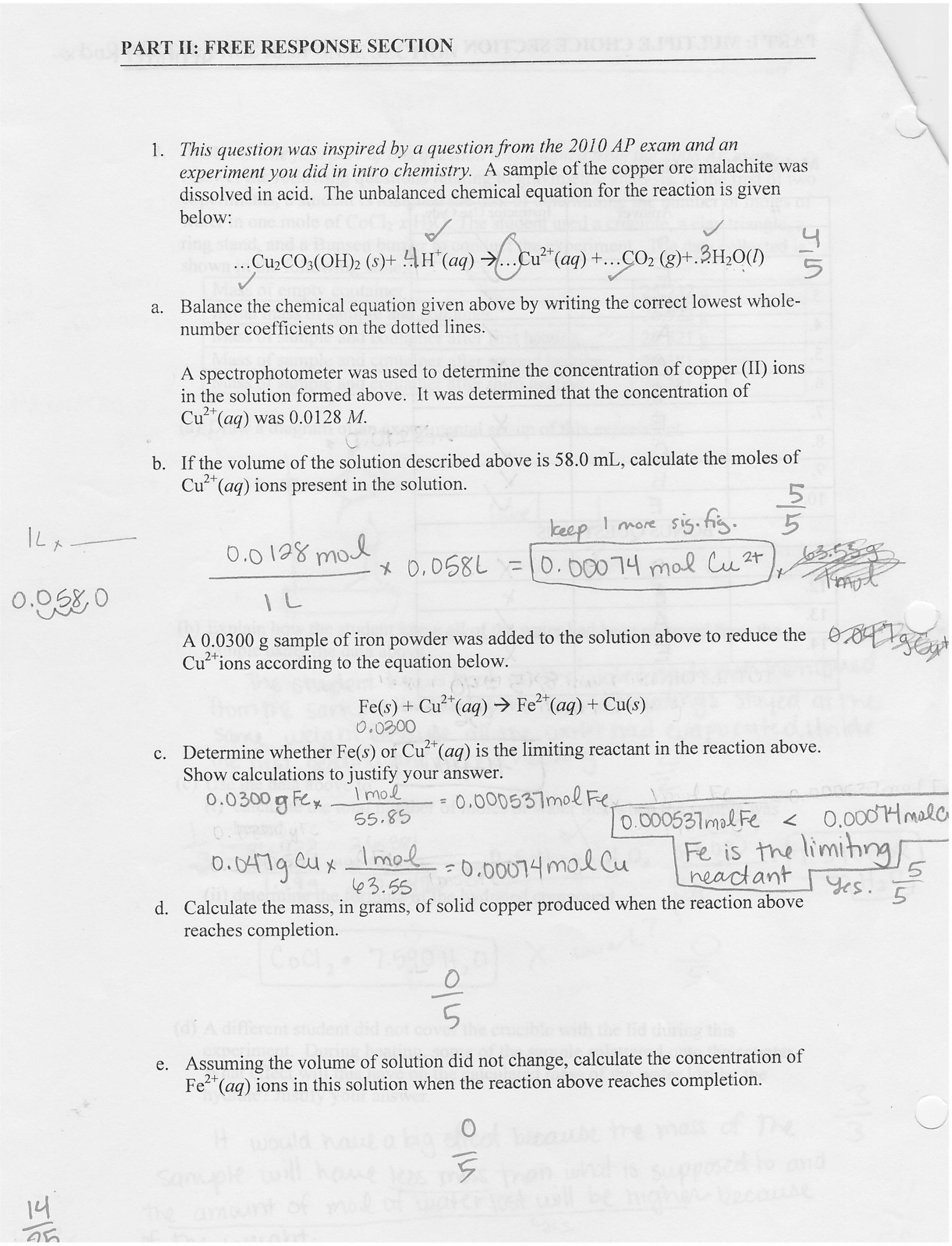
e. Assuming the volume of solution did not change, calculate the concentration of $Fe^{2+}(aq)$ ions in this solution when the reaction above reaches completion.

$$\frac{0.000537\text{ mol Fe}}{0.058\text{ L}} = \boxed{0.00926\text{ M }Fe^{2+}} \qquad \frac{5}{5}$$

very

APPENDIX E (continued)

Raquel:



PART II: FREE RESPONSE SECTION

1. *This question was inspired by a question from the 2010 AP exam and an experiment you did in intro chemistry.* A sample of the copper ore malachite was dissolved in acid. The unbalanced chemical equation for the reaction is given below:

$$\ldots Cu_2CO_3(OH)_2\,(s) + 4\,H^+(aq) \rightarrow \ldots Cu^{2+}(aq) + \ldots CO_2\,(g) + 3\,H_2O(l)$$

✓ ✓ ✓ ✓

$\frac{4}{5}$

a. Balance the chemical equation given above by writing the correct lowest whole-number coefficients on the dotted lines.

A spectrophotometer was used to determine the concentration of copper (II) ions in the solution formed above. It was determined that the concentration of $Cu^{2+}(aq)$ was 0.0128 *M*.

b. If the volume of the solution described above is 58.0 mL, calculate the moles of $Cu^{2+}(aq)$ ions present in the solution.

$\frac{5}{5}$

1L x ———

0.058,0

keep 1 more sig. fig.

$$\frac{0.0128 \text{ mol}}{1 \text{ L}} \times 0.058\text{L} = \boxed{0.00074 \text{ mol } Cu^{2+}} \times \cancel{\frac{63.55\text{g}}{1\text{mol}}}$$

~~0.047g~~ g Cu²⁺

A 0.0300 g sample of iron powder was added to the solution above to reduce the Cu^{2+} ions according to the equation below.

$$\underset{0.0300}{Fe(s)} + Cu^{2+}(aq) \rightarrow Fe^{2+}(aq) + Cu(s)$$

c. Determine whether $Fe(s)$ or $Cu^{2+}(aq)$ is the limiting reactant in the reaction above. Show calculations to justify your answer.

$$0.0300\text{ g Fe} \times \frac{1\text{ mol}}{55.85} = 0.000537\text{ mol Fe}$$

$$0.047\text{g Cu} \times \frac{1\text{ mol}}{63.55} = 0.00074\text{ mol Cu}$$

0.000537 mol Fe < 0.00074 mol Cu

Fe is the limiting reactant

Yes. $\frac{5}{5}$

d. Calculate the mass, in grams, of solid copper produced when the reaction above reaches completion.

$\frac{0}{5}$

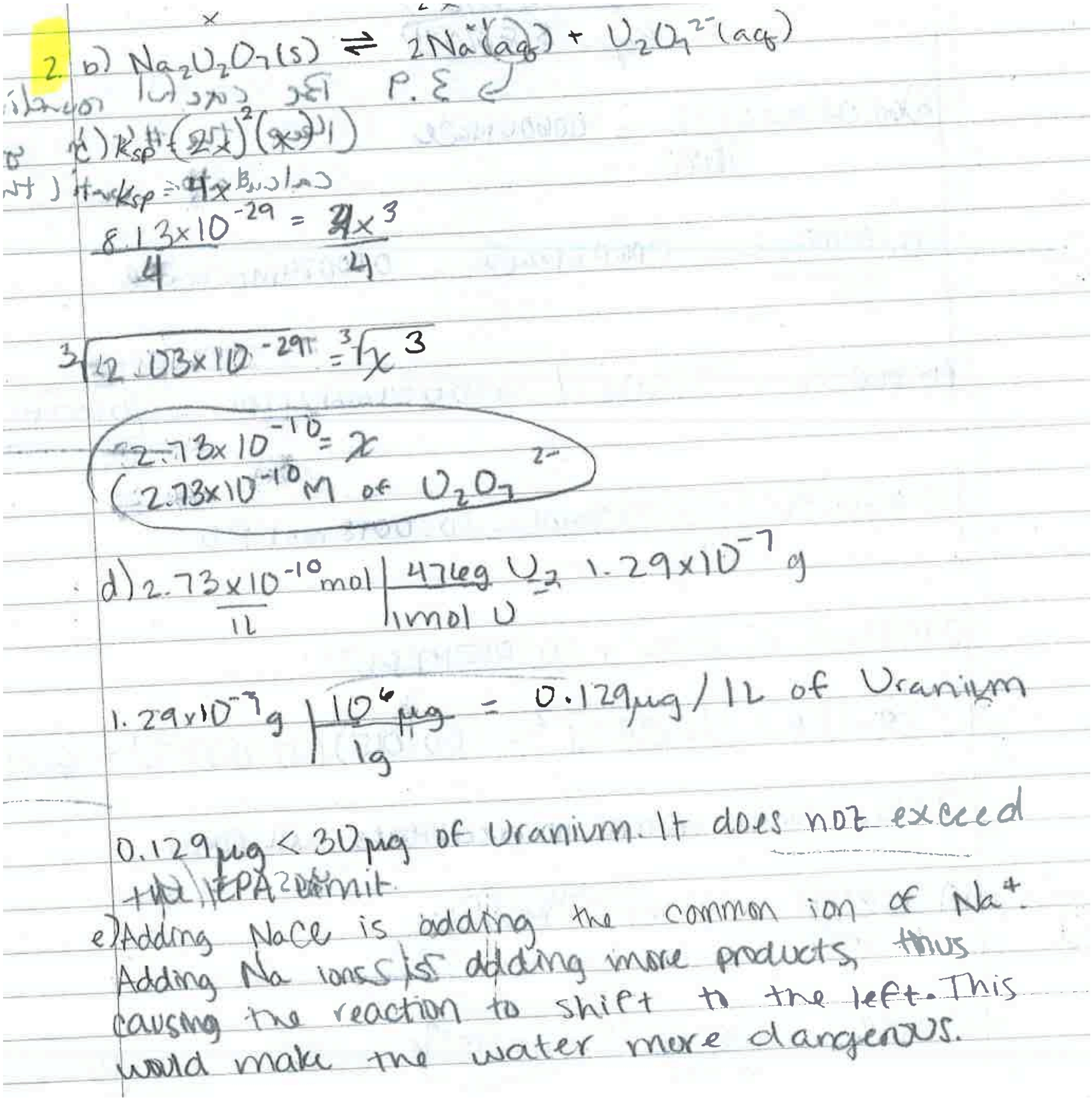
e. Assuming the volume of solution did not change, calculate the concentration of $Fe^{2+}(aq)$ ions in this solution when the reaction above reaches completion.

$\frac{0}{5}$

$\frac{14}{25}$

APPENDIX F: URANIUM MINING PROBLEM

Cristina:



2\. b) $Na_2U_2O_7(s) \rightleftharpoons 2Na^{+}(aq) + U_2O_7^{2-}(aq)$

c) $K_{sp} = (2x)^2(x)$

$K_{sp} = 4x^3$

$\frac{8.13\times10^{-29}}{4} = \frac{4x^3}{4}$

$\sqrt[3]{2.03\times10^{-29}} = \sqrt[3]{x^3}$

$2.73\times10^{-10} = x$

2.73×10^{-10} M of $U_2O_7^{2-}$

d) $\frac{2.73\times10^{-10}\ mol}{1L} \left| \frac{476g\ U_2}{1mol\ U} \right.$ 1.29×10^{-7} g

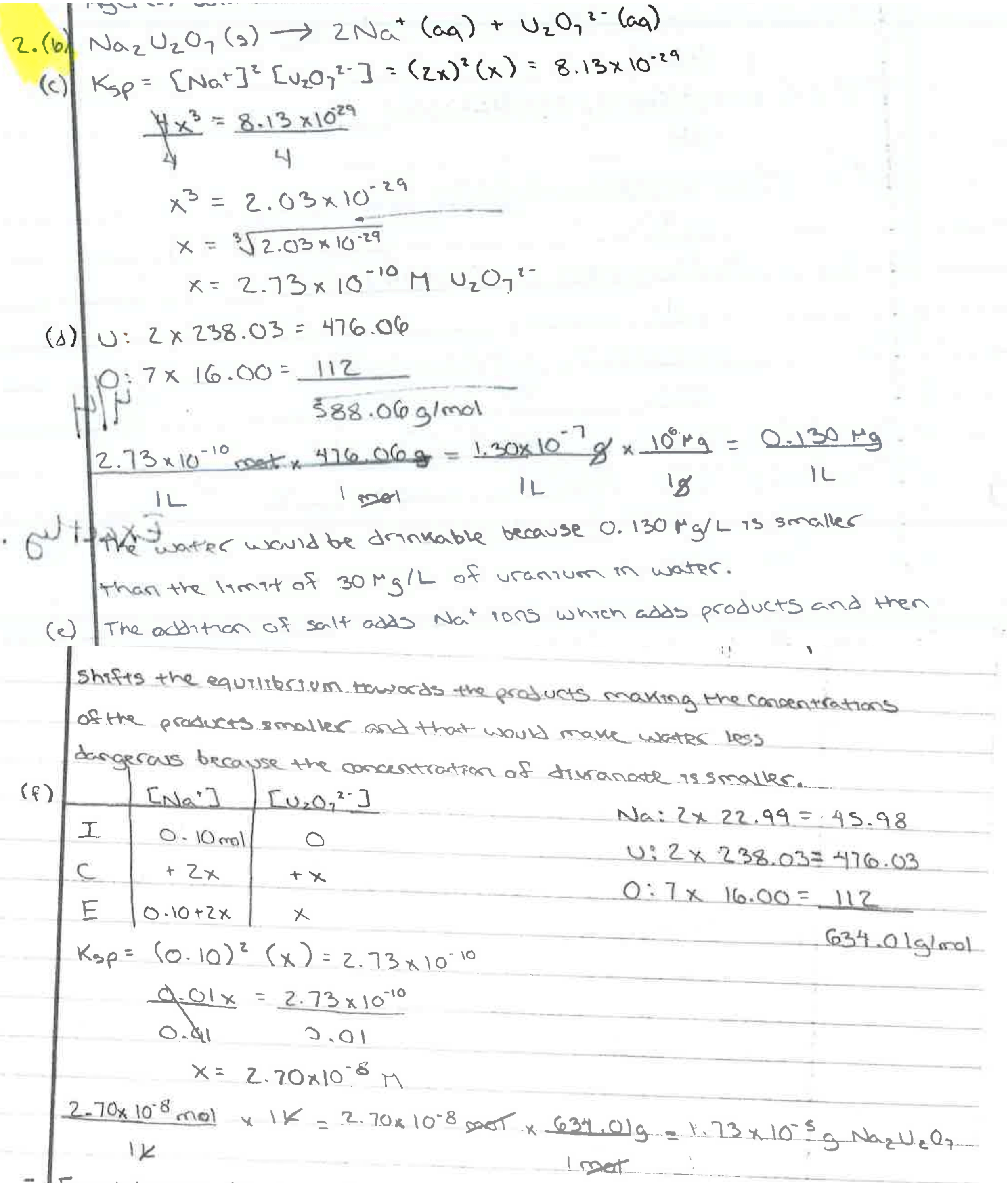
1.29×10^{-7} g $\left| \frac{10^6\ \mu g}{1g} \right.$ = 0.129µg / 1L of Uranium

0.129µg < 30µg of Uranium. It does not exceed the EPA limit

e) Adding NaCl is adding the common ion of Na^+. Adding Na ions is adding more products, thus causing the reaction to shift to the left. This would make the water more dangerous.

APPENDIX F (continued)

Francisco:



2.(b) $Na_2U_2O_7(s) \longrightarrow 2Na^+(aq) + U_2O_7^{2-}(aq)$

(c) $K_{sp} = [Na^+]^2[U_2O_7^{2-}] = (2x)^2(x) = 8.13\times10^{-29}$

$$\frac{\cancel{4}x^3}{\cancel{4}} = \frac{8.13\times10^{29}}{4}$$

$$x^3 = 2.03\times10^{-29}$$

$$x = \sqrt[3]{2.03\times10^{-29}}$$

$$x = 2.73\times10^{-10}\ M\ U_2O_7^{2-}$$

(d) U: 2 x 238.03 = 476.06

O: 7 x 16.00 = 112

588.06 g/mol

$$\frac{2.73\times10^{-10}\ \cancel{mol}}{1L}\times\frac{476.06\ \cancel{g}}{1\ \cancel{mol}} = \frac{1.30\times10^{-7}\ \cancel{g}}{1L}\times\frac{10^6\ \mu g}{1\ \cancel{g}} = \frac{0.130\ \mu g}{1L}$$

The water would be drinkable because 0.130 μg/L is smaller than the limit of 30 μg/L of uranium in water.

(e) The addition of salt adds Na^+ ions which adds products and then shifts the equilibrium towards the products making the concentrations of the products smaller and that would make water less dangerous because the concentration of diuranate is smaller.

(f)

	$[Na^+]$	$[U_2O_7^{2-}]$
I	0.10 mol	0
C	+ 2x	+ x
E	0.10+2x	x

Na: 2x 22.99 = 45.98

U: 2 x 238.03 = 476.03

O: 7 x 16.00 = 112

634.01 g/mol

$K_{sp} = (0.10)^2(x) = 2.73\times10^{-10}$

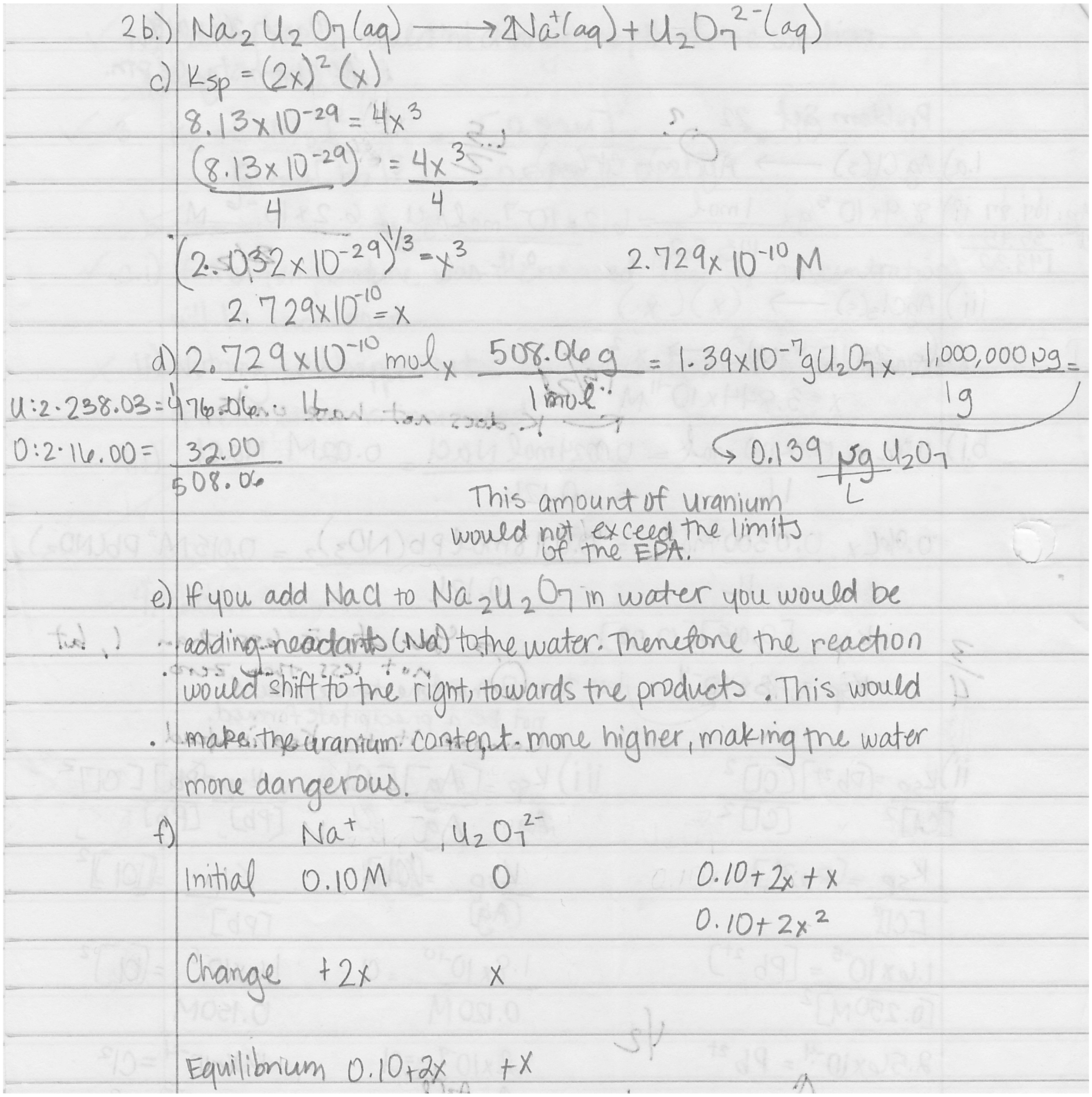
$$\frac{\cancel{0.01}x}{\cancel{0.01}} = \frac{2.73\times10^{-10}}{0.01}$$

$$x = 2.70\times10^{-8}\ M$$

$$\frac{2.70\times10^{-8}\ mol}{1\cancel{L}}\times 1\cancel{L} = 2.70\times10^{-8}\ \cancel{mol}\times\frac{634.01\,g}{1\ \cancel{mol}} = 1.73\times10^{-5}\ g\ Na_2U_2O_7$$

APPENDIX F (continued)

Raquel:



2b.) $Na_2U_2O_7(aq) \longrightarrow 2Na^+(aq) + U_2O_7^{2-}(aq)$

c) $K_{sp} = (2x)^2(x)$

$8.13 \times 10^{-29} = 4x^3$

$\frac{(8.13 \times 10^{-29})}{4} = \frac{4x^3}{4}$

$(2.032 \times 10^{-29})^{1/3} = x^3$

$2.729 \times 10^{-10} = x$

2.729×10^{-10} M

d) $\frac{2.729 \times 10^{-10}\ mol}{1L} \times \frac{508.06\ g}{1\ mol} = 1.39 \times 10^{-7}\ g\ U_2O_7 \times \frac{1{,}000{,}000\ \mu g}{1g} =$

$\rightarrow 0.139\ \frac{\mu g}{L}\ U_2O_7$

U:2·238.03 = 476.06

O:2·16.00 = 32.00

508.06

This amount of uranium would not exceed the limits of the EPA.

e) If you add NaCl to $Na_2U_2O_7$ in water you would be adding ~~reactants~~ (Na) to the water. Therefore the reaction would shift to the right, towards the products. This would make the uranium content more higher, making the water more dangerous.

f)

	Na^+	$U_2O_7^{2-}$
Initial	0.10M	0
Change	+2x	x
Equilibrium	0.10+2x	+x

$0.10 + 2x + x$

$0.10 + 2x^2$

APPENDIX G: ITERATIVE THEORETICAL PROPOSITIONS AND CORRESPONDING CODES

Initial

Theoretical Framework		Codes
Culturally Relevant Pedagogy	Pedagogical Goals (Ladson-Billings, 1995; Moore Mensah, 2011)	Academic Achievement
		Cultural Competence
		Critical Consciousness
	Values & Practices	Caring (Darder, 2002; Parsons, 2005)
		Reflection (Freire, 1998; Howard, 2003)
Critical Pedagogy		Dialogue (Freire, 1970; Howard, 2003)
	Curriculum Planning & Design	Learning for transformation (Duncan-Andrade & Morrell, 2008; Rodriguez, 1998)
		Praxis (Freire, 1970; Mutegi, 2011)
		SSI as Generative Themes (Freire, 1970; Dos Santos, 2009)

APPENDIX G (continued)

2nd Iteration

Theoretical Framework		Codes
Culturally Relevant Pedagogy	Pedagogical Goals (Ladson-Billings, 1995; Moore Mensah, 2011)	Academic Achievement
		Cultural Competence (includes youth popular culture & indigenous ways of knowing)
		Critical Consciousness (includes ideas about decolonization, critiques of science, critiques of STS, critical ideas about race, capitalism)
	Values & Practices	Caring (Darder, 2002; Parsons, 2005)
		Reflection (Freire, 1998; Howard, 2003)
Critical Pedagogy		Dialogue (Freire, 1970; Howard, 2003)
		Comm(unity)
		Hope/Energy
		Discipline/Commitment
	Curriculum Planning & Design	Learning for transformation (Duncan-Andrade & Morrell, 2008; Rodriguez, 1998) - learning to change self or one's own life - learning to change the community - learning to change science - learning to change the world
		Praxis (Freire, 1970; Mutegi, 2011)
		Generative Themes/SSI as Generative Themes (Freire, 1970; Dos Santos, 2009)
		Value of Community/Popular/Funds of Knowledge
		Youth as producers of knowledge and culture – creating opportunities for youth to be public intellectuals

APPENDIX G (continued)

3^{rd} Iteration

Research Question 1: How can socially transformative science curriculum be developed from relevant socioscientific issues (SSI) as generative themes within the context of an advanced placement chemistry course at an urban neighborhood school serving predominately Latin@ and African American youth?

Theoretical propositions:

1A. It is possible to create curriculum that is responsive to the strengths, needs, concerns, and aspirations of marginalized urban communities while also attending to science learning standards. There is no dichotomy between curriculum that promotes academic achievement in science and curriculum that promotes cultural competence and critical consciousness (Aikenhead, Chinn, Barton, Ladson-Billings, Duncan-Andrade and Morrell, Moore Mensah).

i. *To develop socially transformative science curriculum, educators should work with students and community members to identify socioscientific issues (SSI) that are relevant in their teaching context (Dos Santos).*
    - *This requires valuing local knowledge [coal plant, drug unit in terms of blame discussion and valuing home remedies] (Freire, Gutstein, FoK articles in science ed)*

ii. *Then, it is the responsibility of the educator to find the intersections between these issues and the standards they are charged with teaching to create authentic opportunities for students to use content knowledge and skills to intervene in their lives and communities (O'Cadiz, Wong, Torres, Dos Santos, Mutegi?).*

iii. *During the implementation of curriculum, the teacher convenes co-generative dialogues so that students continue to have input into the direction of the course after the initial planning phase [notes from ESERG meetings, reflections] (Tobin, Emdin).*

iv. *To begin with learning standards or canonical science content and then try to inject some component of relevance into a traditional or reform science curriculum will be less effective at promoting all three pedagogical goals of culturally relevant pedagogy: academic achievement, cultural competence, and critical consciousness [units that did this? Stoichiometry, Equilibrium, Kinetics] (Sjostrom and Talanquer, Mutegi, Rodriguez?).*

APPENDIX G (continued)

3rd Iteration (continued)

1B. A socially transformative science curriculum must include opportunities for students to engage with the production and dissemination of scientific knowledge. This engagement must include reflection and critique about the political, cultural, economic, and historical contexts of scientific knowledge production with a focus on Western science as a tool and beneficiary of Western imperialism and a related focus on the complex contributions and other ways of knowing about nature associated with students' ancestors.

- *i. Curriculum includes examples of contributions to Western science from non-dominant people [Aspirin unit, nixtamalization, Mario Molina, Percy Julian, khem-istry]*
- *ii. Curriculum includes and values ways of knowing about nature that are outside of traditional Western science [aspirin unit with Evo Morales, other?]*
- *iii. Curriculum contextualizes Western science innovations and advancements within the history, ideology, and present constructions of colonialism, Western imperialism, white supremacy, capitalism, patriarchy [Odette interview, Cristina interview, aspirin unit, ???]*
- *iv. Students must produce real scientific knowledge.*

Research Question 2: What teaching practices and class structures support or impede the development of a critical counter-cultural community of practice within a science class at an urban neighborhood school serving predominately Latin@ and African American youth?

Theoretical Propositions:

2A. Teaching practices and course structures intentionally emphasize building community.

- *i. The class philosophy explicitly emphasizes learning as cooperative as opposed to competitive (syllabus, summer session sharing of goals and FoK, jigsawing, "We are (as opposed to I am) here...," etc)*
- *ii. Classroom rituals and routines create community, provide energy, and build a classroom counter-culture (protest music, Chicano solidarity clap, transforming the world)*
- *iii. The class is part of a program that has a legacy, traditions, and rituals. (t-shirts, TAs, lab report common rubric and awards, demonstrations at assemblies and report-card pick-up, cultivating interest without limiting access in course selection)*

APPENDIX G (continued)

3rd Iteration (continued)

- *iv.* *The teacher makes decisions about when deviate from the planned curriculum in order to be responsive to students' realities in and outside of the classroom. (Ms. W & acute crisis,ICE tables and ongoing trauma that surfaces)*
- *v.* *The teacher "practices what s/he preaches" (modeling community involvement and ongoing learning with COVER, grad school, struggle for LL)*

2B. Teaching practices and course structures respect students as producers of knowledge and culture.

- *i.* *Students are treated as (public/barriorganic) intellectuals*
  - *a.* *Students are put in pedagogical roles in the classroom, in the community, and in academic settings (like conferences).*
- *ii.* *Questioning is explicitly valued and encouraged.*
  - *a.* *Uncertainty, and disclosure of bias are modeled and encouraged.*
  - *b.* *Objectivity and subjectivity are topics of examination.*
  - *c.* *The class environment is such that students can correct, question, and challenge each other and the teacher without being judgment, shaming, or embarrassment.*
- *iii.* *The teacher (through curriculum, informal talk, modeling, etc) creates and emphasizes a consistent overarching purpose to learning.*

2C. Teaching practices and course structures communicate, establish, and maintain high expectations in terms of academics and community involvement.

- *i.* *The teacher models and requires self-discipline and hard work to achieve goals above and beyond the expectations typical in an urban high school (Raquel and others have said it's the hardest class they've ever taken).*
- *ii.* *Students are provided with opportunities and supports to achieve academically by traditional measures (AP exam review, ISBE review and Odette's completion of this and subsequent skipping of the test – reflect on my shortcomings here too – should I have intervened more on her behalf?).*
- *iii.* *The teacher models a critique of traditional notions of academic achievement and provides opportunities and supports for students to do the same (goal setting and reflections, stereotype threat assignment in soph chem, syllabus, science ed as a civil right).*

APPENDIX G (continued)

4th Iteration

Research Question 1: How can socially transformative science curriculum be developed from relevant socioscientific issues (SSI) as generative themes within the context of an advanced placement chemistry course at an urban neighborhood school serving predominately Latin@ and African American youth?

Theoretical propositions:

*1A. It is possible to create curriculum that is responsive to the strengths, needs, concerns, and aspirations of marginalized urban communities while also attending to science learning standards. There is **no dichotomy** between curriculum that promotes academic achievement in science and curriculum that promotes cultural competence and critical consciousness (Aikenhead, Chinn, Barton, Ladson-Billings, Duncan-Andrade and Morrell, Moore Mensah).*

- v. *To develop socially transformative science curriculum, educators work with students and community members to identify **socioscientific issues (SSI) as generative themes** that are relevant in their teaching context (Dos Santos).*
  - a. *This requires **valuing local knowledge** and **youth popular culture** [coal plant, drug unit in terms of blame discussion and valuing home remedies] (Freire, Gutstein, FoK articles in science ed)*
- vi. *The educator finds the intersections between these issues and the standards they are charged with teaching so that the knowledge and skills taught are useful as **students intervene in their lives and communities** (O'Cadiz, Wong, Torres, Dos Santos, Mutegi?).*
- vii. *During the implementation of curriculum, the teacher convenes **co-generative dialogues** so that students continue to have input into the direction of the course after the initial planning phase [notes from ESERG meetings, reflections] (Tobin, Emdin).*

*1B. A socially transformative science curriculum must include opportunities for students to **engage with the production and dissemination of scientific knowledge**. Engagement includes students producing and disseminating scientific knowledge themselves and developing an understanding and critique of how scientific knowledge is and has been constructed (Rodriguez, 1998 reflexivity and Strojstrom & Talanquer, 2014).*

- v. *Curriculum includes examples of **contributions from non-dominant people** to Western science, especially contributions made by students' ancestors [Aspirin unit, nixtamalization, Mario Molina, Percy Julian, khem-istry](Sleeter, Romero – see ethnic studies & science education editorial, also see Rodriguez on this in 1998 sTc article – it can't just be this, think about reflexivity)*
- vi. *Curriculum includes and **values non-Western ways of knowing** about nature [aspirin unit with Evo Morales, other?]*

APPENDIX G (continued)

4th Iteration (continued)

- vii. *Curriculum* ***contextualizes Western science*** *innovations and advancements within the history, ideology, and present constructions of colonialism, Western imperialism, white supremacy, capitalism, and patriarchy [Odette interview, Cristina interview, aspirin unit, ???] (Rodriguez' reflexivity from sTc is important here)*
- viii. *Curriculum includes authentic assessments wherein* ***students produce and disseminate science knowledge*** *(Rodriguez' authentic activity, Morrell on pedagogy of dissemination)*
- **ix.** *This must include a maintenance of* ***cultural competence*** *so that students can communicate this knowledge with their own families, neighbors, etc.*

Research Question 2: What teaching practices and classroom structures support or impede the development of a critical counter-cultural community of practice within a science class at an urban neighborhood school serving predominately Latin@ and African American youth?

Theoretical Propositions:

2A. Teaching practices and course structures intentionally ***emphasize building a counter-cultural community*** *of practice that aligns with already existing communities of practice in the school community.*

- vi. *The class philosophy explicitly emphasizes* ***learning as cooperative*** *as opposed to competitive (syllabus, summer session sharing of goals and FoK, jigsawing, "We are (as opposed to I am) here…," etc)*
- vii. ***Challenging oppression is normalized*** *(including white supremacy, patriarchy, capitalism, heterosexism, etc) in academic work and through social-political action. (hooks? Gutstein? Darder?)*
- viii. ***Solidarity and empathy*** *are valued (Duncan-Andrade, 2009)*
- ix. *The class is part of a program that has (and fits into) a* ***legacy, traditions, and rituals*** *that build community, provide energy to build upon an already existing counter-culture. [protest music, Chicano solidarity clap, transforming the world, t-shirts, TAs, lab report common rubric and awards, demonstrations at assemblies and report-card pick-up, cultivating interest without limiting access in course selection]. (Duncan-Andrade – Coach, Duncan-Andrade and Morrell, p. 71; Yosso resistant capital; Romero)*

APPENDIX G (continued)

4th Iteration (continued)

x. *The teacher is* ***responsive by knowing when to deviate*** *from the planned curriculum in times of disruption, instability, or crisis. [Ms. W & acute crisis, ICE tables and ongoing trauma that surfaces] (Duncan-Andrade, 2009)*

xi. *The teacher demonstrates* ***authentic care*** *for students* (Valenzuela, Romero, Duncan-Andrade and Morrell)

2B. Teaching practices and course structures encourage identity development for ***students as producers of knowledge and culture****.*

iv. *The teacher views and treats* ***students as intellectuals*** *(public/barriorganic/transformative) (Romero, Morrell, Said, Gramsci)*
   - a. *The teacher places* ***students in pedagogical roles*** *in the classroom, in the community, and in academic settings (like conferences). (Morrell)*
   - b. *Students are given opportunities and* ***tools to critique dominant knowledge*** *and knowledge production. (Strojstrom & Talanquer; Rodriguez*

v. *The class has a* ***dialogic environment*** *characterized by trust so that students can correct, question, and challenge each other and the teacher without judgment, shaming, or embarrassment.*
   - a. ***Questioning*** *is explicitly valued and encouraged.*
   - b. ***Uncertainty****, and disclosure of bias are modeled and encouraged.*
   - c. ***Objectivity and subjectivity*** *are topics of examination.*

vi. *The teacher (through curriculum, informal talk, modeling, etc) emphasizes* ***learning for transformation.***

vii. *Students are asked to* ***reflect on the social relevance*** *of the content and skills they learn and to articulate that relevance in speech and writing.*

2C. Teaching practices and course structures communicate, establish, and maintain ***high expectations*** *in terms of academics and community involvement for teacher and students alike.*

iv. *The teacher models and requires* ***self-discipline and hard work*** *to achieve self-identified goals that exceed the expectations typical in an urban high school [Raquel and others have said it's the hardest class they've ever taken].*

v. *Students are provided with opportunities and supports to* ***achieve academically*** *by traditional measures [AP exam review, ISBE review and Odette's completion of this and subsequent skipping of the test – reflect on my shortcomings here too – should I have intervened more on her behalf?].*

4th Iteration (continued)

vi. *The teacher models a* ***critique of traditional notions of academic achievement*** *and provides opportunities and supports for students to do the same [goal setting and reflections, stereotype threat assignment in soph chem, syllabus, science ed as a civil right] (see Rodriguez' metacognition).*

vii. *The teacher* ***"practices what s/he preaches*** *" [modeling community involvement and ongoing learning with COVER, grad school, struggle for LL] (Duncan-Andrade, 2009; Picower, Freire)*

3. Together a socially transformative science curriculum combined with teaching practices that emphasize building community, barriorganic intellectualism, and high expectations create pathways for students to ***create trajectories of participation in science and in community service or community organizing****. As students move from peripheral to central participants in scientific and social justice communities of practice, they develop emerging* ***identities as scientists, community activists, and transformative intellectuals*** *who understand these identities within the context of legacy of resistance against white supremacy, capitalism, patriarchy, and other forms of oppression*

APPENDIX G (continued)

4th Iteration Corresponding Codes:

1. Socially Transformative Curriculum Codes

1A. No dichotomy
- SSI as generative themes
- Valuing local knowledge
- Valuing youth popular culture
- Students intervene in their lives and communities
- Co-generative dialogues

1B. Engage with the production and dissemination of scientific knowledge
- contributions from non-dominant people
- values non-Western ways of knowing
- contextualizes Western science
- students produce and disseminate science knowledge

2. Teaching practices and Class Structures Codes

2A. Emphasize building counter-cultural community
- learning as cooperative
- challenging oppression is normalized
- solidarity and empathy
- legacy, traditions, rituals
- responsive by knowing when to deviate
- practices what s/he preaches
- authentic care

2B. Students as producers of knowledge and culture
- students as intellectuals
    - students in pedagogical roles
    - tools to critique dominant knowledge
- Dialogic Environment
    - questioning
    - uncertainty
    - objectivity and subjectivity
- learning for transformation
- reflect on social relevance

2C. High Expectations
- self-discipline and hard work
- achieve academically
- critique of traditional notions of academic achievement

3A. trajectories of participation in:
- science
- community organizing or service

3B. emerging identity as a:
- scientist
- community activist
- transformative intellectual

VITA

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Education:

2015
PhD in Curriculum Studies
University of Illinois at Chicago, GPA: 4.0/4.0
Dissertation Title: *Science education as a catalyst for social change? Justice-centered pedagogy in high school chemistry*
Committee: David Stovall (chair), Maria Varelas, Eric Gutstein, Ingrid Sanchez-Tapia, Alberto J. Rodriguez (Purdue University)

August 2005
Masters of Science in Education and Social Policy
Northwestern University, GPA: 4.0/4.0

December 2002
Bachelors of Arts in Chemistry with a minor in Education
University of California at Berkeley, GPA: 3.5/4.0

Teaching License:

Illinois State Board of Education Professional Educator License # 2083439
Endorsement in secondary education and chemistry (registered through July 2018)

Appointments/Teaching Experience:

Spring 2014 – Present
Visiting Lecturer, Curriculum & Instruction
University of Illinois at Chicago
Courses: ED432: Instruction and Assessment in the Urban Secondary Science Classroom, CHEM472: Teaching Methods in Chemistry, CI 551: Practitioner Research in Science Contexts ED471: Educational Practice with Seminar II (supervision of student teachers)

Spring 2012 – Fall 2013
Teacher, Science Department Chair (2006 – 2011)
Chicago Public Schools – Chicago, IL
Courses: Advanced Placement Chemistry, Chemistry, Physics, Environmental Science

Fall 2011 – Spring 2013
Teaching Assistant
University of Illinois at Chicago
Courses: ED432: Instruction and Assessment in the Urban Secondary Science Classroom, CI 551: Practitioner Research in Science Context

Grants:

Co-PI: NSF Noyce Teaching Fellows/Master Teaching Fellows, University of Illinois at Chicago, 2014-2020, $2.9 million + $1.6 million in matching funds (equal PI responsibilities with Maria Varelas and Carole Mitchener)

PI: College of Education Collaborative Community Engagement Grant, University of Illinois at Chicago, 2014-15, $5000

Publications

Morales-Doyle, D. (2014) “Reconnecting STEM and roots: Making chemistry relevant in urban communities. *Spectrum, The Journal of the Illinois Science Teachers Association. 40(1)*.

Stovall, D. and Morales-Doyle, D (2010). “Doc your block Chicago: Critical media inquiry as high school social studies for social justice.” In T. Chapman and N. Hobbel (Eds.) *Social Justice Pedagogy Across the Curriculum: the practice of freedom*. Routledge.

Morales-Doyle, D. and Frausto, A. “Chemistry with the community: Two teachers convergent paths to a critical curriculum.” In E. Morrell, K. W. Yang, & J. Duncan-Andrade (Eds.) *The Urban Pedagogy Reader.* Peter Lang (forthcoming).

Refereed Conference Presentations:

Morales-Doyle, D. (2015, April). *Catalyst for (re)evolution? Critical and culturally relevant pedagogy in secondary chemistry*. Paper presented in the related paper set “De/Reconstructing (re)evolutionary and socially just places of learning in formal science classrooms” at the annual international conference of NARST, Chicago, Illinois.

Morales-Doyle, D. (2015, March). *Relevant Chemistry in Chicago.* Presentation and poster session as part of Teacher Research Day at the 2015 annual conference of the National Science Teachers Association, Chicago, Illinois.

Morales-Doyle, D., & Frausto, A. (2012, April). *Chemistry with the community.* Paper presented at the symposium entitled “Critical Pedagogies Across Subject Areas: Comparative Perspectives from Urban Science, Elementary, and Out-of-school Educational Settings” at the annual meeting of the American Educational Research Association, Vancouver, British Columbia.

Stovall, D., & Morales-Doyle, D., (2009, April). *Doc your block Chicago: Critical media inquiry as high school social studies for social justice.* Paper presented at the symposium entitled "The Practice of Freedom: Social Justice Pedagogy in the United States" at the annual meeting of the American Educational Research Association, San Diego, California.

Invited or Sponsored Presentations, Panels, and Workshops:

Morales-Doyle, D. (2015, April). *Toward Justice-Centered Science Pedagogy.* Invited presentation at the annual business meeting of the Science Teaching and Learning Special Interest Group of the American Educational Research Association in Chicago, IL.

Suriel, R., Rodriguez, A., Gallard, A., Deves, R., Nava, B., Morales-Doyle, D., Tolbert, S., and Sanchez-Tapia, I. (2015, April). Latino/a Research Interest Group (LARIG) Administrative Sponsored Symposium on Latino/as in Science Education at the annual international conference of NARST: A worldwide organization for improving the teaching and learning of science through research in Chicago, Illinois.

Morales-Doyle, D., Segura, D., Villegas, E., Canales, K., Mora, V., Ocampo, E., and Collins, D. (2015, April). *Learning Science for Social Justice – Voices from the Field.* Equity and Ethics Committee sponsored session at the annual international conference of NARST: A worldwide organization for improving the teaching and learning of science through research in Chicago, Illinois.

Morrison, D., Rodriguez, A., Harris-Roberts, D., & Morales-Doyle, D. (2015, March). NSTA Teacher Researcher Day Panel: Embracing Diversity in Science: Benefits and Challenges of Equitable Science Education from Multiple Perspectives at the National Science Teachers Association Annual Conference in Chicago, IL.

Morales-Doyle, D. (2014, June). *Charge to the Graduates/Keynote Address.* Social Justice High School Commencement Ceremony, Chicago, IL.

Morales-Doyle, D. (2013, June). *Charge to the Graduates/Keynote Address.* Social Justice High School Commencement Ceremony, Chicago, IL.

Morales-Doyle, D. (2012, June). *Charge to the Graduates/Keynote Address.* Social Justice High School Commencement Ceremony, Chicago, IL.

Morales-Doyle, D. (2011, October). *NEIU Chicago Grassroots Curriculum Taskforce Student Forum.* Invited Panel member. Northeastern Illinois University.

Morales-Doyle, D. (2011, February). *Teachers as Organizers, Professionals, and Artists – Creating Democracy in and out of School.* Invited panel member at the North Dakota Study Group Annual Meeting, Mundelein, Illinois.

Morales-Doyle, D. & Frausto, A. (2010, February). *Practicing Transformative Teaching Across Content Areas.* Professional Development facilitated at Peoples High School in the Vallejo City Unified School District, Vallejo, California.

VITA (continued)

Morales-Doyle, D. & Frausto, A. (2009, July). *Truth versus Tricknology*. Presentation at the Tucson Unified School District Institute for Transformative Education, Tucson, Arizona.

Morales-Doyle, D. (2009, June). *Charge to the Graduates/Keynote Address.* Social Justice High School Commencement Ceremony, Chicago, IL.

Morales-Doyle, D. (2009, May). *Teaching in Content Areas for Social Justice.* Presentation to Kelvyn Park Social Justice Academy, Gary, Indiana.

Gutstein, E., Morales-Doyle, D., & Frausto, A. (2009, March). *Teaching Math and Science for Social Justice*. Presentation for Teachers for Social Justice, Chicago, Illinois.

Stovall, D. & Morales-Doyle, D. (2008, July). *Doc Your Block Chicago*. Presentation at the Tucson Unified School District Institute for Transformative Education, Tucson, Arizona.

Morales-Doyle, D. (2008, April). *Talkin' Bout: Freedom Schools*. Invited panel member in an online panel discussion on the Education for Liberation Network website.

Morales-Doyle, D. (2008, April). *Greater Lawndale Little Village School for Social Justice Science Curriculum and Assessment.* Presentation to a delegation of science educators from the Swedish government, Chicago, IL.

Morales-Doyle, D. (2008, March). *Educators Reclaiming Civic Responsibility: Teacher Activist Groups in New York, Chicago and San Francisco*. Panel presentation at the American Educational Research Association Annual Meeting, New York, NY.

Morales-Doyle, D. (2007, June). *Teacher as Activist: Organizing Collectively for Justice*. Workshop at Education for Liberation Network Free Minds, Free People Conference, Chicago, IL.

Morales-Doyle, D. (2007, June). *The Halls of Justice: Creating and Sustaining a Social Justice School*. Panel Presentation at the Education for Liberation Network Free Minds, Free People Conference, Chicago, IL.

Morales-Doyle, D. (2007, April). *Linking Research and Activism for Social Justice in Chicago: An Invitation to Dialogue*. Panel presentation at the American Educational Research Association Annual Meeting, Chicago, IL.

Morales-Doyle, D. (2006, November). *Environment through the lens of Children and Family Law: The slow effects of lead-paint on children, families, and the community.* Invited panel member. Northwestern University School of Law, Chicago, IL.

VITA (continued)

Consulting, Fellowships, Boards, and Committees:

July 2014 – Present	Local School Council Community Representative Eberhart Elementary School, Chicago, IL
July 2009 – June 2012	Advisory Local School Council Teacher Representative Chicago, IL
January – July 2008	Curriculum Developer Black Youth Project Center for the Study of Race, Politics, and Culture University of Chicago
Summer 2005, 2006	Teacher Fellow Center for Curriculum Materials in Science School of Education and Social Policy Northwestern University
Summer 2006	Collaborating Teacher Chemistry Literacy Project Graduate School of Education University of California, Berkeley
Fall 2005	Member, High School Transformation RFP Selection Committee Chicago Public Schools
Fall 2004 – Spring 2005	Facilitator, ChemCom Professional Development Group Chicago Public Schools Math & Science Initiative
Spring 2003	Member, Textbook Selection Process Chemistry Working Group Chicago Public Schools Math and Science Initiative

Professional Organizations:

2009 – Present	American Educational Research Association, Student Member (Divisions B, G, and K)
2012 – Present	NARST – A worldwide organization for improving science teaching and learning through research, Graduate Student Member
2014 – Present	National Science Teachers Association
2004 – Present	Teachers for Social Justice, Chicago (Coordinating Committee Member, 2007-08)