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Critical Climate Awareness:

Re-imagining Climate Change Teaching and Learning

A dissertation submitted in partial satisfaction of the requirements for the degree

Doctor of Philosophy

in Education

by

Heather Freeman Clark

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ABSTRACT OF THE DISSERTATION

Critical Climate Awareness:

Re-imagining Climate Change Teaching and Learning

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Professor William Sandoval, Chair

The objective of this dissertation was to design and study a transformative model of climate change education that foregrounded sociopolitical processes and was socially relevant to Black and Latinx urban high school students. The intervention was implemented at the Mann-UCLA Community School in South Los Angeles while distance learning was mandated by the COVID-19 pandemic and was part of a research-practice partnership with a chemistry teacher. Using the Participatory Design Research methodology, I designed the learning context and documented how this instructional model structured classroom engagement and supported the outcomes of learning climate science and developing critical climate awareness. A mixed methods approach was used for analysis of data including pre/post assessments of climate science knowledge and climate concern, formative assessments of critical awareness of climate change, classroom artifacts, classroom observations, and interviews with focal students. Findings on classroom engagement, organized with the Connective and Productive Disciplinary Engagement framework, show that organizing instruction around the sociopolitical dimensions of climate change was productive. Participation was structured around students' critical awareness of social issues in their community and their imagined futures when they could participate in the transition to low-emission energy sources. Student engagement embodied the four principles of Connective and Productive Disciplinary Engagement more strongly over time as they grappled with authentic problems of climate change in their community. The sociopolitical framing of climate change was also productive for learning climate science concepts and developing students' critical climate awareness. Findings show a statistically significant improvement in students' understanding of canonical scientific concepts and a shift towards awareness of and concern about climate change. Performance on formative assessments shows students made progress in explaining critical aspects of climate change, specifically in ascribing agency for causes and solutions. The significance of these findings is that centering sociopolitical, local dimensions of climate change does not diminish canonical, standard-aligned learning opportunities. Foregrounding social justice and inviting students' critical awareness into the science classroom as a sensemaking resource supported many students in developing sophisticated explanations of climate change in their community. This research contributes an approach to climate change instruction that advances culturally-relevant, justice-centered science pedagogy.

The dissertation of Heather Freeman Clark is approved.

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2022

DEDICATION

For Agustín, my North Star. You guide, orient, and inspire me.

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I thank the chemistry students at Mann-UCLA Community School classes of 2021, 2022, and 2023. Earning the trust and respect of these bright, bold, resilient students was a privilege. I promise to do everything I can to help them build a future where they can thrive.

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Chapter 1: Introduction

Earth's climate is warming at an unprecedented rate due to carbon-fueled industrial capitalism (UNESCO and UNFCCC, 2016). The resulting disruption to the global climate systems are causing a socioecological crisis that has disproportionate consequences for marginalized and vulnerablized communities (Francis, 2015; Klein, 2014; Wheeler, 2011). Science educators have an obligation to prepare youth to engage as informed and critical stakeholders regarding the socioecological future but are failing to help learners know what to actually do with the knowledge and skills they develop in schools (Drewes et al., 2018; Holthuis et al., 2014; NRC, 1996, 2012).

Both climate change and science education face critical issues of equity, and at the nexus of these two issues are a range of unique challenges to providing rigorous and actionable science education for minoritized students. First, minoritized students are historically and currently under-served and underestimated in school science classrooms, where deficit perspectives are pervasive (Barton, 2003; Medin & Bang, 2014a). Second, while the climate crisis impacts low-income communities of color first and hardest, ontologically, climate change is not a reality relative to other social and environmental threats (Levinson, 2012). Third, the persistent and narrow focus on a mastery of disciplinary knowledge as the desired outcome of school science lessons ignores the evidence that simply understanding the scientific principles of the climate system is not enough to support action (McNeill & Vaughn, 2012; Stevenson et al., 2016). Instead, a constellation of outcomes—many of which are disruptive to the status quo of schooling—are needed. Last, all youth must learn to live low-emission lifestyles in order to ensure a sustainable future. However, it is unjust to ask those living in poverty to shoulder the responsibility of undoing the damage from past emissions (Henderson et al., 2017).

Project Objectives

The objective of this dissertation was to design a transformative model of climate science education. As a model of instruction, it addressed a wide range of conditions in the learning environment, such as curriculum, participation structures, and power dynamics. In terms of being transformative, it disrupted the status quo by a) foregrounding the social and political mechanisms that drive scientific processes and b) making climate science immediately meaningful and useful to students. The designed transformative outcome was the development of critical climate awareness. I build on Freire's (1970) general notion of critical awareness and conceptualize an understanding of the systems and structures that create and sustain climate inequalities. After participating in the instructional intervention, the goal was that the students would better understand local climate socio-scientific pheneomona and potentially take action on climate issues in their communities. Additionally, I hope to advance an understanding of climate science learning as political by centering power dynamics in my investigation (McKinney de Royston & Sengupta-Irving, 2019; The Politics of Learning Writing Collective, 2017).

Research Questions

As a design-based research study, the intervention is an important aspect of this dissertation (DBR Collective, 2003). I seek to understand student learning and participation as products of the intervention context and aim to answer two questions within the transformed activity: (1) How does instruction that emphasizes the sociopolitical dimensions of climate change support the learning of climate science and the development of critical climate awareness? (2) In what ways do the sociopolitical dimensions of climate change structure engagement in climate change learning?

Chapter 2: Conceptual Framework

In this chapter, I first present background literature on climate change education including how climate science appears in science education standards for the first time, the shift to teaching science as a practice, and a review of effective climate science classroom interventions. I also present a synthesis of three transformative approaches to science education—socio-scientific issues (SSI), place-based and critical approaches—which I argue support the design of this novel instructional model. Second, I present my theoretical framework anchoring this work in a sociocultural perspective. Last, I situate my work in the Connective and Productive Disciplinary Engagement (CPDE) framework. In this section I operationalize key concepts such as equity, critical climate awareness, and the political and relational dimensions of climate science learning, as well as the principles of CPDE that guided my design and analysis.

Background

Situating Climate Change Education in Current Science Education Reforms

The Next Generation Science Standards (NGSS) represent the most progressive standards for science education yet because they strive to support learning science as a dynamic set of practices rather than a fixed set of knowledge. Importantly, they are the first standards to offer teachers the opportunity and incentive to discuss themes that center on the human impact upon the environment, including climate change (NGSS Lead States, 2013; NRC, 2012). For all of the positive features of the NGSS, they are still imperfect in many ways—three of these imperfections are central to this work.

First, the NGSS are flawed in their conceptualization of equity. The NGSS maintain the status quo of science by aligning accessibility with equality and prioritizing measurable and reproducible performance without interrogating structural inequity or representing diverse perspectives (Hoeg & Bencze, 2017; Rodriguez, 2015). This lack of interrogation includes problematizing epistemological assumptions and therefore the NGSS ignore epistemological diversity that is essential in supporting students from non-dominant communities (Bang & Marin, 2015). Neoliberal ideological commitments embedded in the NGSS ignore the harms that can result from scientific enterprises as well as the unequal distribution of those harms (Morales-Doyle et al., 2019). When teachers develop their instruction around the NGSS, it can be argued these standards position teachers as promoters of this status quo of the scientific enterprise.

Second, the demands of the NGSS pose significant challenges for practicing teachers. To shift to the new standards entails radical changes, such as organizing curriculum around natural phenomenon that require explanation and reorganizing the discursive practices within the classroom (Reiser et al., 2017). For example, Anderson et al. (2018) designed an intervention to support NGSS-aligned learning of the carbon cycle that was implemented at 94 schools and found that the schools with the most resources were the most successful and that all partners required substantial investment in material, human, and social resources. Even with extensive professional development, teachers struggle to support the productive student to student dialogue that is required for authentic engagement in science practice (Sandoval et al., 2018).

Third, the NGSS are flawed in their conceptualization of environmental issues. The NGSS scrupulously avoid the social and political aspects of climate change and climate action, leaving teachers to figure out for themselves how to fill the gap. While sustainability is included throughout the standards, environmental challenges are presented from the ontological stance of universalism and the epistemic stance of scientism which combine to exclude the socio-political dimensions of the challenge (Feinstein & Kirchgasler, 2015). Additionally, the NGSS promote disconnected agency with problematic themes embedded in performance expectations, such as the environment existing as an entity separate from humans and ascribing agency to autonomous actions or process (like combustion or industrialization) rather than to specific social actors (Hufnagel et al., 2018). I have found that when teachers strive to learn and align their instruction to the NGSS, they adopt the embedded problematic values (Clark et al., 2020).

Climate Change Education Challenges and Interventions

Classroom intervention research has illuminated numerous unique challenges and pitfalls as well as supported the development of best practices in climate change education. Teaching climate change is challenging for educators for a range of reasons including the following: teachers often do not know the fundamental geoscience underlying climate systems; the topic is undeniably social and emotional, making the common (and harmful) practice of presenting science as objective difficult; it is politically divisive; and it is trans-disciplinary, while school science is taught in silos (Arslan et al., 2012; Hestness et al., 2014; Jacobson et al., 2017; Kahan, 2012; McKenzie & Bieler, 2015; Plutzer et al., 2016; Shepardson et al., 2012). Additionally, Sandoval et al. (2016) suggest that teachers need to know the epistemology of science and the applications of science to students' everyday lives. However, there is no indication that science teachers are prepared to grapple with the uncertainty that is inherent in the conflicting information surrounding climate change discourse in the United States.

For students, learning climate change is challenging for another set of reasons. Research has extensively documented students' confusion and misconceptions about the persistent and enduring causes and consequences of climate change (Breslyn et al., 2017; Drewes et al., 2018; Plutzer et al., 2016). While disciplinary knowledge is only one valuable outcome of schooling, evidence in environmental education suggests that a basic understanding of the scientific phenomenon behind an issue (for example, the mechanisms of the greenhouse effect) is critical for taking effective environmental action (Robelia & Murphy, 2012). Therefore, students' persistent confusion after instruction on topics such as the carbon cycle, the greenhouse effect and the impact of various pro-environmental behaviors may represent a legitimate barrier to developing a capacity to engage with climate change problem solving. Second, the spatial and temporal distance of many of climate change's consequence renders the phenomenon a distal threat (Hanson-Easey et al., 2015). Specifically, many students' perception of the idea of climate change as abstract can partly be understood as a result of both the geographic distance and the future-orientation of the most worrisome consequences. The distal nature of this threat may cause learners to struggle with the reality of changes and as a result, they distance themselves from the phenomenon. This psychological distance may be compounded for urban students of color due to the normative narrative of climate change that is most prominent in public discourse. The conversations around climate change are dominated by a white middle-class narrative associated with the environmental movement which may not resonate in urban minority neighborhoods (Lewis & James, 1995; Schlosberg & Collins, 2014; Tzou et al., 2010). As a narrative of environmental justice is becoming more prominent, it is essential to anchor climate education in the narratives of youth and not assume that the dominant narrative is relevant.

In spite of these and other challenges, interventions have illuminated a number of effective practices, each of which support a specific outcome for students learning about climate change. Within the most cumulative review of literature in the field, Monroe et al. (2019) point to a broad strategy for supporting climate science disciplinary understanding which is to make climate science immediately useful and relevant to students' everyday lives. They suggest several specific teaching strategies; First, the strategy of engaging students in discussions about their own and others' viewpoints on climate change increased support for the scientific consensus of anthropogenic warming and helped students reconcile contradictions in climate change theories (Holthuis et al., 2014; Klosterman & Sadler, 2010). Second, the strategy of engaging learners in designing and implementing school or community projects to address a specific aspect of climate change (such as making a public service announcement) supports shifts in students' attitudes and behaviors including participation in pro-environmental activities (Rooney-Varga et al., 2014). Additionally, a wide range of novel instructional interventions involve practices that support more diverse outcomes. For example, instruction with agent-based computer models helps students understand the climate as a complex system, instruction with interactive visualization can reduce deceptive clarity, and epistemological discourse can support climate change concern (Holthuis et al., 2014; Jacobson et al., 2017; Svihla & Linn, 2012). Lastly, in a conceptual argument developed from their work with Indigenous communities, McGinty and Bang (2016) recommended that climate science learning: a) emerge from place, b) be informed by critical historicity, c) actively disrupt power structures, and d) target political and collaborative shifts. They argued that these principles can support marginalized learners in developing the transformative social relations that will be required to address inequity in education and climate.

While these successes are laudable, the important fact remains that current approaches to climate science education do not prepare students to use their knowledge to take any concrete action (Drewes et al., 2018; Holthuis et al., 2014; Tasquier et al., 2016). I interpret the concern about preparing students to actually do something as relating to the worry that students do not transfer their school-based learning to out-of-school, everyday contexts that matter in their lives. This is not surprising for climate change learning, as it is largely true for science learning in general. There exists an "empirical vacuum" in regard to if, how, when, and why students transfer their science learning (Feinstein, 2011, p. 2). Unfortunately, “next to nothing” is known about how students’ participation in science class impacts their judgment of science-related issues in everyday contexts (Sandoval et al., 2016, p. 482).

The complexity of climate science and the controversy surrounding climate change may magnify these challenges, as may the absence of justice and equity-oriented teaching approaches. To understand how to support students in translating the learning and skills they develop in school into reasoning and actions around issues that matter to them in their communities, it is necessary to look beyond climate science education research. As Lundholm (2019) argued, it is necessary to shift the framing of climate change to recognize the phenomenon as one piece of a large-scale collective action dilemma. Below I will review three distinct, transformative approaches to education that have synergy and can support efforts to design equitable and empowering instructional models of climate science learning.

Socio-Scientific Issues Approach

The goal of an approach to science education anchored in SSI is to empower students to handle the science-based issues that shape their current and future worlds. A SSI is defined as a complex, open-ended, ill-structured, and often contentious dilemma with no definitive answer that is informed by economics, social, political, and ethical considerations and in which there is a central role for both social and scientific factors (Sadler, 2004). Framing science instruction around SSI has a transformative potential because this instruction method can position science classrooms as a context in which students have the freedom to explore issues that are both scientifically and socially significant, preferably as judged by those students. This contrasts with traditional approaches to teaching science because of the emphasis on inquiry and problem-solving (Sadler, 2009).

Decision making based on complex and contradictory evidence is a robust topic of interest in SSI research that illuminates some of the challenges of designing climate science learning opportunities to support diverse types of engagement and action. Environmental issues in general, as a type of SSI, are difficult to act upon because there is a general gap in awareness between the goods and services that humans rely on and the impact of those goods and services on the environment (Hadjichambis et al., 2015). Part of this gap stems from the fact that evidence on environmental impacts is often uncertain and contradictory (Kollmuss & Agyeman, 2002). When presented with complex evidence on SSI, youth often do not recognize ambiguity in the evidence and may assume that conflicting evidence means that the scientific community has not yet reached a consensus and as a result, primarily make decisions that rely on common sense rules or values (Albe, 2008; Emery et al., 2015; Zeidler & Newton, 2017).

Climate change is arguably the quintessential SSI and successful learning environments have been designed that focus on climate science learning from a SSI approach (Colucci-Gray, 2014; Zangori et al., 2017). The real potential of an SSI approach to climate science education is that it offers the opportunity for students to explore the ways in which the world can be socially just. Most research on SSI does not engage issues of inequity and history, similar to traditional schooling, but the porous boundaries of the SSI approach create expansive opportunities for teaching the socio-political aspects of climate change. As Levinson (2012) suggested, the power of a SSI approach to climate change education may lie in asking students what actions can they take to help achieve a just society instead of simply asking them what they know, think, and feel about environmental issues.

Community and Place-Based Science Approach

A second approach to science education with transformative potential is a community- or place-based approach. From this perspective, local spaces—including ecological and built features—are educational assets. This approach works against the isolation of schools from the communities they are part of and helps students understand place as a social construct by foregrounding narratives of local and regional politics (Gruenewald, 2003). A place-based approach serves to transform students' first-hand experiences into resources that support the relevance and meaningfulness of scientific concepts for engaging in that place (Smith, 2007). In practice, this is often accomplished through simulating social and community problem solving or inviting students to solve real-world problems that they have identified (Bouillion & Gomez, 2001; Buxton, 2010). For example, one classroom intervention supported middle school students in designing solar powered recycling bins to address the local problem of diverting waste away from landfills as well as the global problem of reducing carbon emissions (Schenkel et al., 2019).

Community and place-based approaches to science education can be transformative in climate science learning because these approach makes it impossible to separate social and scientific processes as they manifest in a community. Therefore, implementing these approaches can be an excellent way to help students unpack socially unjust consequences of climate change—many of which are linked to colonialism, capitalism, and racism (Ghosh, 2016). To reach this potential, it is essential to start place-based pedagogy from students' narratives of place rather than assume that dominant environmental narratives resonate with urban youth (Tzou et al., 2010). Students' narratives of place would also honor diverse human-nature relationships that learners bring to the classroom (Bang & Marin, 2015; Medin & Bang, 2014b).

Critical Approach

Critical approaches to education may be particularly important in understanding climate change learning because of the centrality of power dynamics within this approach. As Esmonde and Booker (2017) asserted, power is ever present in all learning contexts and no learning design can successfully disrupt power if power is not taken in to account. This understanding of learning as inseparable from social life and geopolitical projects can support the conceptualization of and design for equity in learning (McKinney de Royston & Sengupta-Irving, 2019; Nasir & Hand, 2006). The work of Paulo Freire (1970) on critical pedagogy and transformative approaches to education provides essential conceptual tools for understanding the relationship between education, power, and oppression in order to help bring about equitable social transformations (Vossoughi & Gutiérrez, 2017). The majority of climate science education currently taking place in schools is aligned with what Freire would describe as the banking model of education because it socializes students into the world as it is. The banking model of science education teaches a depoliticized version of the scientific phenomenon. Hodson (2003), in advocating for an action-oriented science curriculum, warned of the senselessness and harm caused by depoliticizing science education. He argued that when teachers and curriculum avoid confronting political interests and social values underlying scientific practices that students, as young citizens, may not "look critically at the society we have, and the values that sustain it" and may not ask "what can and should be changed in order to achieve a more socially just democracy to ensure more environmentally sustainable lifestyles" (p. 654).

A problem-posing approach—Freire's contrast to the banking model—offers an alternative in which students can imagine and create the world as it could be (Vossoughi & Gutiérrez, 2017). To strive for this outcome, it is essential to develop critical consciousness, described as reflection and action upon the world in order to transform it, and sociopolitical consciousness, described as the ability to critically analyze the political, economic, and social forces that shape society and one's status in it (Madkins & McKinney de Royston, 2019; Vossoughi & Gutiérrez, 2017). Freire and other scholars in his lineage have conceptualized these developmental outcomes as antidotes to structural oppression because they can unlock individual and collective agency that is constrained by sociopolitical inequality (El-Amin et al., 2017). Furthermore, they can replace an individual's feelings of isolation and self-blame for their challenges by instilling a sense of engagement in the broader collective struggle. The development of these types of consciousness occurs in ongoing cycles, with one stage being the development of critical awareness, which involves gaining knowledge about the systems and structures that create and sustain inequity (El-Amin et al., 2017).

Various scholars have worked to adopt Freire's vision of education to develop justice-oriented pedagogies. The most established is Ladson-Billings' (1995) culturally relevant pedagogy which has been widely adopted for many disciplines but remains under-developed for science education. Below I will describe the efforts by two groups of scholars to develop disciplinary-oriented critical approaches for science education. First, Barton and other colleagues conceptualize critical science agency (CSA) as an outcome of science learning for minoritized youth (Barton, 2003; Barton & Tan, 2018; Basu et al., 2009). They explained that the development of CSA involved students a) gaining a deep understanding of science and the modes of inquiry associated with scientific concepts, b) identifying themselves as experts in one or more realms associated with science, and c) using science as a foundation for change, such that as their identity develops, their position in the world also advances. Their ethnographic and design studies were often focused on identity development and the leveraging of diverse resources in science learning spaces to support both agency and disciplinary knowledge.

Some scholars have adopted the concept of CSA for climate science education. Specifically, McNeill and Vaughn (2012) aligned the outcome of CSA with the definition of a climate literate person as someone capable of making informed and responsible decisions with regard to actions that may affect climate. Second, Morales-Doyle (2017, 2019) developed social justice science pedagogy as a framework to challenge large scale oppressive structures (such as white supremacy) by addressing inequality in science education. This work theorizes that anti-oppressive, critical education is a catalyst for social transformation. Through chemistry classes, Morales-Doyle implemented Youth Participatory Action Research to position students as transformative intellectuals able to address problems of social and scientific inequality. These critical approaches to science learning provide educators the opportunity to build on existing pedagogical strategies as well as develop conceptual tools for transformative instructional models. Centering power dynamics in the design and investigation of climate science learning may bring the outcomes of equity, critical awareness, and social transformation into reach.

Synergy in Transformative Approaches

In exploring these three approaches to science education—SSI, community-based, and critical—it is clear that there are several important areas of overlap as well as gaps in the conceptualized tools and empirical evidence. The synergy in these approaches supports the design rationale of this project. Working at the intersection of these approaches may allow me to fill some of the existing conceptual gaps. First, the synergy that exists at the convergence of these approaches offers support and principles for imagining a form of climate science education that goes beyond teaching just the science. In adhering to all three approaches, educators are encouraged to value the social and political context as essential educational assets and strive for students to experience science as relevant and to understand canonical science concepts.

The potential benefits of working at the nexus of these approaches has been highlighted in a few instances. For example, in Dos Santos' (2009) work developing a critical approach to scientific literacy, he conceptualized SSI as parallel to generative words used in Freirean approaches to literacy. In this case, SSI and critical approaches are complementary and generative because understanding and taking action on SSI embodies the principles of praxis. Similarly, Buxton (2010) implemented a social problem-solving intervention aiming to engage students in praxis and found that local, community-based actions represented the most accessible sites for action. Further examples include designed opportunities for students to co-opt school tasks for exposing, critiquing, and addressing their own experiences of injustice and for teachers to notice, solicit, and legitimize students' lived lives and community-based wisdom (Barton & Tan, 2019; Barton et al., 2020). Lastly, nearly 20 years prior, Hodson (2003) asked, "What kind of science education is appropriate as preparation for this relatively unknown world?" (p. 648). His response was to conceptualize a politicized science education that gave students the opportunity to confront real world issues by grounding content in socially and personally relevant contexts. In 2022, the world is substantially and rapidly changing and likely to only become more complex and uncertain. Thus, the need for politicized science education at the nexus of these three transformative approaches is more essential than ever.

I see three gaps in these approach that can each connect to the challenges and opportunities in climate change education. First, each approach tends to focus on interventions at different scales; SSI and place-based approaches are most often used to develop stand-alone units or curricula while a critical approach is used to develop broader scale pedagogical philosophies. To develop a model of instruction, both practical, implementable unit-level strategies and holistic, theory-driven philosophies are needed. Second, I identified that all three approaches lack clarity on how to support students in actually putting their school science learning into action, which is noted a shortcoming in climate change education research (Drewes et al., 2018; Holthuis et al., 2014). While an orientation to action can be found in place-based and critical approaches, neither the design principles nor conceptual frameworks exist to help teachers as facilitators of learning or students as learners in translating science learning to climate action. Because climate change is a result of complex power dynamics across social, temporal, and spatial scales, it is impossible to learn about or act upon climate change without understanding power. Reimagining climate education will require moving away from the banking model of education and embracing outcomes of schooling beyond disciplinary learning.

The third gap that exists amongst these approaches is the clearly operationalized definitions of what the social, political, and relational features of climate science learning entail. Since foregrounding these features is advocated across the approaches, it is necessary for teachers and researchers to have a pedagogical strategy in order to understand which features of social, political, and intrapersonal life are important to learners. Conceptual work drawing on civics education and scientific literacy begins to highlight these concepts by defining two political orientations that science education needs to address: the use of scientific knowledge in making decisions on legitimate areas of public concern and the production of scientific knowledge by promoting and regulating various fields of research (Rudolph & Horibe, 2016). Ambiguity in these concepts may need to be defined for each learning environment or research context, but some guiding definitions that apply to climate change broadly are needed as a starting point.

Theoretical Framework

The principles of sociocultural theory guide my conceptualization of learning, the design of the learning environment, and the analysis of change in students' participation throughout this dissertation. Specifically, the principles of learning as participation and prolepsis are central to this work. Vygotsky's (1978) original sociocultural theory suggests that learning occurs through social interactions by internalizing and generalizing functions that are first encountered socially. From this perspective, Rogoff (2003) described learning as a transformation in participation. This participation can also be described as diverse repertories of practice that an individual acquires through engagement in cultural practices (Nasir et al., 2014). The important implications of this definition of learning for this dissertation are that authentic opportunities to engage in culturally meaningful practices support learning and that I can work to organize activities that move students towards greater engagement and recognition in the domains of climate science and critical awareness of inequalities (Nasir & Vakil, 2017).

The principle of prolepsis is also central to a sociocultural understanding of learning and thus is a critical tool in understanding how the past, present, and future interact in moment-to-moment interactions. Cole (1996) described prolepsis as "the cultural mechanism that brings 'the end into the beginning'" (p. 183) and "a nascent experience of the future in the present" (p. 184). The implication of this principle for my dissertation is that both the history and projected future of a student matter in learning. Understanding how interactions between teachers and students relate to cultural history and inform participation in activities in the present opens expansive educational opportunities.

My theoretical understanding of learning as proleptic is powerful for my goals of achieving equity in education because I believe that through learning, individuals can re-mediate and re-imagine the world as it could be (Cole & Griffin, 1983; Gutiérrez & Vossoughi, 2010). Organizing climate science instruction for what is "not yet" can support hope and possibilities in students by orienting learning as "a formative anticipation of a possible future" (Vossoughi & Gutierrez, 2017, p. 139). As both a theory and a consequential everyday practice, prolepsis forms the basis of Bang and Vossoughi's (2016) description of transformative social change as:

> The interweaving of structural critiques with the enactment of alternative forms of here-and-now activity that open up qualitatively distinct social relations, forms of learning, and knowledge development, and contribute to the intellectual thriving and well-being of students, teachers, families, and communities. (p. 175)

Through this dissertation, I aim to promote transformative social change in one science classroom. A sociocultural theoretical framework will allow me to study the interactions between students' histories, here-and-now activities, and dreams for the future.

Connective-Disciplinary Engagement in Developing Critical Climate Awareness

In this dissertation, I look to observable qualities of group interaction for their analytical import (Engle, 2012; Erickson, 1992). To methodologically accomplish this in alignment with my theoretical assumptions, I must operationalize several concepts. First, I provide a definition of equity that guided this work in order to explicate how my scholarship seeks to address and provide an understanding of hierarchical relationships of power within my research setting (Philip et al., 2018). My definition aligns my methods with my ethical commitments and helped me answer Vossoughi and Vakil's (2018) question about "to what end" I hope students will learn in my design. Next, I describe my conceptualization of critical climate awareness and what it means for a student to develop this outlook. Last, I describe the CPDE framework and how it forms the foundation of how I document participation in science learning (Agarwal & Sengupta-

Irving, 2019; Engle & Conant, 2002). My definition of critical climate awareness rests on an understanding of the connective-disciplinary dimensions of learning—specifically the political and relational aspects—and therefore I end this section by connecting my understand of CPDE as a mediating process to critical climate awareness as an outcome of participation.

Defining Equity

My guiding definition of equity explicitly stands against any definition of success in science education that contributes to economic inequality or environmental degradation. For this dissertation, I adopt Morales-Doyle's (2019) definition of equity, which is to:

> Equip students to survive in the world as it is while we inspire them to imagine and fight for the world in which they and others would thrive. This means that students have access to sanctioned knowledge and institutional opportunities even as they develop critiques of that knowledge, alternate forms of knowledge and techniques to deconstruct and destabilize oppressive institutions. (p. 5)

Designing learning environments from a perspective that centers power and politics requires critical consideration of how students will utilize learned content. I am not designing for an outcome wherein students maintain the status quo of climate change, but rather one in which students feel empowered to disrupt inequality and work collectively towards justice. The nature of the NGSS requires that I make my commitment to equity and disrupting the status quo explicit because there are performance expectations (PEs) in the NGSS that encourage students to perpetuate the harm and injustice of the scientific enterprise, such as by exploring engineering solutions to exploit unconventional fossil fuels (PE high school earth science and systems 3-2). I believe it would be unethical and inequitable to design a lesson that supports students in applying their disciplinary knowledge to this end. As Morales-Doyle (2019) asserted, "When we recognize that inequity is intertwined with the forces of imperialism and capitalism that have caused global warming and global conflict, we are forced to consider the ends and the content of an equitable science education differently" (p. 5). My critical approach problematizes the NGSS and the status quo of science education in order to highlight the power and politics inherent in the science of the climate crisis.

This definition of equity also guides my considerations and transformative vision of a future that is more socio-ecologically just. Socioecology refers to a view of systems in which ecological and built structures and agents are inseparable and interacting across levels. This view of nature/culture relations makes it possible to see how current systems and practices—ranging from governance to teaching—are complicit in the stagnation of socioecological challenges and also makes it possible to imagine transformative futures (Bang & Marin, 2015). This relational perspective centers partner-like power dynamics in decision making and participation.

Defining Critical Climate Awareness

Critical climate awareness is an understanding of the systems and structures that create and sustain climate inequality. The systems and structures of climate change include scientific, social, political, and economic structures and systems. The two scientific systems relevant to high school level science are the greenhouse effect and the carbon cycle. Economic and political systems include carbon-based, extractive infrastructures managed by capitalist and governmental institutions to fulfill development and profit-driven agendas while social systems relate to the lifestyle that cheap carbon affords the human population. Climate inequalities speak to the distribution of climate consequences, specifically the inequality in the geographic distribution of extreme or disrupted climate patterns as they correspond with socially and economically marginalized populations. These climate consequences include (among others) extreme heat, the spread of disease vectors, and sea level rise; the patterns of distribution differ between the global north and south as well as between communities in LA (IPCC, 2013; Morello-Frosch et al., 2009). This view of climate inequalities situates the consequences of climate change as experienced by collective social groups. Developing critical climate awareness requires linking an understanding of how inequality forms with why and by whom those inequalities are experienced today. This conceptualization expands the boundaries of a climate system to include the political and relational along with the scientific.

For this dissertation, I designed the chemistry learning context to present opportunities for students to explain climate change critically as a sociopolitical and scientific phenomenon. To support the outcome of critical climate awareness, my design of the learning environment was guided by the CPDE framework; I conceptualize critical climate awareness as developing through connective disciplinary engagement. Below I define CPDE to explain how these dimensions guided the design of the learning environment that afforded students the opportunity to develop critical climate awareness, and then I explain how critical climate awareness is inherently connective.

Defining Connective and Productive Disciplinary Engagement

Engle (2012) described productive disciplinary engagement (PDE) as a phenomenon observable in classrooms as well as a high-level set of design principles. Agarwal and Sengupta-Irving (2019) argued that disciplinary engagement rests upon social relations and dynamics of power and therefore advanced an addition to the PDE framework by suggesting that connectivity is also needed, evolving the framework into CPDE. Below I first define engagement, productive and connective-disciplinary (the dimensions of the framework) and subsequently define the four principles that participants embody through their engagement—problematizing, authority, accountability, and resources.

Productive

For engagement to be productive, there must be significant growth or progress from beginning to end (Engle, 2012). I assessed the productivity of engagement with three measurable outcomes and three observable interactions that are comparable at different times. The outcomes are conceptual learning (becoming aware of disciplinarily correct answers and reasons to accept those answers), increased awareness and concern for the threat of climate change, and increased critical awareness of climate change. The observable interactions include students asking new questions, rejecting normative views, asserting critical views of the discipline, and making connections between the sociopolitical and scientific climate systems.

Engagement

Engagement describes aspects of learner participation that researchers and practitioners can directly access, such as how many learners are participating in an interaction, the intensity of participation, and the responsiveness of participants to one another (Engle, 2012). I customized the measures of engagement to consider the cultural background of the students and the ways in which remote learning transforms the nature of participation. The importance of this customization is to ensure that I did not equate a lack of participation with a lack of engagement. I measured engagement by monitoring emotional displays, spontaneous reengagement, the number of students participating, responsiveness of students contributing to each other and to the overarching question/anchoring phenomenon of the storyline as well as asking unprompted questions and minimal procedural questions.

Connective-Disciplinary

A foundational argument of this work is that climate change learning is inherently and simultaneously scientific and sociopolitical. I frame disciplinary climate change learning as inseparable from connective climate change learning, and therefore describe the two dimensions as one. Based on Engle's (2012) work, for engagement to be disciplinary there must be some contact between what students are doing and the issues and practices of the discipline's discourse. For engagement to be connective, it must acknowledge the centrality of power, which is a historical and sociopolitical formation that privileges certain forms of knowing and being over others (Agarwal & Sengupta-Irving, 2019).

I conceptualize the discipline of climate change as the study of the causes, consequences, and solutions to rampant carbon emissions and global climate disruption. The discipline includes sociopolitical systems and scientific systems that are linked by the historic and current reliance on fossil fuels and the current and future transition to zero-carbon energy. Scientific systems include the chemical, physical, and biological components and processes of the hydrosphere, biosphere, atmosphere, lithosphere, and cryosphere. Sociopolitical systems include economic, political, legal, and cultural institutions. In the context of the United States and U.S. science education, it is critical to acknowledge that these sociopolitical systems are built on capitalist, racist, and colonial relationships that divide humans from nature and from one another. This view of the discipline rejects technocentric solutions in favor of a zero-carbon transition that re-imagines democracies, economies, and cultural priorities while healing injustices and inequalities. For climate change learning to be connective-disciplinary, it must include both scientific and social aspects of the discipline. The scientific aspects of the discipline are codified by the NGSS, so students working towards competence in the PEs and practices will be disciplinary. Additionally, students must have contact with the political, economic, and social dimensions that define the discipline of climate science because science does not exist independent from these features (Cordero et al., 2020). Recasting engagement as fundamentally connective expands the notion of disciplinary education as resting upon dynamics of privileged power, social relationships, sociocultural history, and personhood, and expands the concept productivity to include creating epistemic diversity and justice that safeguards the rightful presence of minoritized students in STEM (Barton & Tan, 2019).

Recasting PDE as CDPE does not add a principle to the original four, but rather expands each of the principles with a new focus on epistemic diversity as well as historicity and identity (Agarwal & Sengupta-Irving, 2019). First, the theme of epistemic diversity redresses epistemic injustices that systematically discredit the everyday sensemaking practice of minority learners that fall outside canonical western knowledge. Each principle of PDE is expanded to include privilege heterogeneity in perspectives, meanings, practices, and values of knowing and doing STEM that are historically and culturally constituted. Second, the theme of historicity and identity relates to being and becoming and elevates relationality and temporality in the principles of PDE. This theme ensures the recognition of learners as individuals who are shaped by social, cultural, and political history over time. The impact of these two foci is embedded in my description of the four principles below.

Problematizing

Problematizing is a process individual or collective action to grapple with an intellectual problem or uncertainty which are open questions from the students' perspective within reach of the students. A problem or uncertainty is genuinely problematic and not easily resolved by students, responsive to students' interests, motivations, practices, histories, identities, or values, and embodies a "big idea" of the discipline that is not obvious to students to ensure that students have a reason to care about addressing the problem. The process of grappling with, taking up, or addressing a problem or uncertainty can take the form of discussing, asking questions, debating, researching, modeling, or reflecting. It is not required that an uncertainty be solved, or a problem be fixed for problematizing to be legitimate. Within the context of connective-disciplinary uncertainties, sociopolitical dimensions are intertwined with science and elevate personal and community experiences as legitimate bases for being perplexed or doubtful about an issue.

The practice of politicizing science is essential to my conceptualization of the principle of problematizing. Politicizing involves confronting sociopolitical values underlying scientific practices to look "critically at the society we have and the values that sustain it" and to ask, "What can and should be changed in order to achieve a more socially just democracy?" (Hodson, 2003, p. 654). For climate change learning, this involves confronting the ways in which climate change is embedded in hierarchical systems, entrenched in relationships of power, and tied to particular visions of the world. The practice of students bringing their critical awareness of other social issues to their learning of science is a critical aspect of politicizing.

Authority

Authority describes the process of students having agency to play an active role in defining and addressing problems as well as encouraging cultural agency to share a diversity of perspectives. Giving students authority can involve positioning them as stakeholders in the problem they pursue, contributors to shaping collaborative problem solving, authors of knowledge, transformative intellectuals in disrupting injustices, and active participants in other intellectual roles. Engle (2012) described four types of authority on a sequential scale of least to most authority (each dependent on the prior), and she predicted that higher positioning results in higher engagement. The first type is intellectual agency; when given it, students are authorized to share what they actually think about a problem rather than being asked to simply match the ideas of teacher or textbook. This type of agency includes the authority to problematize an issue in the first place. This also includes authority for ideas informed by students' social location, identities, history, and community-based experiences. Next is authorship, in which case a student is identified as the author of an idea. Contributorship follows, wherein that idea contributes to the ideas of others. The final type of agency on the scale involves being positioned as a classroom authority, in which a student's ideas become increasingly influential over others.

The practice of politicizing science is also central to the principle of authority. Critical climate awareness includes an argument for direct or indirect political action and civic engagement in response to the climate crisis. These actions situate agency for addressing the problems of climate change in the hands of diverse constituents and elevate the authority of social movements. Embedding the practice of politicizing science in the theme of authority helps me to identify how epistemic diversity is prompted when agency comes from cultural, personal, familial, and local ways of knowing and being.

Accountability

Accountability describes students' intellectual work being responsive to the concepts, practices, and norms established by stakeholders inside and outside of the classroom. The central aspects required for students to remain accountable to a broad diversity of others are the justification of ideas and the discipline needed to construct their own understanding. Students can be asked to rationalize how their ideas make sense to themselves, peers, internal authorities, and external authorities—each explanation represents an increasing challenge for the process of justification. Students' justifications support the legitimacy of their ideas as related to their identity, culture, and history and the generativity of these ideas to the discipline, the past, present, future, and to each other.

The practice of scientizing everyday life and experiences is a key practice embedded in the principle of accountability. Scientizing involves understanding everyday practices and experiences as related to science (Ahn et al., 2016; Clegg & Kolodner, 2014). Accountability is embodied in scientizing when students identify, label, question, and reflect on the scientific concepts and practices involved in everyday observations and experience of climate change. This practice was designed as a classroom norm to ensure that students would learn to justify a claim, prediction, argument, or demand with personal, cultural, or local evidence and reasoning, thereby asserting those domains as scientific and legitimately belonging in science class. The practice of scientizing also amplifies historicity and identity within the framework of accountability because it highlights the ways in which cultural, familial, and everyday practices, language, and sensemaking can be framed as scientific practices.

Resources

Resources function at a different level than the other three principles as they support the principles. Resources include anything that students need to support their work and the sociopolitical dimensions within that work. Many resources are relational, animating identities, histories, and racial narratives, and epistemically diverse, inviting cultural and community-based experiences into disciplinary work. Relational resources used in sensemaking can be imagined as proleptic relationships, such as the transformative collaborative relationships needed to address the climate crisis. Additionally, an essential designed resource was students' critical awareness of other social issues which they used as a lens for understanding climate science and starting point for developing critical climate awareness.

Intersection of Critical Climate Awareness and Connective-Disciplinary Engagement

I used the four principles of CPDE to create a socio-politically gapless explanation of climate change in order to guide the design of the learning context. Table 1 presents critical climate awareness as consisting of five components that make up a gapless explanation alongside the principles of CPDE that were implemented to create this learning environment (resources are not included since they work at a different level and apply to all five components). Recasting PDE as CPDE elevates the political and relational aspects of learning that are core features of critical awareness. The political and relational dimensions of climate change learning in Table 1 are labeled in italics as relationality and politicizing. Below I elaborate on these dimensions to explain how critical climate awareness can be an outcome afforded by connective-disciplinary climate change learning.

Political Dimensions

Learning is inherently political, meaning that it is "embedded in and articulated through hierarches of power and tied to particular visions of possible futures" (The Politics of Learning Writing Collective, 2017, p. 5). At a similarly broad level, Erickson (2006) conceptualized politics in learning as the ways in which relationships are "power-laden, pre-constructed by history and weighted by social gravity" (p. 237). In connective-disciplinary climate change learning, there are several ways in which the political dimensions of learning engage students in developing critical awareness. First, it is political for students to question, reject, or assert normative assumptions of science education (Agarwal & Sengupta-Irving, 2019). For example, questioning the nature-culture divide or constructing nature as person-less are sociopolitical acts. This discourse not only erases Indigenous peoples as part of settler-colonial domination, but it also ignores the ways that humans have an intertwined relationship with the climate system.

Table 1

Components of Critical Climate Awareness as Achieved in Implementation Through CPDE

Critical climate awareness	Implementation achieved with CPDE
Canonical scientific system Greenhouse gases trap infrared radiation which warms the atmosphere	Problematize: apolitical explanatory accounts of climate change need revision and additional evidence relevant to students' lives Accountability: Hold students accountable to the norms of politicizing, scientizing, and localizing
Anthropogenic global warming Humans are emitting greenhouse gases which traps more infrared radiation which warms the atmosphere more	Problematize: engage in *politicizing* to connect scientific and sociopolitical systems Problematize: politicize the human-nature divide, *relationality* in situating oneself as part of the environment Resources: locally and socially relevant data; amplify historicity and identity as sensemaking resources; students' identities, culture, and history are generative to the discipline, past, present, and future
Agency for emissions These emissions of greenhouse gases are driven by political and social motivations	Problematize: *relationality/*relationships to power underlying carbon emissions Resources: amplify relational resources that animate racial & counter narratives as sensemaking resources
Distribution of climate disruptions A warmer atmosphere disrupts climate systems locally and those disruptions are more severe for poor communities of color, many of whom emit the least	Problematize: question why climate disruptions disproportionally burdening low-income communities of color Authority: position students with intellectual agency to share observations, experiences, questions, and solutions for climate change Authority: engage in *politicizing* science through position students as experts of climate change in their community Accountability: elevate the relationship of climate science to social movements
Climate change solutions Urgent collective actions can address climate disruptions and inequalities	Problematize: question what actions can and should be taken Authority: argue for direct and indirect political action; position students as stakeholders in the problems they purse and the problems they experience *(relationality)* Accountability: engage in scientizing everyday climate experience to hold solutions accountable to students past, present, and future lives

Second, it is also political for students to interrogate, support, or position themselves or others in relation to sociopolitical practices, such as direct and indirect political action and civic engagement. Direct political action includes normative practices such as voting while indirect political action in the environmental sphere includes, for example, supporting public policy decisions that enable the public to act in pro-environmental ways (Kollmuss & Agyeman, 2002). Third, it is political for students to historize, de-historize, contextualize, or de-contextualize a variety of aspects of the scientific discipline or their community. The historicity and contextuality of science disciplines, the scientific enterprise, and knowledge of climate change all deeply link science learning with broader geopolitical and social agendas (McKinney de Royston & Sengupta-Irving, 2019).

Relational Dimensions

Learning is relationally constituted, and relationships between individuals and collectives are central to understanding how climate change emerged and how it can be solved (DiGiacomo & Gutiérrez, 2016; Lundholm, 2019). My research setting limited the types of relationships I was able to study. I confined my data collection to the classroom and therefore to the interpersonal relationships within the classroom as well as relationships that students made visible through their discourse and practices. There are several categories of relationships that are central to relationality in climate science learning. Starting from the most observed in classrooms: student-student and student-teacher relationships are important for understanding if and how students position themselves and others in collaboration when working towards classroom goals. Connected to this are students' relationships to themselves, including their past, present, and future self. This relationship to the self is essential in a proleptic understanding of learning. Next, students' relationship to their community and place—as shared through the stories, resources, and practices that they make visible in interaction—are important for understanding how students situate themselves as members of and participants in the climate system. Last, students' relationships to institutions and levers of power are important to document. Lundholm (2019) argued that relationships between individuals and the collective (with the collective representing societal institutions, the government, and activist movements) are important in understanding climate change causes and consequences.

Critical awareness embodies a central focus on collectives and relationships in collectives. Freire (1970) and scholars in his lineage conceptualized critical awareness as helping people engage in broader collective struggles rather than experience oppression in isolation and self-blame. This dimension of critical awareness can be transformative for climate education because individual causes and solutions are generally the only ones presented to students in curricular resources, which ignores the scientific consensus on collective causes and the need for collective solutions (Meehan et al., 2018; Wynes & Nicholas, 2017). Textbooks in the United States recommend low-impact, individual climate mitigation activities like upgrading light bulbs, while research on emission reduction suggests high-impact, collective strategies like investing in green energy sources (Girod et al., 2014). Jorgenson et al. (2019) defined collective action as actions taken in common by a group of individual actors in pursuit of a perceived shared interest. This frames collective action as inherently social because it involves voluntary action taken in common by a group rather than the collective sum of individual actions. Presenting students with individual solutions to climate change or explanations of climate disruptions as linked to individual actors could cause feelings of isolation or hopeless, while presenting causes and solutions as anchored in collectives can lead to liberation.

Research Questions

By designing a learning environment at the intersection of NGSS-aligned instruction with the transformative approaches of SSI, place-based, and critical science education, I hope to study student participation and outcomes that might not appear outside this novel context. Understanding power dynamics, centering identity, and historicity, as well as intrinsically linking scientific and sociopolitical systems, can define critical awareness in contrast to non-critical awareness of climate change. This background of empirical and conceptual literature supports my design and methods outlined in the next chapter to answer my research questions. I hope to show the ways in which an emphasis on the sociopolitical dimensions of climate change structures engagement in learning using the CPDE framework (research question 2) and supports learning science and developing critical awareness (research question 1).

Chapter 3: Methods

In this chapter, I introduce the context and participants/partners of this project. I then outline my position as the researcher and ethical commitments as linked with my participatory design research (PDR) approach. As part of explaining this methodology, I also outline my previous work, including initial designs and relationship building. Next, I present the data sources, and conclude this chapter by describing the measures and analytical approach.

Setting

Community and Historical Moment

This work took place at the Mann UCLA Community School located in South Los Angeles. Before describing the school, it is important to describe the social, geographic, and historic context of the community as all are important to the students that will participate in this study. Dating back to the beginning of the 20th century, South Central Los Angeles has historically been an African American neighborhood. The name South Central became an umbrella term for Black Los Angeles after the prospect of jobs and less overt racism drew families to the area during the Great Migration and after World War II. Later, racially restrictive housing policies created and maintained segregation. The neighborhood has been victimized by discriminatory and violent policing policies that originated in the 1960s—the same decade in which Interstate 10 was built through the neighborhood and in the process damaged its character, ecology, and economic value. For the past 40 years, Latino families joined the community rapidly and now demographically outnumber African Americans. Compared to the rest of the city of Los Angeles, South Central has a lower median household income, lower levels of completed education, and the highest rates of violent crimes (Sonksen, 2017). While the community is under-served and marginalized, it is also home to a vibrant network of entrepreneurs and activists who are organized around residential oil drilling, affordable housing, and urban agriculture.

The mild Mediterranean climate of South LA is a defining part of the character. However, California's average temperature has increased by three degrees Fahrenheit in the past 100 years; Los Angeles has warmed by five degrees Fahrenheit (NASA, 2008). The storied climate is now threatened by increasingly frequent and intense summer heat waves and droughts. South LA, like other urban cores, also experiences exacerbated extreme summer heat due to the urban heat island effect. While California is leading efforts in climate change mitigation (for example, California's 100% Clean Energy Senate Bill-100), the national and international efforts to mitigate and adapt are inadequate to meet the crisis. Researchers posited that the past 20 years presented the last chance to keep global warming to less than two degrees Fahrenheit, and with that opportunity lost, it is realistic to prepare for global climate disruption (IPCC, 2013).

While the social, geographic, and historic context are important, the defining feature of the 2020–2021 school year was the COVID-19 pandemic that forced schooling to take place remotely and devastated the livelihoods and well-being of many families in South LA. The number of COVID cases, hospitalizations, and deaths were disproportionally high and engagement in online schooling was disproportionally low in the community.

School and Research-Practice Partnership

The Mann UCLA Community School began a partnership with UCLA's School of Education in 2016 to transform the school. Prior to the partnership, the school experienced rapid decline in enrollment and was labeled as a failing school in 2004 and 2015 (Quartz, 2018). UCLA's resources and expertise in education and social justice made the university well situated to support a transition to a partnership and a community school. The community school model is organized around four pillars that include: integrated student supports, expanded learning time and opportunities, family and community engagement, and collaborative leadership and practices (Oakes et al., 2017). Additionally, the relationship with UCLA can be characterized by a number of research-practice partnerships (RPPs) that involve long-term collaborations between practitioners and researchers organized to investigate problems of practice and solutions for improving schools (Coburn & Penuel, 2016). Community schools embrace the link between learning and community to ensure that students have opportunities to access rich, challenging, and culturally relevant pedagogy (Daniel et al., 2019).

Participants

While teacher-level data is not part of this dissertation, none of this work would be possible without Darlene Tieu (Ms. T), the teacher with whom I collaborated on design and who opened her classroom to me. Our RPP was largely organized around supporting her as an educator. My working partnership and friendship with Ms. T have both influenced the trajectory of this RPP in numerous ways and our relationship is a critical aspect of this research (Jackson et al., 2020). I collected data on Ms. T's learning and practice that I will write about in the future.

Ms. T is a young Vietnamese American woman and was in her third year of teaching during this study. She received an undergraduate degree in a science field and a master's degree from UCLA. She is a self-proclaimed science nerd, and her educational philosophy is deeply rooted in social justice. Ms. T teaches middle school science and 10th grade chemistry, she is chair of the science department, and she is involved in numerous leadership and research activities. Our collaboration and friendship began in the summer of 2018 when we co-planned an instructional unit for Ms. T's Masters Inquiry Project and my second-year project. We then committed to a long-term partnership because we both found the work fulfilling and productive.

The participants in this dissertation are the 10th grade students in Ms. T's two sections of chemistry class. On the roster, 44 students were enrolled but 11 of the students attended less than a quarter of the classes (which we attribute to the challenges of the pandemic). Due to this attendance issue, I count only the 33 students who regularly joined class as the participants in this study. With the modified online school schedule, students had 2.5 hours of science a week, split between two longer periods and one short period. Demographically, the students are 52% African American and 48% Latinx with 22% designated as English Language Learners (Quartz, 2019). Over the years, I have built a list of student assets that includes their inquisitive nature, playful competitiveness, fearless questioning, gusto to get their hands dirty, and intimate friendships. I also invited all the students to take part in interviews; 12 students participated (with assent and parent consent) in three interviews. The pseudonyms and demographics of the interviewed students are presented in Table 2.

Table 2

Interview Student Pseudonyms and Demographics

Pseudonym	Age	Snapshot of identity and history
Tia	15	African American/biracial, lifelong South LA resident
Laura	16	Chicana, lifelong South LA resident
Jessica	15	African, newcomer to the United States
Lachelle	15	African American, lifelong South LA resident
Kari	15	African American, newcomer to South LA
Monica	15	Chicana, newcomer to South LA
Sara	17	Latina, Spanish speaker, newcomer to the United States
Oscar	15	Latino, Spanish speaker, newcomer to the United States
Naeem	15	African American, lifelong South LA resident
David	16	Latino, Spanish speaker, newcomer to the United States
Ty	16	African American, lifelong South LA resident
Carl	16	African American, lifelong South LA resident

Positionality and Ethical Commitments

I come to this work as a guest and an ally to the community I hope to collaborate with and learn alongside. I understand climate change and climate science from my own perspective which is informed by years of training in the physical sciences and a life best described as privileged. Years ago, I believed that the most fragile aspects of this planet were its ecosystems and their functions and I worked to ensure that my own students understood how to avoid causing harm. Over time, I have come to understand that ecosystems are in fact incredibly resilient and will survive humanity; what is fragile are the livelihoods and well-being of the most vulnerablized people and communities that are systematically and structurally limited in their ability to adapt to environmental degradation. This understanding, combined with my belief that all learners have the right to access the powerful epistemology of science to help them negotiate and disrupt the changes happening in their life, inspires my research.

As I strive for political clarity, my position as an outsider demands that I grapple with ways to ethically design for learning outcomes determined in collaboration with students and teachers. Several commitments guide me in this work. First, I did not work towards behavioral changes as an outcome—a common goal of many interventions in environmental education. For me to design for behavioral change would de-historize the reality of the causes of climate change and would be patronizing, and possibly imperialist. Luxury emissions of carbon and a capitalist system are responsible for the climate crisis and today's youth in South Los Angeles should not be asked to shoulder the burden of undoing that damage. Second, I am committed to not placing Western modern science in oppositional dichotomy with other ways of knowing. This effort will help me to avoid placing implicit value on normative Western approaches to climate change. I hope this approach is humanizing for non-dominant students and sensible because approaching the climate crisis from the Western perspective that caused it is not likely to help anyone (Bang & Medin, 2010; McGinty & Bang, 2016).

In this PDR project, I occupied several different roles informed by my position and shaped by my partnerships. My relationship with Ms. T is the most significant within the context of this dissertation. Race and power mediate this relationship in significant ways, and I committed to earning trust through a) attending to how priorities are set, b) developing core propositions to guide collaboration, and c) engaging in on-going member checks (Vakil et al., 2016). Regarding my ethical engagement with students, I prioritized consent, participant privacy, and reciprocity (Drew et al., 2007). Since student participants were minors, I asked their parents/guardians to grant permission for participation in this study. I generated written consent forms in English and Spanish with plain language about the benefits and potential risks of the study. I also asked for assent from students after explaining the research objectives and processes (see Appendix E). This conversation and assent process addressed the voluntariness of participation, participant privacy, and access to data and on-going analysis. Lastly, I committed to reciprocity which I embodied by honoring students' voices and narratives in designing lessons around their questions, observations, and curiosities.

Participatory Design Research

My methodological and analytical approach is design-based research (DBR) (Brown, 1992; Gravemeijer & Cobb, 2006; Sandoval & Bell, 2004). This approach is characterized by its simultaneous commitment to a constellation of research outcomes which include: the production of innovative learning environments, knowledge about how such environments work in the settings for which they were designed, and more fundamental knowledge about learning or teaching (DBR Collective, 2003). DBR requires carefully defining the context of my research setting as well as the nature and development of my collaborations. The scope of my research context will include both exogenous design (involving instructional and activity materials, strategies, and structures developed for the purpose of research) and endogenous design (involving the materials and practices that are already in place or are devised by the local participants as part of their engagement) (Tabak, 2004). Attending to both is essential because I am not simply testing whether or not a design works, but rather as Sandoval (2004) stated, "the question is really how it works" (p. 217).

Regarding my collaborative partnership, as previously described in my position statement and description of participation, this dissertation aimed to represent the non-hierarchal relationship between Ms. T and myself. All exogenous designs were collaboratively constructed not only for the purpose of research but to meet the needs Ms. T sees in her students. Additionally, I aimed to center the voices of students in the design process of specific tools, but I know students will greatly impact the endogenous design. As a result of these commitments, it is essential that my methods attend to power in these relationships. The DBR tradition offers a range of approaches, and I have opted to adopt a PDR approach (Bang & Vossoughi, 2016). Amongst the different DBR traditions, my commitment to collaborative design and research is best aligned with PDR because this approach supports me in attending "to the ways in which critical historicity, power, and relational dynamics shape processes of partnering and the possible forms of learning that emerge in and through them" (Bang & Vossoughi, 2016, p. 174).

Previous Work

In preparation for this DBR study, I spent two years engaged in ethnographic observation, relationship building, and iterative preliminary design. Below, I briefly outline my collaboration and findings. In the 2018–2019 school year, Ms. T and I planned an eight-week instructional unit for students to answer the driving question “What is happening here and now with our climate?” We anchored our inquiry in the phenomenon of regional temperature increase in Los Angeles. I introduced the tool of the NGSS phenomenological storyline to Ms. T in order to organize our lesson planning; the concept of community-based science oriented our design work (Resier et al., 2015). We conceptualized community-based science as a learning environment that anchors instruction in a local scientific phenomenon that is relevant to students’ everyday experiences (Clark & Gyles, 2019). My research question for the year was: How does community-oriented science support student understanding and modeling of climate systems? First, I found that students learned a tremendous amount even when the context of their learning was imperfect and shifting. Students took a disciplinary knowledge assessment before and after the instructional intervention and I found a statistically significant change from a mean of 3.67 ± 2.31 in the pre-test to a mean of 8.25 ± 2.90 in the post-test ($F(1,27) = 62.481$, $p = <0.000$) with a large effect size of 0.689 (Clark & Sandoval, 2020a). Second, along with students engaged in the scientific practice of modeling, I developed a holistic rubric to assess student improvement in the practice and evaluate how they incorporated place-based and personal experiences in their model (Clark & Sandoval, 2020b). Overall, my findings suggest that by incorporating community-oriented science, students felt more welcome to include local, sociopolitical drivers of change in their explanations of scientific mechanisms which helped make climate change more relevant.

In the 2019–2020 school year, Ms. T and I collaboratively planned her entire instructional year. Prior to the instruction being interrupted by the pandemic, I documented lesson implementation in memos and fieldnotes. Ms. T and I started with the California NGSS framework and we anchored four out of the six units suggested in the framework in local phenomenon, continuing our focus on community-based science. The most important design outcome of the year was a first iteration of one of the design embodiments described below: a science curriculum of “what ought to be” for the two focal units of the year. This tentative curriculum is not only coherent and place-based, but oriented around the social context of climate science and the social levers of change needed to open expansive opportunities for new learning objectives and new relationships. Specifically, this approach to imagining a climate science of “what ought to be” allows students to use science to disrupt social inequality and imagine a more just socioecological future. In addition to this design accomplishment, I have become a trusted and respected member of the school and classroom community.

Data Sources

Within this project, I used a single group pre/post design because my primary aim was to document changes in my key outcomes that occurred as a result of participation in the intervention (Shadish et al., 2002). To trace the potential causal factors involved in that change, I added methods to capture and analyze the details of student engagement throughout the intervention.

Assessments

All students took three types of assessments or tasks, two as pre-post tests given at the beginning of the year and end of the year, and one as a formative end-of-unit task given after units 1, 2, and 4. Each assessment is a proxy of students’ learning—a contextual snapshot of student thinking that I triangulate with other data sources in order to understand classroom participation. First, I assessed disciplinary knowledge using two previously implemented and validated instruments that I combined into one assessment. The first instrument was the Climate Science Content Knowledge Assessment designed for middle and high school age students

(Drewes et al., 2018). The assessment consists of 18 multiple-choice questions on the sub-categories of: mechanisms of the greenhouse effect, climate change effects, impact of human action, and mitigation and adaptation strategy. For the second portion, I drew a subset of five questions on the radiative forcing of greenhouse gases from the Visualizing the Chemistry of Climate Change Project (see Appendix A) (Versprille et al., 2017). A total of 31 students took this pre-test and 27 students took the post-test; 25 students took both, which is the sample I used for statistical analysis.

For the second assessment, I measured climate change concern amongst the students using the Six Americas survey (Maibach et al., 2009). I used a 15-question version of the survey that has been widely used nationally and validated with adolescents (Holthuis et al., 2014). Questions are related to four sub-categories: global warming beliefs, issue involvement, climate-related behavior, and preferred societal response (see Appendix B). The results provide an audience segmentation typology ranging from alarmed (high belief in global warming, most concerned, most motivated) to dismissive (low belief in global warming, least concerned, least motivated). A total of 36 students took this pre-test and 30 students took the post-test; 30 students took both the pre- and post-test, which is the sample that I used for statistical analysis.

Third, I developed a formative task as an end-of-unit assessment for students to take after each unit to assess critical climate awareness (see Appendix C for the three tasks evaluated in the Findings on Outcomes chapter, with the fourth tasked presented in the exact format that students received). The tasks prompted students to respond to policy proposals in Los Angeles' Green New Deal with questions oriented to the social and scientific features of critical climate awareness. I collected all four tasks associated with the four units, but only analyzed the tasks that followed unit 1 (as a pre-assessment) and units 2 and 4 (the focal units). Fourteen students completed the unit 1 task, 15 students completed the unit 2 task, and 17 students completed the unit 4 task; 8 students completed all three formative tasks. I designed the task to be a written assignment and most students did complete it in writing. However, a small number of students were unable to complete the task using writing as the mode of participation, so they completed it orally instead. Specifically, three students completed tasks 2 and 4 as a conversation in which I read them the question and then typed in their responses. This method ensured that students had an opportunity to elaborate, clarify, and better express their thoughts and understanding.

Interviews

I conducted three interviews with the 12 participating students (see Appendix D). Overall, the objective of the interviews was to elicit students' thinking about climate change and perceptions of their engagement when sociopolitical dimensions of climate change are foregrounded in science class, and to see if that thinking and perception changed over time. Within the first interview, I asked a set of structured questions on students' personal history and a set of five questions about their thinking on climate change, four of which I asked again in the final interview. The middle interview was a document-elicitation interview. I used the students' critical climate awareness task from unit 2 as the document and asked the students to tell me more about parts of their writing that touched on features of critical climate awareness. In addition to repeating these four structured questions during the third and final interview, I also asked a set of three semi-structured questioned focused on students' experiences in the class.

Artifacts and Observations

I collected the students' digital science notebooks as artifacts of their participation and engagement. A total of 20 activities from the student notebooks were collected for analysis, including diagrammatic models, warm-ups, exit tickets, reflections after guided discussions, and worksheets that surfaced student thinking and understanding of climate change at that moment. Across the 33 student participants, the average number of assignments completed was nine out of 20, and only six students completed 18 or more assignments. Artifacts are therefore a patchy and incomplete record of engagement. I also collected the lesson plans co-developed with Ms. T over the year and I took observational fieldnotes, accompanied by analytical memos, for every class period I attended. Over the 75 days of classes, I observed both periods of chemistry class on 60 days, just one period on 12 days, and on three days I missed both classes. My field notes included descriptions of lesson enactment and student participation, reflections of design conjectures, paraphrased versions of Ms. T's lectures, as well as notes on student participation that came in three forms: speaking, public Zoom chat, and private Zoom chat to myself or Ms. T.

Measures and Analytical Approach

As a DBR study, two types of analysis took place. First, I performed micro-cycle (daily) analyses of the intervention in action in order to document changes to the intervention as they occurred and to iteratively refine the design for the next cycle. This was followed by a retrospective analysis that I performed after the implementation was complete in order to construct the findings (Cobb et al., 2003). Below I outline the analytical approach for a mixed-methods retrospective analysis organized by analytical measure—critical climate awareness, climate science learning, and classroom engagement.

Critical Climate Awareness

I measured critical climate awareness by triangulating four data sources: the Six Americas survey as a measure of concern for and awareness of climate change; the formative assessments as a measure of orientation towards critical awareness of climate change; the second interview in which students engaged in a document-elicitation conversation about their second formative assessment; and the structured pre/post interview questions as a measure of orientation towards critical awareness of climate change.

Six Americas Survey

The Six Americas survey was scored with an SPSS syntax for discriminant analysis to conduct audience segmentation (Maibach et al., 2011a; Maibach et al., 2011b). For the analysis, I assigned each participant to a "segment" based on their responses as well as a corresponding numerical value to allow for further analysis (e.g., alarmed is a 1 and dismissive is a 6). I analyzed the students' profile distribution before and after instruction using a Wilcoxian signed-rank test to examine differences between the time periods. This statistical test was ideal because the variables are ordinal data, ranked in order of strength of belief and engagement with climate change issues, and because the data are non-normally disturbed. Furthermore, identified segment types (the dependent variable) are ranked and statistically significant differences between pre- and post- instruction distributions can be identified. These survey items have been tested for validity and reliability with a representative sample of over 15,000 Americans and therefore I assume that my sample of participants does not violate test assumptions.

Critical Climate Awareness Formative Tasks

I designed the formative tasks to elicit student thinking around the critical dimensions of climate change. The first part of the task included two questions intended to orient students to the structures and systems of climate change while the second- and third-parts oriented students to climate inequalities. I analyzed student responses with an a priori coding framework that organizes the major components of critical climate awareness. Adopting Sandoval's (2003) definition of overall quality and Sandoval and Millwood's (2005) modification to conceptual quality in their work analyzing students' explanations of natural selection, I defined the conceptual quality of students' tasks as reflecting the extent to which a series of major components of climate science and change are articulated and warranted. I conceptualized five major components of critical climate awareness that explicates the connections to the systems as well as the structures of climate change and inequalities (see Table 3).

Coding with this conceptual quality framework took place in three phases. First, in NVIVO I created a high-level code (nodes) for each of the five components of conceptual quality and I used structural coding to index students' response into these five nodes (Saldaña, 2016). Second, I printed out all the coded excerpts and began to sort the excerpts by hand based on the topics and themes that students mentioned. The goal of this step was to move from my a priori categories to a more inductive approach to understand the types of student thinking within each component of critical climate awareness. By hand, I wrote interpretations of the students' writing on the printed excerpts which served as preliminary codes; some of the preliminary codes were informed by my analytical memos that I wrote immediately after collecting the tasks while others emerged during this analysis and opened an opportunity to interpret data with grounded theory (Charmaz, 2006; Glaser & Strauss, 1967). This inductive approach was very important to me because students' ideas surprised and humbled me, and several codes defied and expanded my thinking about what critical climate awareness might look like. Third, I consolidated my preliminary codes to the codebook described in Table 3 and input these codes into NVIVO to facilitate code comparison and data visualization. I reflected on and member checked this codebook in three conversations with Ms. T and she shared that analysis resonated with her assessment of the students' work.

Table 3

Codebook for Conceptual Quality in Formative Tasks

Components	Boundary of components	Codes
Canonical Scientific System	Description of scientific, global, physical (canonical) system of greenhouse gases trapping infrared radiation which warms the atmosphere	Canonical description of carbon cycle
		Canonical description of greenhouse effect
		Naïve description of carbon cycle
		Naïve description of greenhouse effect
Anthropogenic Global Warming	Social and political structures modify the climate system; description of emissions can be localized and specified with sources	Canonical description of global warming and mechanisms, including emissions and land use; identifiable sources of emissions; sociopolitical structures as part of mechanism
		Naïve description of global warming and mechanisms
Agency for Emissions	Human decisions, actions and structures modify the climate system; Agency is ascribed to specific actors; motivations for emissions can be linked with specific benefits of to those actors and the inequalities and injustices embedded in those motivations	Ascribe agency to an actor including corporations, government, scientists, humans/all people, we/us, and powerful individuals
		Ascribe agency to an action or actor
		Describe a motivation for emissions including development, power, and profits
Distribution of Disruption	There are inequalities in the distribution of consequences; there is a wide range of consequences; inequalities in those distribution can be linked to systemic disenfranchisement	Describe a consequence of climate change: air pollution, extreme weather, disrupted food/agriculture systems, illness, melting glaciers, destruction of habitat
		Describe actors that experience consequences including humans/all people, we/us, low socioeconomic, me/my family, people of color
		Describe locations that experience consequences including our community, polluted communities, socially vulnerable
Solutions	Description of how to address climate change; Climate change is a large-scale collective dilemma; adaptation, mitigation and resilience building are all possible in communities	Describe mitigation solutions including zero-carbon electricity production, reforestation, and zero-carbon transit system
		Describe resilience building solutions
		Describe actors engaged in solutions

After coding was complete, I originally worked to describe longitudinal change in students' overall conceptual quality. This process revealed the challenges of studying this novel outcome and instead of describing trajectories in developing critical climate awareness, I described the extent to which individual students and groups of students developed this outcome as a snapshot of their thinking when they completed each of the tasks. I ended my analysis with another round of member checking with Ms. T.

Interviews

I transcribed all interviews using Otter AI and then I corrected the text to ensure a match with the audio and added in laughs, pauses, and gestures. Understanding transcripts as theory, I wanted to have denaturalized transcripts that included “um” and “uh” in order to capture the ways students worked through the questions (Ochs, 1979). Later, I created naturalized transcripts as well for readability. I used two out of the three components of the interviews in data triangulation to measure critical climate awareness: the document-elicitation conversation about the carbon cycle formative assessment (the second interview conducted after unit 2) and the structured pre/post interview questions. To analyze the document-elicitation portion of the second interview, I applied the same coding process for conceptual quality of critical climate awareness as described above for formative tasks. I selected this analytical approach because the interview protocol invited students to reflect and expand upon their initial writing, therefore I consider the interview to be an extension of the task. In fact, the clarification I gave in the interviews allowed students to articulate their thoughts in a more elaborate and sophisticated way than when writing independently. I view interviews as a pedagogical encounter and therefore anchored my analysis in the understanding that these conversations were extensions of students’ classroom learning experiences (Vossoughi & Zavala, 2020).

For the structured pre/post interview questions, I reduced the data by organizing responses in tables that matched and compared individual students’ responses to each question (Seidman, 2006). I then counted the topics and issues that each question surfaced for students and compared the occurrence of topics in the pre and post interviews. Each of the four structured interview questions gave students an opportunity to discuss one or more components of critical climate awareness. For example, the question "How do you think climate change affects you?" presented an opportunity for students to talk about the distribution of disruption of climate consequences and "How do you affect climate change?" allowed them to ascribe agency to themselves or others. I analyzed the individual responses and the trends across the group of 12 students for changes in the ways the components of critical climate awareness were discussed.

Climate Science Learning

I investigated climate science learning in order to identify changes in disciplinary knowledge and to assess students' conceptual competence. I adopt Gresalfi et al.'s (2009) definition of competence as a collection of skills or abilities of an individual and attributes of participation in an activity system. Using this definition, a student would be deemed competent as a trait of interaction and as a function of the opportunities that a student has to participate competently as well as the ways that an individual takes up those opportunities. Following this understanding of competencies, I expected students to draw on different competencies as they participated in different contexts. I had hoped to observe and measure those variations across practices and contexts but given the ways in which remote learning and the COVID-19 pandemic limited data collection, I have just two data sources to serve as proxies of disciplinary knowledge: the pre/post tests of disciplinary knowledge and the first section of the formative tasks. I applied the same analytical framework of conceptual quality described for examining critical climate awareness to my analysis of disciplinary competence.

Although the pre/post tests on conceptual knowledge do not tell a full story of what students know or think about sanctioned, canonical climate science concepts, I rely on them heavily since they were the only data source available for the majority of students. Given this cautionary note that I am at risk of over-emphasis one imperfect measure, I analyzed the disciplinary knowledge assessments for changes in the mean score between the pre- and post-tests with a paired *t* test in SPSS. I employed Holm's sequential Bonferroni procedure to correct for family-wise errors that may have occurred due to testing for multiple hypothesis (i.e., the *p* value was adjusted to be more conservative because of the multiple dependent samples *t* test) (Holm, 1979). Effect size for paired samples were generated in SPSS and interpreted via Cohen's *d* guidelines for instructional effect (Cohen, 1992).

Classroom Engagement

My second research question is focused on how classroom engagement was structured in the designed learning environment that foregrounded sociopolitical dimensions of climate change. I measured engagement by combining three data sources to create a comprehensive record of student participation and thinking in class: classroom artifacts, observational field notes, and the semi-structured final interview questions.

I analyzed engagement of the period 3 students as they worked towards creating their diagrammatic models in units 2 and 4. I did not analyze engagement in period 1 because so few students participated that I did not have adequate data to trace ideas over time. Descriptions of the activities of each day of the two focal units are included in Chapter 4 while details of the interaction are presented as findings in Chapter 5. I used the analytical approach described below for all three data sources and anchored my process in the suggestions by Engle and Conant (2002) and Agarwal and Sengupta (2019) for analyzing CPDE. However, my approach has important deviations from their suggestions because most work on CPDE involves the analysis of face-to-face interactions. Rather than analyze traditional discourse, I drew on the infrequent verbal participation by students who could not see one another, Ms. T's revoicing of contribution that students sent to her in a private chat, and public Zoom chats (all captured in my observation field notes). I combined these observations with proxies of engagement: written artifacts created during class and the interviews. These proxies are a temporally distal engagement, but they represent students' thoughts about and reflections upon the interaction and are therefore an extension of the interaction. Written artifacts, as a proxy, embody how students interacted during activities, and the interviews as a proxy were an opportunity for me ask questions about student thinking that I was unable to ask in the moment. I have never seen published work on CPDE applied to retrospective proxies of engagement, but I found they allowed me to gain a robust insight on interaction and to share this method as a contribution to the post-COVID-19 field.

I analyzed data in a four-step process. In step 1, I organized all three data sources into a table that contained a detailed content log of engagement. First, I input the observation field notes in order to have a chronological record of the activities and participation. Next, I matched the student artifacts from the digital notebooks with the record of class. For unit 2, artifacts include four activities from the digital notebooks (the diagrammatic model, an exit ticket, a warmup, and an inquiry reflection), two whole-class consensus models, and one individual model. For unit 4, artifacts include six notebook pages (the diagrammatic model, four exit tickets, and one inquiry reflection), one whole-class consensus model, and three revisions of individual models. Last, I input the interview excerpts to match the activity that the students were reflecting on. It was through this analysis that I identified the sequences of interaction that I present in the findings.

In step 2, I looked for the four principles of CPDE in both Ms. T's teaching and the students' engagement. I needed to describe the degree of CPDE in both contexts because I aim to show how the students appropriated the principles rather than reproduced the ways that Ms. T embodied them in her teaching. I used structural coding methods to deductively segment the interactions in the content log based on the extent to which they embodied each principle: problematizing, authority, accountability, and resources (Saldaña, 2016). Table 4 includes a summary of the definition of each of the principles. The definitions of the principles are rooted in Engle and Conant's (2002) original definitions and Agarwal and Sengupta's (2019) contribution of epistemic diversity and history/identity to elevate connectivity in the principles but are tailored to my intervention—an approach encouraged by Engle (2012) to ensure that the design and cultural considerations of each context are considered. In this step, I looked at the principles by first reviewing the content log of engagement and asking, "Does this sounds like problematizing?" based on my conceptualization of the principle. When I identified an interaction that I associated with problematizing, I asked a series of questions about the principles drawn from Engle (2012). For example, for problematizing I asked, "What big ideas and disciplinary assumptions are students engaging with? What sociopolitical dimensions were surfaced by these ideas and assumptions?" For authority, I asked, "How did Ms. T use her authority to legitimize students problematizing? In what ways did student politicize climate science?" I wrote out my answer to these question in the content log and I repeated this process for each principle. In one joint-analysis session with Ms. T, we engaged in this process of asking structured questions about a segment of the data together. This member checking calibrated my independent analysis of the full data set.

Table 4

Guiding Definitions of the Four Principles of CPDE

Problematizing	Authority	Accountability	Resources

Grapple with intellectual problem or uncertainty
 	
Could include:
• What to do
• What to conclude
• How to justify an action
• Deciding between competing alternatives
Must:
• Be open questions from students' perspective
• Be within students reach
• Elicit student curiosity
• Be genuinely problematic
• Be responsive to community and needs
• Embody a big idea of the discipline
Designed to take the form of politicizing which:
• Confronting sociopolitical dimensions
• Looking critically at what creates and sustains climate inequalities
• Connecting critical awareness of social issues
	Students have agency to play an active role in defining and addressing problems
	
	Happens through positioning (by teacher, self, or others) as:
	• stakeholders in the problem they pursue able to share what you think
	• authors of ideas and knowledge
	• contributors to problem solving
	• local authority of ideas
	• transformative intellectuals in disrupting injustices able to share ideas informed by students' social location, identities, history, and community experiences
	Designed to take the form of politicizing which includes:
	• situating agency with diverse and local stakeholders
	• elevating agency of social movements
	• arguing for collective political actions
		Intellectual work is responsive to the concepts, practices, and norms established inside and outside of the classroom
		
		Justify ideas to:
		• peers
		• internal authorities
		• external authorities (social and environmental justice movements)
		Justifications recognizes:
		• the legitimacy of ideas related to students' identity, culture and history
		• generativity of these ideas to the discipline, the past, present and future, and to each other
		Designed to take the form of scientizing:
		• identifying, labeling, questioning, and reflecting on scientific concepts and practices in everyday life
		• making a claim, prediction, argument, or demand to meet personal, cultural, or local needs
			Anything needed to support connective disciplinary work
			
			Could include:
			• sufficient time to engage with a problem
			• multiple relevant sources of information
			  • scaffolds that opened up new opportunities to learn
			  • cohesive unit to develop the needed skills, knowledge, representations, materials, and technologies to pursue questions
			  • identities
			  • histories
			  • racial narratives
			  • cultural and community-based experiences
			• critical awareness of other social issues

In step 3, I analyzed the content log for instances when CPDE was not achieved. To look for these moments, I reviewed each activity and asked another set of questions suggested by Engle (2012). These included: "How are problematizing and resources balanced? How are authority and accountability balanced? Did the students or Ms. T slip into well-learned, normative practices of schooling (such as reproducing right answers)? Did Ms. T or I foreclose, misinterpret, or ignore a student connective-disciplinary contribution because we struggled with the expanding our own epistemic horizon?" In step 4, I used my analysis of problematizing, authority, accountability, resources, and short-circuited moments as evidence, or a set of explanatory factors, to describe the degree to which these interactions constituted a case of CPDE. Specifically, I described the degree to which the interactions embodied the dimensions of CDPE; the goal was to categorize the degree of each dimension as strong, moderate, or weak. As Engle (2012) suggested, I rated each dimension as stronger to the extent that more aspects of my criteria (summarized in Table 5 from the description in Chapter 2) for connectivity-disciplinary, productivity, or engagement were embodied. To conclude my analysis of CDPE, I worked through two types of comparison: differences and similarities in Ms. T and students' engagement, and differences in units 2 and 4. First, I compared Ms. T's embodiment of the principles to students to identify the ways in which the students made them their own or reproduced Ms. T's framing. Second, I compared the ways in which each principle was embodied in the two units to explore differences over time. I also engaged Ms. T in a final round of member checking when we prepared conference presentation on these data.

Table 5

Summary of Criteria for CPDE

Engagement	Productive	Connective Disciplinary
Emotional displays	Ask new questions	Address climate science scholarship
Spontaneous reengagement	Reject normative views or assert critical views of the discipline	Address sociopolitical scholarship on climate change
Asking unprompted questions	Make new or more sophisticated connections between the sociopolitical and scientific systems of climate change	Use local funds of knowledges
Minimal procedural questions	Create epistemic diversity	Use evidence in scientific ways
Number of students participating	Recognize learners as shaped by social, cultural, and political history	Use scientific practices
Responsive to contributions of others	Recognize learners as change agents	Use evidence in critical ways
		Use sociopolitical practices
		Use relationality, temporality, historicity, identity, and community or cultural knowledge in sensemaking

Chapter 4: Intervention Design and Enactment

The COVID-19 pandemic transformed the implementation of this design and data collection, as well as students' lives and learning experiences. I am extremely proud of the community that Ms. T and I created for the students, which always prioritized well-being, joy, and the empowerment of scientific thinking. At the same time, I was unable to see students in person or to implement this design fully. In this chapter I explain the guiding design embodiments of the intervention, the modifications made for remote learning, and the norms of student participation in distance learning. This includes a detailed description of artifacts collected for individual students and modes of engagement. I also provide the timeline of the full-year intervention and then give a detailed description of the two focal units: unit 2 focused on the carbon cycle and urban greenspace, and unit 4 focused on the greenhouse effect and extreme heat. The goal of this chapter is to provide a detailed summary of intervention as implemented, the norms of Ms. T's teaching, and the learning opportunities afforded to students.

Design Embodiments

Understanding design as a theoretical activity, Ms. T and I created tools and activity structures that we hypothesized would support the desired forms of engagement and learning outcomes (Cobb et al., 2003; Sandoval, 2004, 2014). Specifically, I conjectured that classroom activities and participation focused on sociopolitical and scientific dimensions of climate change could connect to students' lives, support learning climate science, developing critical awareness of climate change, and foster connective-disciplinary engagement. The primary tool that we designed is a curriculum that presents a socio-politically gapless, place-based explanation of climate change and climate justice that was informed by students' lived experiences. This explanation of the phenomenon of climate change explicitly addresses hierarchies of powers and situates socio-political and scientific dimensions as inseparable (Philip et al., 2018). As a place-based and student-informed curriculum, its social and local relevance for students stems from centering dimensions of the phenomenon that are visible or consequential to Black and Latinx communities in South LA. This sociopolitical explanation of climate change allowed Ms. T and to create storylines that illustrated how the sociopolitical and scientific dimensions of climate change related to their own communities (Resier et al., 2015).

There are two activity structures that Ms. T and I designed to support the learning outcomes and connective engagement. First, we foregrounded the sociopolitical mechanisms of climate change by engaging students in politicizing science. This is the practice of confronting the socio-political values underlying scientific practices and concepts to look "critically at the society we have and the values that sustain it" and to ask, "What can and should be changed in order to achieve a more socially just democracy" (Hodson, 2013, p. 654). Ms. T modeled this practice almost daily and gave students regular opportunities to learn the practice. For example, Ms. T interrogated, questioned, and contextualized the systems and relationships of power embedded in climate systems, such as fossil fuel companies using their power to maintain our daily reliance on their products rather than low carbon energy. Ms. T also positioned herself and students in relation to political practices and processes, such as being a consumer of fossil fuels who cannot afford the more expensive low-carbon technology and therefore has limited agency in decision making. Activities that gave students opportunities to politicize climate science were fundamentally connective by design. Politicizing science is the primary way that Ms. T's teaching embodies the design principles of problematizing and authority. Second, each unit of the year culminated in the creation of a diagrammatic model that explained an aspect of climate change and examined local, collective climate actions to address climate injustice. Activities were designed throughout each unit that engaged students in gathering evidence for these models and for revising and testing models. A designed practice within this activity structure was scientizing everyday life and experiences. Scientizing involves understanding everyday practices and experiences as related to science (Ahn et al., 2016; Clegg & Kolodner, 2014). For climate change modeling, this involved identifying, labeling, questioning, and reflecting on the scientific concepts and practices involved in everyday observations and experiences of climate change, and using the evidence created through this practice to justify connective-disciplinary work. Ms. T modeled the practice for students regularly to establish it as classroom norm, to which explanations, claims, and arguments were accountable. Scientizing was the primary way that Ms. T embodied the design principle of accountability.

Design Modifications and Norms of Participation in Distance Learning

With the modified online school schedule, students had 2.5 hours of science a week in two longer periods and one short period; this was 1.5 hours less instructional time than normal. Reduced instruction time resulted in Ms. T teaching 4 units instead of 6 and shortening or cutting many planned activities. Instruction over Zoom fundamentally shifted the nature of Ms. T's teaching, the sense of community in the classroom, and student interactions. Ms. T did create classroom routines and connected to students, but the students never connected with each other, and I never fully connected with many students. Student also had almost no opportunities to collaborate with each other, which dramatically shifted the implementation of activity structures that originally relied on peer-to-peer discourse. Table 6 presents a summary of participation for 25 out of the 33 student participants in the class including their patterns of engagement, estimate of attendance, and number of artifacts that I collected (out of the 20 digital notebook entries like diagrammatic models, 4 formative critical climate awareness tasks, and 4 pre/post assessments).

This table does not include seven students in the class because they turned in 0 to 4 of the collected artifacts and I have no record of their participation in my observation field note.

Table 6

Description of Norms of Participation

Pseudonym	Period	Camera	Participation habits	Attendance	Artifacts (n=28)
Tia	3	On	Spoke private & public chat	~95%	27
Laura	3	Off	Private & public chat	~95%	27
Jessica	3	Off	Private & public chat	~95%	28
JJ	3	Off	Private chat	~50%	5
Rubi	3	Off	Private chat	~50%	5
Monica	3	Off	Private chat	~95%	19
Sara	3	Off	Private & public chat	~75%	24
Oscar	3	Off	Private chat	~95%	14
Ossi	3	Off	Private chat	~95%	19
David	3	Off	Private chat	~75%	9
Anna	3	Off	Private chat	~95%	11
Juan Carlos	3	Off	Private & public chat	~75%	18
Jim	3	Off	Spoke, private & public chat	~95%	22
MJ	3	Off	Spoke, private & public chat	~95%	20
Lachelle	3	Off	Private chat	~95%	13
Ty	1	Off	Private & public chat	~95%	10
Carl	1	Off	Private chat	~75%	12
Helen	1	Off	Spoke, private & public chat	~95%	26
Naeem	1	Off	Private chat	~95%	27
Kim	1	Off	Spoke, private & public chat	~50%	10
Kari	1	Off	Private chat	~75%	9
Dan	1	Off	Spoke, private & public chat	~50%	10
Jani	1	Off	Private chat	~50%	10
Gil	1	Off	Private chat	~50%	6
Hanna	1	Off	Private chat	~75%	5

Big Ideas and Timeline of Implemented Units

With the goal of developing a transformative instructional model for climate science, Ms. T and I designed a year-long intervention. Table 7 presents a summary of the curricular sequence for the year. There were five total units with the first unit (unit zero) representing a two-week period of community building, framing of the academic year, and elicitation of student wonderings. The next four units are modified versions of the California NGSS Framework's (Science Framework for California Public Schools, 2016) suggestion for six NGSS-aligned phenomenological storylines. While this intervention addressed many of the suggested PEs, the anchoring phenomena are localized versions of the broad, global, and abstract phenomena suggested. These localized phenomena were informed by students' questions and wonderings.

Table 7

Year-Long Sequence of Storylines

Segment big idea (dates)	Anchoring phenomenon	Overarching question
0. Framing of the year to political and social levers of change in scientific phenomenon (Aug 2020)		Elicitation of students' wonderings and observations about their community
1. The flow of energy released from fuels in combustion reactions powers our world (Sep 2020)	Used vegetable oil can replace diesel fuel, but we keep drilling diesel in our neighborhood	Why aren't we using vegetable oil to fuel our cars?
2. Carbon is transformed and transferred and is always conserved (Oct-Dec 2020)	Land use in LA, including the lack of parks, decreases the carbon reservoirs of the city	How does land use in LA impact the carbon cycle?
4. Energy change in chemical reactions shows the change in chemical bonds (Jan-Feb 2020)	Different chemical reactions produce different temperature changes	How do chemical reactions are happening all around me?
4. Human activity has altered the climate system (March-May 2021)	Carbon-dependent infrastructure has unbalanced the greenhouse effect	What are the impacts of LA getting hotter?

During unit zero, Ms. T introduced a guiding question to students: "How can we use chemistry to explain inequalities in climate change?" Each unit of the year addressed the three components of this question: chemistry as a tool or lens for investigating and explaining; climate change as a phenomenon that impacts our lives, futures and community; and, inequality as an unjust feature that shaped experiences with climate change. This question was linked to the anchoring phenomenon of each unit, which oriented the goals and learning outcomes of the activities.

Focal Units

Units 2 and 4 were the focal units that addressed climate change-specific phenomena. Appendix F presents a detailed, chronological summary of the daily question and activities addressed in each lesson, as well as the sociopolitical and scientific dimensions of climate change included in each class. In the narrative below, I elaborate on the Ms. T's enactment of the design, specifically her pedagogical strategies for bringing the sociopolitical and scientific dimensions together and for modeling the practices of politicizing and scientizing. I also elaborate on the prompts, objectives, and learning outcomes for various activities to provide a high-level summary of the focal units. The goal of this narrative is to contextualize the more detailed analysis of student engagement using CPDE in the findings chapter.

Unit 2: Carbon Cycle and Urban Greenspace

The guiding question of unit 2 was, "How does land use in LA impact the carbon cycle?" This question explored the notion that carbon, like all matter, is conserved in its chemical transformations and transfers. The phenomenon of investigation was the lack of parks in South LA, which decrease carbon sinks. The unit was oriented to students' lived experiences with parks and the multiple social and ecological benefits that the community is deprived of when parks are not available. Students worked throughout unit 2 to create and revise models that layered land use changes, issues of social justices, and the mechanisms of the carbon cycle.

To launch the unit on 10/20, Ms. T guided students in a comparison of land use between South LA and Beverley Hills to explore the question, "How is land used in LA?" Projecting an aerial map of LA as a resource and encouraging students to use their own experience moving between neighborhoods of the city, Ms. T had students generate a preliminary lists of land use categories. Next, they learned the academic vocabulary of the five official land use types (residential, commercial, industrial, recreational, and transportation). Ms. T intentionally selected these locations for their major differences and to link the social problem of park access and the scientific problem of rising temperature. To wrap up the class, Ms. T connected the daily question to the unit's driving question on the connection to carbon. She explained that carbon is everywhere, and through the lens of chemistry the students could understand where carbon is, how it is moving, and how that impacts life. Both the warm-up and the exit ticket asked students to describe land use near their home in everyday language and then using the academic vocabulary that they developed.

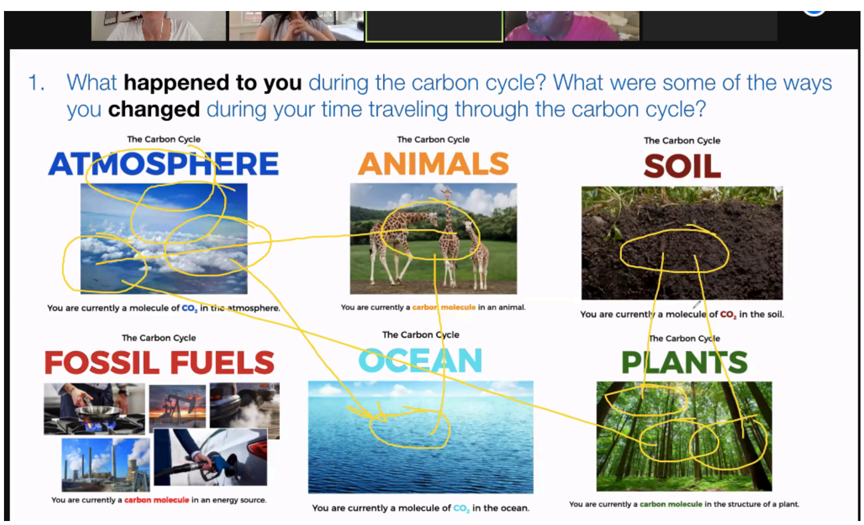
Classes on 10/22, 10/27 and 10/29 did not address sociopolitical dimensions but instead were dedicated to direct instruction on canonical chemistry concepts. Ms. T's framing remained oriented to the real world, community problem of limited greenspace altering the carbon cycle in South LA, which may have helped students understand the purpose of their classroom work as explaining socio-scientific issues in their neighborhood. However, this was not reflected in student participation. The activities were focused on understanding carbon chemistry as a foundation for understanding the carbon cycle. Carbon chemistry included analyzing the element, identifying its atomic properties, investigating the bonding and reaction tendencies of carbon based on valence electrons, and generalizing from this information to help students to write balanced chemical equations. There was limited connection to climate change over these days. The notebook activities included fill-in-the-blank worksheets such as listening the number of protons in elements, counting atoms on the product and reactant sides of a chemical equation, and predicting bonding based on valence electrons.

Classes on 11/3 and 11/5 each started with checking in on the presidential election, as of course the news was distracting and engaging. There was anxiety about Trump being re-elected and the social unrest that could result. Ms. T, the students, and I processed the news as a group. Then, as planned, the class returned to the sociopolitical dimensions of climate change. We discussed how humans are part of the environment, the carbon cycle, and the climate system.

Ms. T modeled identifying the chemical transformations caused by everyday actions and activities, and accounting for membership, participation, and relationships to and with ecological systems and process. The activity of these two classes was in a Google survey that had students embody the journey of a carbon atom as it moved between spheres of the Earth. The activity engaged students in exploring human's role in the carbon cycle and continued the scientific work around the conservation of atoms in reactions. In the activity, students rolled dice to pick one of six options of the survey, and this randomly determined their journey in the carbon cycle. For example, if they were carbon in a fossil fuel would they stay in the ground or would they be extracted and combusted sending them to the atmosphere. Reflection questions from this activity included: what happened to you during the carbon cycle? Is it possible for carbon to disappear? Figure 1 shows Ms. T's annotations as a student responded to these questions.

Figure 1

Screenshot of Carbon Cycle Game

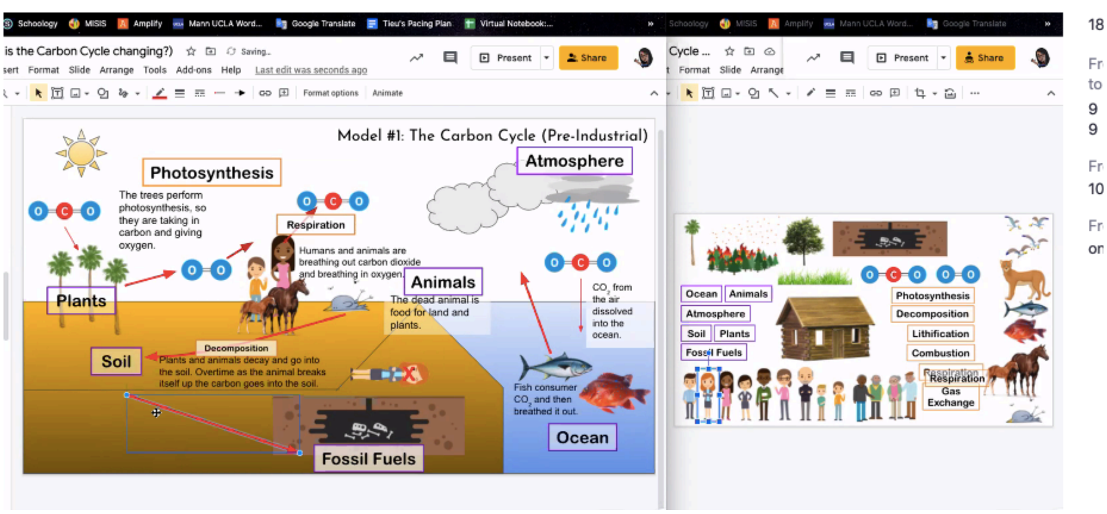


Class on 11/10 transitioned from a global scale to a local scale and engaged the students in the daily question of "How does carbon cycle in South LA?" The activity was focused on creating a whole-class consensus model of the pre-industrial, balanced carbon cycle in LA. Ms.

T positioned students as experts on LA who could generate a better model than the generic textbook version. She also framed the model of the past as a tool in order to later model the present that would explicitly include inequalities in land use that they noticed on the first day of the unit. Ms. T started with a history review of how the industrial revolution transformed daily life as a way to engage the students in identifying the many places where land use had changed, transforming the sinks and fluxes of the carbon cycle. Using stickers in a Google slide, Ms. T built the model and narrated her thinking out loud while asking students to identify local versions of the cycle that they explored in the global version of the cycle (Figure 2). Ms. T did not clearly position the carbon cycle as a phenomenon connected to climate change, and from the students' perspectives, the two processes likely were disconnected. Ms. T had not developed a sophisticated, cohesive way to consistently link daily activities to climate change.

Figure 2

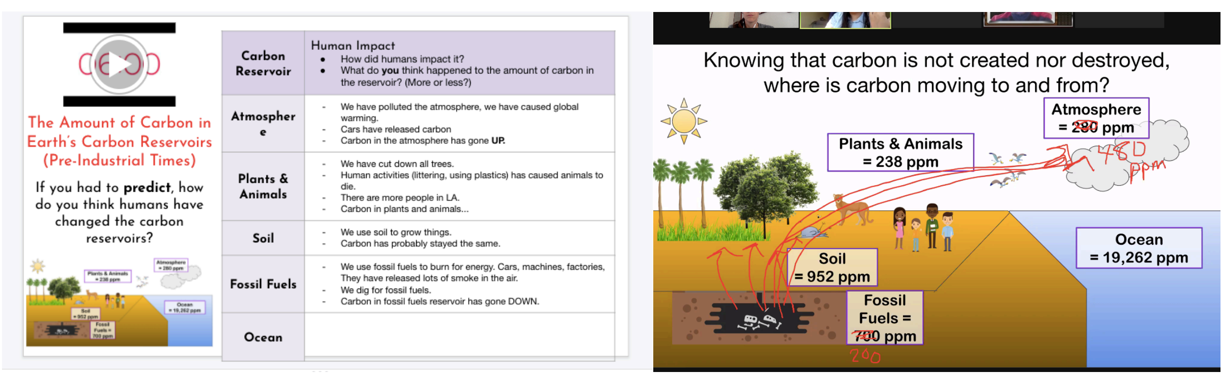
Screenshot of Creating the Consensus Model of the Pre-Industrial Carbon Cycle



Classes on 11/12 and 11/17 were structured as an opportunity to gather evidence on how humans have changed the carbon cycle. This lesson was an essential step to creating a present-day carbon cycle model. During the warmup for these classes, students were asked to respond to the following questions, “What parts of climate change could change your life or life in South LA? What are some ways that we can slow down climate change in South LA?” With this warmup, Ms. T began the work of connecting the phenomenon of the carbon cycle and climate change to one another, and she also continued her work of situating climate change as relevant to students’ lives and communities. Ms. T also introduced drivers of change to the carbon cycle that are sociopolitical. Ms. T gave students quantitative data on how much carbon was stored in different reservoirs in 1880 and today as a way to highlight the increase of carbon dioxide in the atmosphere and the decrease in the lithospheres as a result of combustion of fossil fuels for human industrial activity. Figure 3 shows a screenshot of the table that students completed in their notebooks and the annotated diagram that Ms. T presented to predict and verify quantitative changes to the reservoirs of the carbon cycle and the human actions associated with those changes, but without identifying specific social actors. The exit ticket for these classes asked students to, “Describe the parts of the carbon cycle we see in South LA.”

Figure 3

Screenshot of Activity Organizing Carbon Cycle Data



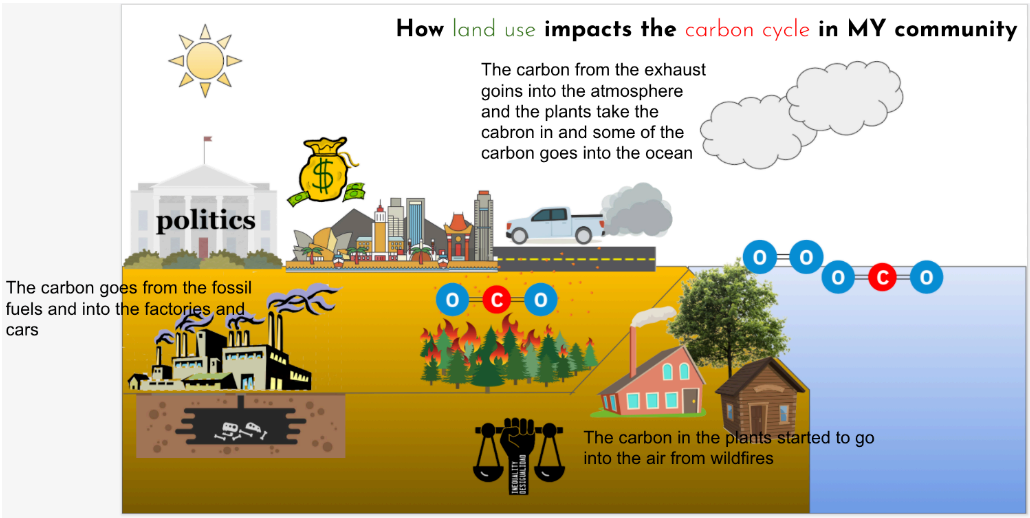
Class on 12/1 was the first class of the unit entirely dedicated to climate change as a phenomenon. Ms. T used resources from her training with Climate Reality (Al Gore’s non-profit) to define climate change, link it to land use and the carbon cycle, and build a sense of hope rather than despair about the future. The daily question was, “What is climate change and what can we do about it?” The warm-up asked students to continue to expand their thinking from the previous class and respond to the similar question, “How does climate change affect our lives in South LA?” Using a graph of temperature and carbon dioxide over the past 800,000 years, Ms. T defined carbon dioxide, methane, and water vapor as greenhouse gases that have fluctuated in concentration over Earth’s history but now have changed more rapidly than ever due to anthropogenic emissions. She used the blanket metaphor to explain how greenhouse gases insulate and warm Earth but did not fully explain the greenhouse effect. Following this, Ms. T walked through the global consequences of climate change such as hurricanes, heat waves, and infectious disease spread, which generated some emotional responses of fear and worry from students. Class ended with a whole group discussion on the ways in which the world and LA are coming together to fight climate change, which generated a lot of comparisons to the collective efforts of groups during the COVID-19 pandemic.

Class on 12/3 continued the discussion of hope and solutions for climate change by focusing on LA’s Green New Deal. Ms. T presented a range of technological and sociopolitical actions that are in progress or planned for LA which she said show that “humans know how to clean up the mess we made.” She guided students through reading and describing some of the targets in the Green New Deal, such as having all citizens live within half a mile of a park and to have 50% tree canopy cover. Students contributed their ideas on the social and ecological benefits of each of these changes and how they might impact their own lives. Ms. T scientized the Green New Deal targets by leading students through an activity to estimate how each target would impact land use, the carbon cycle, and the temperature change associated with anthropogenic global warming. Specifically, students filled out a table that asked them to describe how and why increased recreational land use would decrease atmospheric carbon dioxide concentrations and temperature. This activity connected the social process of policies like the Green New Deal with the scientific processes of increasing the flux of carbon into the biosphere through photosynthesis.

Class on 12/8 was spent working on the formative assessment task for critical climate awareness. The non-profit community group Grown in LA was introduced as an example of a locally operated effort through which citizens are working to increase the quality and quantity of greenspace in in South LA. Ms. T embedded a review of key scientific and social concepts into the five prompts of the task. The final classes of the unit on 12/10 and 12/19 were dedicated to allowing the students to individually revise the present-day carbon cycle model. In each student's digital notebook, Ms. T copied the class consensus model and explained the task in several steps. First, she explained that the imaginary intended audience was LA's Director of Parks and Recreation and the students' biology teacher from last year; this audience was chosen to encourage students to include both scientific and sociopolitical dimensions. Second, Ms. T provided a summary of big ideas from the units that students could include in their revision as well as stickers that represented each including: the greenhouse effect, climate change, economics, politics, community issues, and inequities. The remainder of the class was spent offering one-on-one support to students in their revision. Figure 4 presents an example of a student's final model for unit 2.

Figure 4

Example Final Model of the Carbon Cycle



Unit 4: Greenhouse Effect and Extreme Heat

The guiding question of unit 4 was, "What are the impacts of LA getting hotter?" Through the framework of this question, students explored the big idea that human activity has altered the greenhouse effect. The phenomenon of investigation was the reliance on carbon-dependent infrastructure in LA (specifically for transportation and electricity), and how this reliance has unbalanced the greenhouse effect and resulted in increased frequency and intensity of extreme heat events that disproportionally burden low-income communities of color like South LA. The unit was oriented to students' lived experiences with extreme heat and the technology they use every day that directly or indirect results in carbon emissions. Students worked throughout unit 4 to create and revise models that layered emission-reduction actions in their neighborhood, issues of social justice, and the mechanisms of the greenhouse effect.

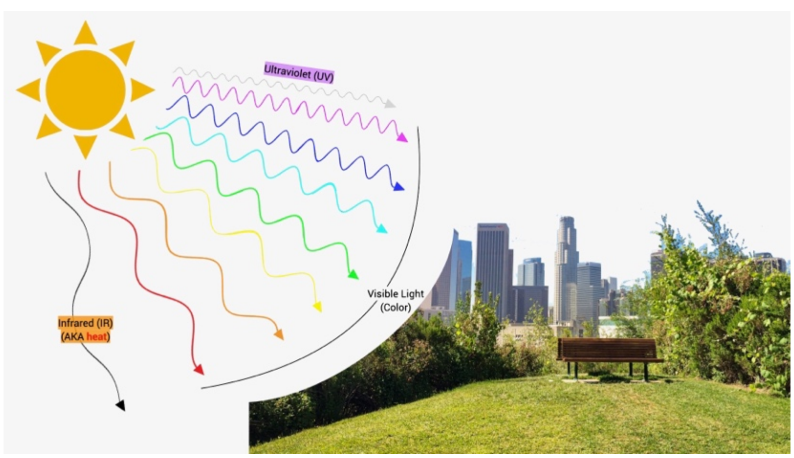
To launch and frame the unit, on 3/2 Ms. T lead an activity that guided students through five "stations" of data on heat waves. The daily question was also the exit ticket and asked students to describe how their lives are affected by heat waves. The stations included a broadcast from a local television station from the August 2020 heatwave that swept the region, data visualizations on food prices verses temperature, and hospitalization rates by race in the region during heat waves. The goal of presenting such varied data was to help students move away from focusing on the immediate, physical discomfort of hot days and to think about the less visible, less direct, systemic changes that extreme heat bring to everyday life. Ms. T also began to introduce inequalities in disrupted climate change by engaging students in a discussion in which they labeled their experiences with the 2020 heatwave as racialized and classed.

In the next class on 3/4, Ms. T presented canonical definitions of key vocabulary terms within climate science, engaged the class in crafting a shared understanding of the differences between climate change and global warming, and defined “system” with pool-and-flux logic. In reviewing the PEs and DCIs on how energy in the atmosphere impacts weather and climate, the focus of this class was on understanding that climate is changing. The class looked at evidence of extreme weather driven by climate disruption in Texas, California, and New York and engaged in a discussion about what is normal weather for an area and how abnormal weather is linked to changing climate. This class connected the sociopolitical and scientific dimensions of climate change by weaving together real human stories and students’ personal experiences with quantitative and qualitative data on changes in climate. The exit ticket for the day gave students an opportunity to write their own definitions of climate change and global warning to show their understanding of how the concepts are linked.

The next two classes on 3/9 and 3/11 explored the concepts of electromagnetic radiation and albedo to help students understand the first step in the mechanism of the greenhouse effect (ultraviolet radiation from the sun is absorbed by dark surfaces on Earth and released as infrared radiation). While class on 3/9 was solely focused on scientific dimensions and did not address any sociopolitical dimensions of climate change, in both classes Ms. T presented these lessons as localized and personalized with graphics that included locations in LA that the students were familiar (for example, Figure 5 showing electromagnetic waves hitting a familiar part in Downtown LA). She also created an activity using thermal images that helped students connect the idea that black surfaces got hotter than white surfaces in the sun to the interaction with electromagnetic radiation. Class on 3/11 ended with students working towards explaining urban heat island in answering the following exit ticket question, "Which areas of LA might be getting hotter and why?" Students did not come to understand this concept well; in responding to the exit ticket, students described urbanization, population density, and traffic as responsible for heat but did not make connections to solar energy or albedo.

Figure 5

Example of Scientific Phenomenon Presented as Locally Relevant

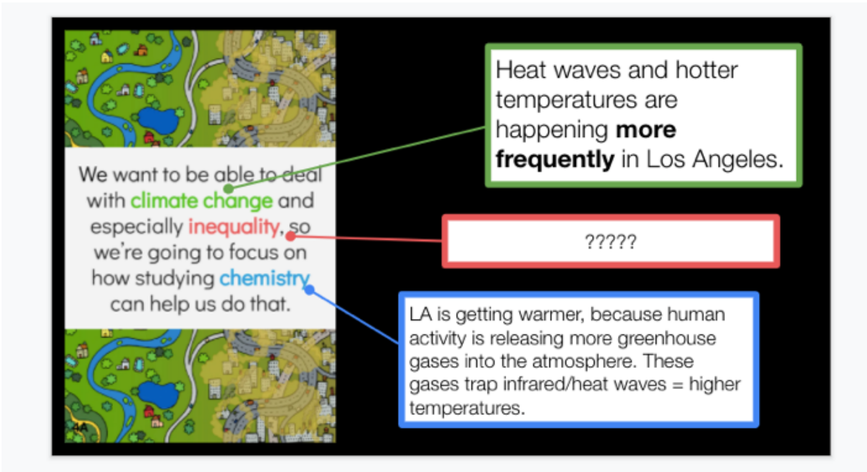


Over 3/18 and 3/23 the students engaged in various activities to investigate the mechanisms of the greenhouse effect as well as the consequences of unbalanced atmospheric carbon and energy budgets on LA. Class started with a review of combustion chemical reactions from unit 1 (the balanced reaction of a hydrocarbon and oxygen as reactants, and water and carbon dioxide as products). After exploring data on emissions from the transportation and electricity sectors, Ms. T used a Google JamBoard to document students' thoughts on actions that increase and decrease carbon emissions. Ms. T explicitly ascribed agency for emissions to various social actors, including individuals reliant on carbon-dependent technology, corporations that build and profit off the technology, and governments that drive policies to impact access to technology. These discussions foregrounded the sociopolitical drivers of an unbalanced greenhouse effect, linking combustion reactions of fossil fuels with social motivations of generating energy or profits. Students also engaged in a simulation of the greenhouse effect (on the pHET website) where they got to see how greenhouse gas concertation and temperature respond to changes in emissions. Activities ended with a reflection on local, classed experiences with extreme heat; Ms. T used reflection questions addressing the difference in luxury and subsistence carbon emissions and the disproportionate distribution of climate consequences and climate resilience to continue the discussion on inequalities.

The next class did not address a scientific dimension of climate change but was focused exclusively on sociopolitical dimensions. Ms. T organized class on 3/25 around the daily question, "Does inequality play a role in how LA deals with warmer temperature?" The students decided quickly that the answer to this question was yes, and Ms. T used another Google JamBoard to document personal experiences of resilience and hardship with heat and to brainstorm climate solutions. Ms. T also revisited the guiding question of the year; she left a blank for the words *chemistry, inequality*, and *climate change*, and then filled them in with specific concepts related to extreme heat. As shown in Figure 6, she went on to explain that the chemistry aspect was related to the greenhouse effect, the climate change aspect was frequency of heat waves, and the inequality was that South LA is getting hotter than other areas of LA and has fewer resources for mitigation, adaptation, and resilience for climate change and other social issues. The next week of school was spring break.

Figure 6

Screenshot of Activity Structure that Brought Sociopolitical and Scientific Systems in Contact to Answer the Year-Long Driving Question



The next two classes on 4/6 and 4/8 drew on a historical perspective to ascribe agency for emissions specifically to industrial, colonial, capitalist enterprises rather than ascribing responsibility universally and uniformly. Ms. T discussed how humans have been living on and modifying Earth for centuries, but it is only since the industrial revolution that emissions have unbalanced the greenhouse effect. Class on 4/6 was a totally new effort; Ms. T was inspired by reading *Braiding Sweetgrass* and meeting the leaders of Indigenous communities at a climate leadership training hosted by Al Gore's non-profit organization. Class was essentially a monologue with very little opportunity for student engagement with just an exit ticket that asked, "The GHE has only recently changed, but humans have been around for a long time, so what changed?" Ms. T shared differences between Western, anthropocentric relationships with nature and Indigenous, reciprocal environmental philosophies. As a one-off class, it is unclear if it had an impression on students. However, it was very important to Ms. T to begin developing her pedagogical strategies to center on Indigenous epistemologies.

Class on 4/8 gave students the quantitative tools to discuss the atmospheric changes post-industrialization, including parts per million (ppm) as a unit of measurement and the flux of carbon into the atmosphere from various carbon reservoirs. Students asked why the seemingly small difference between 260 and 415 ppm carbon dioxide (pre-industrial and present-day concentrations) was such a big deal, which gave Ms. T an opportunity to discuss the fact that the greenhouse effect is very sensitive to atmospheric changes. During the last half of class on 4/8, students worked on creating their first iterations of their greenhouse effects models. Ms. T and the students together created a class consensus model of the past (pre-industrial) and present (post-industrial) greenhouse effect in LA (Figures 7 and 8). Using stickers in a Google slide, Ms. T asked students to respond to a series of questions that sequentially built the components of the model; for example, she asked students to identify sources of heat and sources of carbon dioxide, and students suggested she add the sun and cars. In the end, she asked students to explain what the temperature was because of all the stickers added and the students added a thermometer symbolizing the temperature increase.

Figure 7

Consensus Model Created to Explain the Pre-Industrial Greenhouse Effect

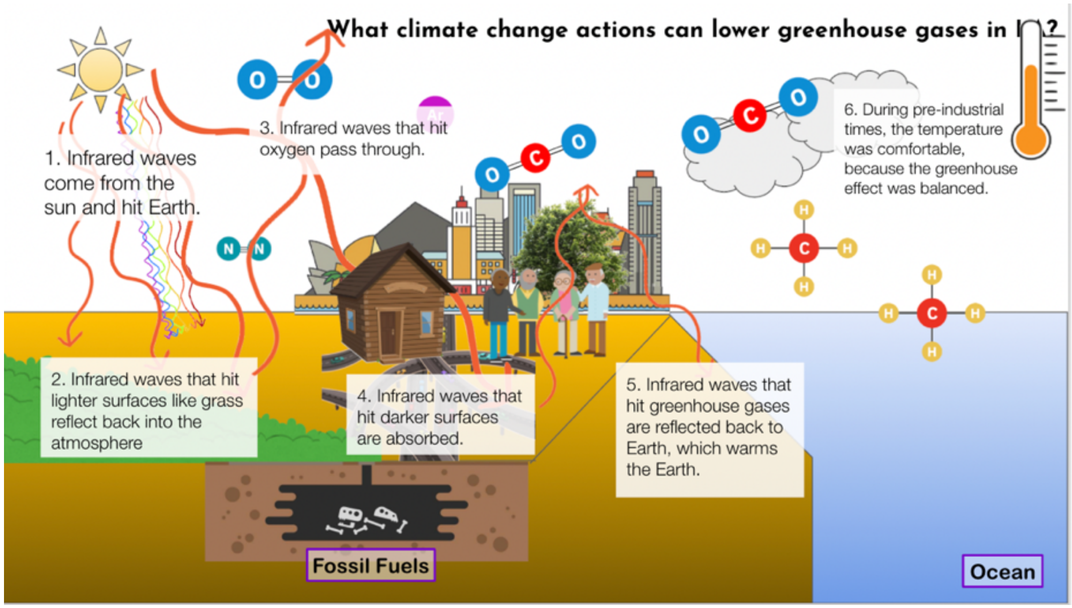
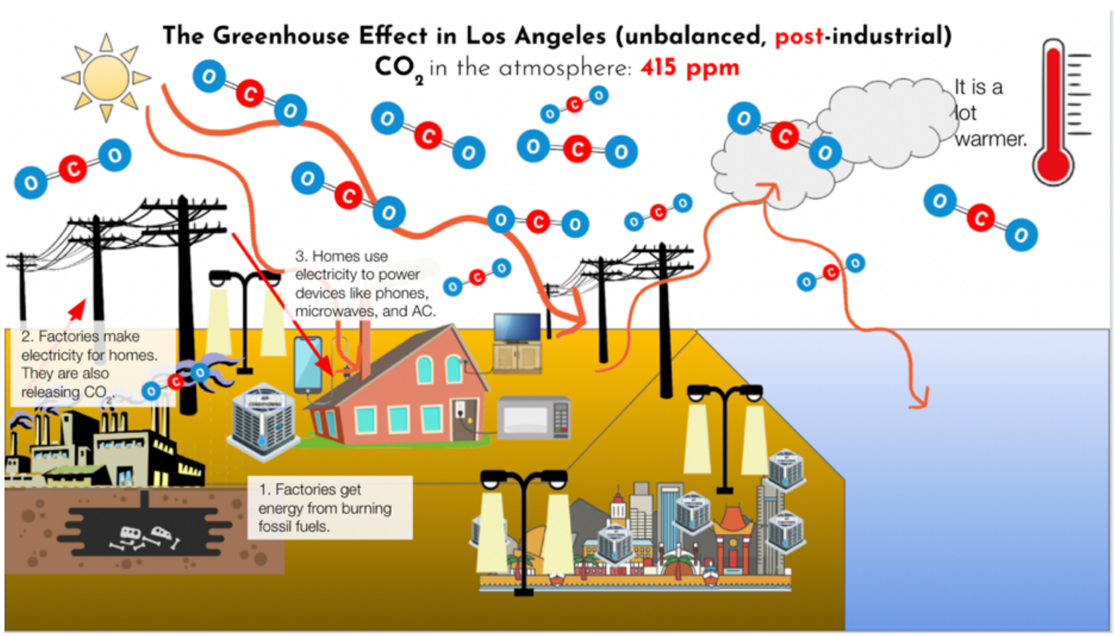


Figure 8

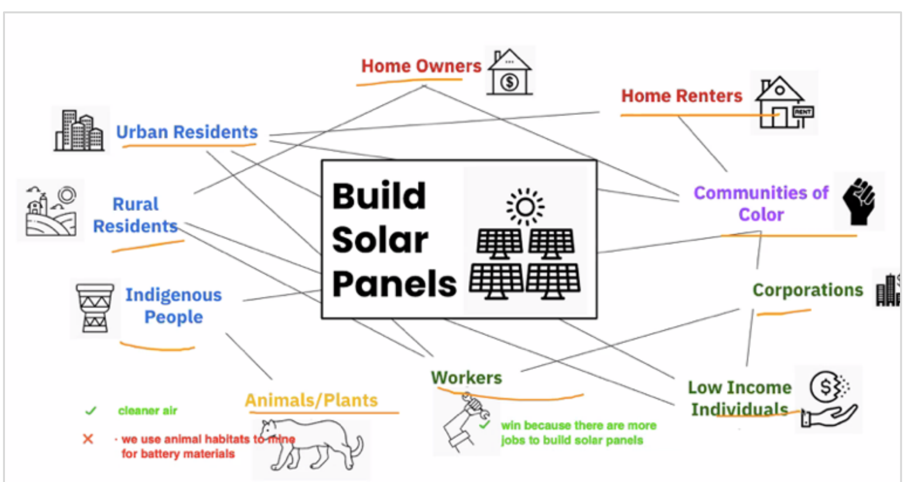
Consensus Model Created to Explain the Present-Day Greenhouse Effect



Classes on 4/13, 4/15, 4/22, 4/27, and 4/29 had poor Wi-Fi connections and therefore progress through the guiding questions was very slow and interrupted. The five classes were dedicated to exploring an online simulation for climate policies and projected warming called En-Roads. In the activity, students could manipulate various levers—for example, increasing investment and utilization of carbon sequestration technology or solar panels—to quantify the impact of projected degrees of warming, from two to eight degrees Celsius. This was a very global-scale and socio-politically oriented tool. Ms. T paired this simulation with discussion of vocabulary on political, economic, and social levers of change. She introduced the idea of subsidies as incentives and taxes as disincentives, and highlighted the network of stakeholders that benefit or are harmed by the various actions and inactions (see Figure 9). The discussion of winners and losers invited students to connect their critical awareness of issues facing various stakeholders (such as low-income communities, renters, blue collar workers, and animals) to their understanding of the cost-benefit analysis of emissions reduction.

Figure 9

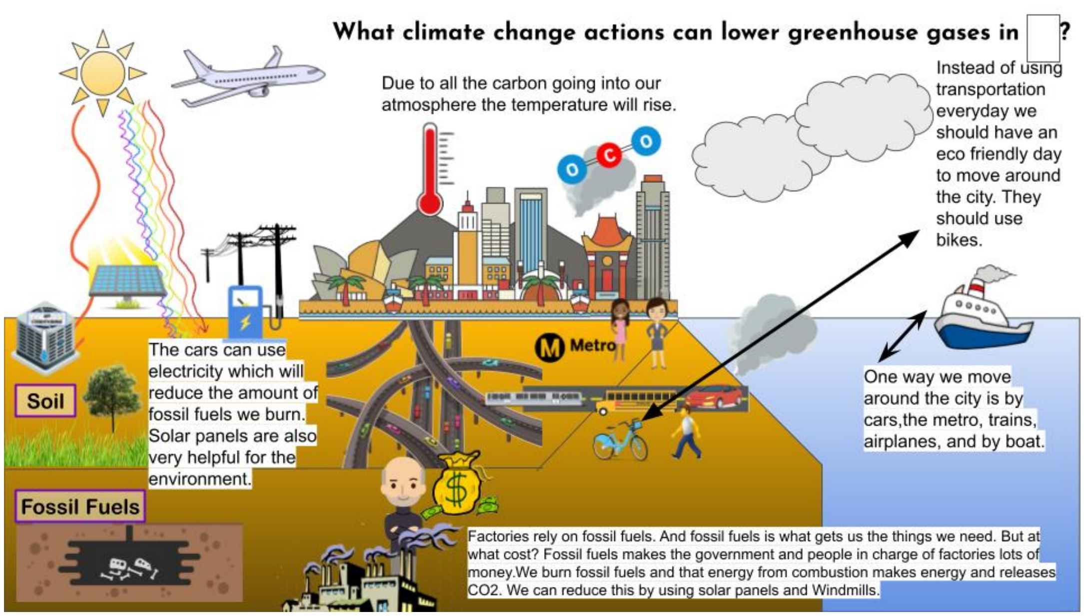
Example of an Activity Structure that Engaged Students in Politicizing Climate Change by Examining the Impact of Climate Actions on a Web of Stakeholders



The last weeks of the unit, from 5/4 to 5/20, were focused on creating individual models of the greenhouse effect in LA and emission reduction strategies to mitigate extreme heat. Ms. T developed a set of scaffolds to supports students in modeling both scientific and sociopolitical dimensions. She guided students through a series of questions on electricity and transportation as sources of emissions to help them add stickers to show components, arrows to show the flow of carbon or energy, and descriptive labels to their models. After making the series of revisions, the students also tested their models with a comparison to professional climate models to evaluate if their own models told the same stories. After testing, they revised their models again to match the professional models more closely. Figure 10 is an example of a student's final model. Ms. T helped students address sociopolitical dimensions by providing icons that represented economics, justice, and politics, such as the bag of money in Figure 10. After this, unit 4 ended with two days dedicated to completing the critical climate awareness task.

Figure 10

Example of a Final Model of the Greenhouse Effect



Chapter 5: Findings on Engagement

In this chapter, I present my findings on student engagement that allowed me to answer my research question focused on the ways in which a sociopolitical focus structured classroom engagement. I used the CPDE framework to analyze interactions. The framework was ideal for studying this learning environment because it makes visible the unseen generative resources of disciplinary knowing and doing among minoritized students during their deep involvement in (and progress on) learning the concepts, practices, and characteristic of the science and politics of climate change. Participation in connective-disciplinary learning is a mediating process of developing the learning outcomes of critical climate awareness and learning canonical concepts. Therefore, the extent to which CPDE occurred supported the extent to which these outcomes developed.

My goal in this chapter is to describe and analyze engagement in units 2 and 4 for the students in period 3 chemistry. This analysis draws on in-the-moment observations of interaction (spoken out loud or written in the Zoom chat) as well as two proxies of interaction: writing in student notebooks during classroom participation and the temporally distal artifact of interviews in which students reflected on their participation. The interactions I present were selected because they represent how students grappled with the big ideas of the unit. Additionally, they relate to the work done to create the unit's final project—the diagrammatic models. For each interaction analyzed in the focal units, I present three things: a high-level summary of participation (who and how) and the topic addressed, the interaction itself (turns of talk, transcript, or writing), and the analysis of the principle(s) identified in the interaction. After analyzing both units, I rate the embodiment of each of the principles in units 2 and 4 to summarize and compare the focal units. Ms. T's actions became more sophisticated and refined over time, as expected, and she increasingly gave students greater opportunities to appropriate and differentiate the principles in their actions.

Analysis of Interactions in Focal Unit 2

In unit 2, Ms. T and students grappled with urbanization as a cause of climate change as well as the social and ecological harms of unequal access to green space in South LA. In describing the CPDE principles in this unit, first I show the relationship between problematizing and resources. Specifically, I trace Ms. T's efforts to politicize decision making about urban land use and the relational resources she offered to support that work, as well as students' responses to her efforts. Second, I show how relationality was embodied in the principle of authority. Specifically, I trace how students reproduced Ms. T's positioning of participation in altering the carbon cycle. Table 8 shows a summary of the key interactions that I describe and analyze from unit 2.

Table 8

Key Interactions in Unit 2

Date	Summary of Key Interactions
10/20	Ms. T and students compared land use and associated carbon sinks between South LA and Beverly Hills; students shared their critical awareness of racialized and classed inequalities in access to urban green space
10/22-10/29	Ms. T led guided and individual activities on the chemical properties of carbon that she framed as relevant tools for understanding the socioecological benefits of parks
11/3-11/5	Students used the carbon cycle game and individual reflection to explore how carbon moves globally and locally; Ms. T situated humans, including students, as part of the climate system and elevated socio-political drivers of increased carbon to the atmosphere; Ms. T and students used undifferentiated language (we/us/all humans) to situate students as participants in the causes of climate change
11/10-11/17	Whole class activity to create consensus model of carbon cycle; Ms. T positioned students as experts on their local community to create a model that is useful to South LA; student thinking on agency and actors in unbalancing the carbon cycle was probed and students identified actions, actors, and objects as responsible for carbon emissions
12/1-12/3	Guided discussion connecting the carbon cycle to climate change and sociopolitical solutions; Ms. T modeled the practice of scientizing in her analysis of LA's Green New Deal; Ms. T projected proleptic hope for the future; Ms. T and students used undifferentiated language (we/us/all humans) to situate students as participants in the solutions to climate change; Ms. T provided and encouraged scientific and relational resources
12/10-12/19	Individual revisions of present-day carbon cycle model; students used their critical awareness of social inequalities to explain how a lack of greenspace contributes to an unbalanced carbon cycle

Ms. T launched unit 2 on 10/20 with an activity that compared land use in Beverly Hills and South LA. She ended class with an introduction to the unit's guiding question exploring connections between the carbon cycle, urban green space, and extreme heat caused by climate change. Four students participated by responding to questions through private Zoom chat messages and 10 students completed the warm-up and exit ticket. To start the activity comparing side-by-side aerial photos, Ms. T explained how she wanted students to participate by saying,

> Land use is not equal across LA and racism plays a big role in how land is used across LA. I want you to use what you learned about redlining in history class in this unit. Think about the places you've been here in South LA and around the city, or the stories your friends and family have told you about places they've been. (Ms. T, 10/20)

Students shared their observations that Beverly Hills homes had bigger yards and that there were more parks and golf courses—they also expressed emotions of frustration at these differences. Students also expressed a racialized and classed understanding of these differences in land use. Ms. T read the students' contributions out loud, some anonymously and sometimes naming the student. For example, MJ wrote in the chat, "Damn [Beverly Hills] looks way better. It's just a white neighborhood," and later added, "F*** racism we breathing the same air we are all the same with different color of skin." Sara wrote in chat that, "the people living there are famous and rich, even I think there is no drilling oil areas there." This statement showed a connection to unit 1 in which students had identified that urban oil drilling is concentrated in low-income communities of color. Monica wrote, "My parents told me about Beverly Hills it's rich people." Ms. T occasionally elaborated on students' comments. For example, after Monica's comment she said, "yes, money and power make a big difference. Monica has known about this since she was kid, you all know these differences." In response to Ms. T repeatedly asked students to look for differences between communities and explanations for these differences, Tia wrote, "More parks; white neighborhood; rich and famous people." Ms. T ended the activity by celebrating students' contributions and encouraging them to keep bringing in ideas about race, politics, money, and science "at the same time."

Ms. T actions embodied the principles of problematizing and accountability, and the students' actions embodied the principles of problematizing and resources. First, Ms. T politicized land use in South LA as unequal and unequitable compared to Beverly Hills. This politicization represents problematizing because she confronted the sociopolitical dimensions of the causes and consequences of climate change. Second, Ms. T held students' intellectual work accountable to knowledge they learned in history class, and to ideas, observations, and experiences from outside the classroom. This represents accountability because she recognized the legitimacy of students' community-based knowledge in justifying their ideas and therefore established this recognition as a classroom norm. Third, students recruited their critical awareness of social inequality as a sensemaking resource. Specifically, they identified racialized and classed differences across LA communities. Students' critical awareness of social issues was one of the designed resources that Ms. T intentionally encouraged in order to support students' connective-disciplinary work. Fourth, students built on Ms. T's politicization of land use by suggesting racialized and classed explanations for inequalities. This represents problematization because this issue was genuinely problematic for the students and the discussion allowed them to connect critical awareness of social issues to climate science.

The next three classes (10/22, 10/27, and 10/29) were dedicated to exploring the canonical scientific concepts of periodic properties that were cohesively framed as tools for understanding inequities in the carbon cycle. There was almost no student participation on these days besides answering procedural questions and completing the worksheets related to the periodic table of elements. To launch an activity about the abundance of carbon in the world, Ms. T said, "We see carbon in everything, but the amount of carbon in different places and things is different. What do you see out your window right now? Does it store a lot or a little?" She did not intend these to be rhetorical questions, but no students responded. To launch another activity on the chemical reactions of carbon and identify trees as carbon sinks, Ms. T said, "Let's remember that Beverly Hills has more trees than South LA, so there is more carbon there."

Ms. T embodied the principles of problematizing, accountability, and resources while launching these activities. First, Ms. T problematized the distribution of carbon sinks when she identified South LA as having less parks and green space than another neighborhood previously identified as more privileged. Through this activity, Ms. T and the students looked critically at inequalities in the ecological benefits of parks. Second, Ms. T built on her previous accountability actions and began to hold students' intellectual work accountable to the norm of scientizing. She promoted the practice of scientizing when she asked students to see the objects outside their windows as part of chemical transfers and transformations. With this classroom norm, Ms. T continued her actions of legitimizing the value of students' community-based observations and holding classroom work responsive to the community. Third, Ms. T's invitation to engage in the practice of scientizing situated students' everyday observations as valuable sensemaking resources in understanding carbon chemistry. She framed students' community-based experiences as resources to support connective-disciplinary work.

On 11/3 and 11/5, students worked through the carbon cycle game and reflected on the human's role in the carbon cycle. Five students participated in discussions and six students completed the reflection worksheet. Ms. T opened the discussion of anthropogenic changes to the carbon cycle by asking for examples of the human's role and students responded with public and private Zoom chats. For example, Lachelle wrote, "we pollute;" Tia wrote, "we eat plants;" and Jessica wrote, "we extract crude oil." Ms. T read these contributions out loud. Jim simply wrote "fossil fuels," at which point Ms. T asked for elaboration, prompting him to write, "we dig them up." Ms. T evaluated this comment as correct when she said, "Yes, we need energy from fossil fuels." To summarize students' contributions on anthropogenic changes to the carbon cycle and transition to the next question, Ms. T said, "We need energy, so we use fossil fuels to power our cars and cook and heat our homes." In the written reflection worksheet, students responded to the same question about the role of humans. Jessica, Lachelle, and Sara wrote,

> [Human activity impacts the carbon cycle when] bad carbon emit from factories and the cars we drive around. It isn't good for plants to take in that carbon and it is also bad for the atmosphere too. Also, human affect the plants part of the carbon cycle because humans cut down a lot of trees and plants which means there will be few plants to take in the carbon and produce oxygen which can later affect humans because too much carbon in the atmosphere is really bad and we need oxygen to breathe. (Jessica, notebook 11/5)

"[Human activity impacts the] fossil fuel [part of the carbon cycle] because humans dig it up to fuel their cars and machines." (Lachelle, notebook 11/5)

> The part [of the carbon cycle that humans impact is] when I'm in the animal, because maybe I'm the carbon in the animal and a human can come in kill it, like when I'm in the tree because a human can come and cut it. I think it is bad because the carbon still there somewhere trying to find friends to be with. (Sara, notebook 11/5)

During these interactions, Ms. T's action represented problematizing in two ways, and both Ms. T and the students' actions embodied the principle of authority; relationality is embodied in the principles of authority and problematizing. First, Ms. T politicized the mechanisms of climate change by elevating the sociopolitical drivers of change in unbalancing the carbon cycle. By linking fossil fuel extraction and combustion with the social systems of transportation, she looked critically at a big idea of the discipline, specifically the dependence of social structures on fossil fuels. It is important to note that in this problematization, Ms. T did not surface the power dynamics embedded in this reliance on fossil fuels. Second, Ms. T politicized the human-nature divide that is dominant in Western science and science education that sets humans apart and outside of natural systems. Ms. T situated the students as part of environmental systems as a way to counter this normative narrative and establish relationality regarding students' relationship to the natural world. She did this with a constant and consistent use of the terms we and us in order to position the students as members of and participants in the climate system.

Third, Ms. T's use of we and us also embodied the principle of authority. In positioning students as part of natural systems, she also positioned herself and students as stakeholders with agency who play active roles in addressing the problem of carbon emissions in these sociopolitical and scientific systems. It is important to note that in this embodiment of authority, Ms. T did not differentiate participation as a function of power. She used we/us to position students as part of a uniform and universal group of humans. Absent from these interactions were the relational resources of power dynamics to help students grapple with historicity, identity, and privilege regarding their contributions to unbalancing the carbon cycle. In this way, students did not have a necessary resource to fully problematize inequalities in land use during these classes. Fourth, the students' actions embodied authority in ways parallel to Ms. T's actions. They used the phrases we, us, and all humans in undifferentiated ways to position themselves as playing an active role in the unbalanced carbon cycle. Neither students nor Ms. T asked "Who exactly is 'we'?" or accounted for power, collectives, history, and identity in positioning themselves as part of climate systems.

Classes on 11/10, 11/12 and 11/17 were dedicated to creating whole class consensus models of the pre-industrial and present-day carbon cycle. Many students participated in class, but their contributions were brief (one to two words). Ms. T organized the modeling by presenting an activity structure that invited this form of participation; she asked a targeted question about an aspect of the carbon cycle (e.g., How does carbon get from the land to the air?), students responded in the chat with brief responses, and Ms. T evaluated and revoiced those contributions with elaborations and academic language. Ms. T launched the third day of modeling by saying, "Today we are going to add to our model what humans are doing." She contrasted a generic diagram of the carbon cycle with the model they would produce by situating the day's task as focused on modeling South LA in 2020. To accomplish this framing, Ms. T said, "You all live here, and you all live in the present day, so you know what this model needs to be better."

After this introduction, the structured activity began with an initiate, respond, evaluate-elaborate format. For example, Ms. T asked if students wanted to add trees and JM wrote "yes." Ms. T responded, "Let's remember people living in Beverly Hills have more power and money and voice and so they get all the parks you saw. Those trees store carbon and that helps climate change." In another instance, Ms. T asked what cars did to the carbon cycle. Jessica wrote, "release carbon dioxide," and Ms. T responded, "Yes, gas-powered cars do. And we now have Teslas and when I was young there were no electric cars. The technology we have now is so cool." Following this, Ms. T asked for more examples of how carbon concentrations in the atmosphere had increased over time and Laura wrote, "they have released a lot of smoke in the air." My own participation in the class was not a daily occurrence, but on this day, I asked, "Laura, could you tell us who 'they' is that you mentioned?" Laura did not respond, so I directed the question to the whole class: "Who can help Laura out? When you think about who puts carbon in the atmosphere, who exactly are you thinking about?" In response, Anna wrote “machines,” Tia wrote “the government,” Jim wrote “we dig up fossil fuels,” and Sara wrote “fossil fuel combustion.” The activity continued with this structure until the class completed their model.

In these interactions, Ms. T’s action embodied problematizing and both Ms. T and students’ action embodied the principle of authority. First, Ms. T continued and expanded her problematizing of the mechanisms of climate change by elevating the sociopolitical drivers of change in unbalancing the carbon cycle. In politicizing the inequalities in access to urban greenspaces (with her reference to Beverly Hills having more parks), she confronted the sociopolitical mechanisms of change and invited students to grapple with justifying past actions around land use decisions. In this way, she problematized climate change by looking critically at climate change causes as linked to the “power, money, and voice” that Beverly Hills has, and that South LA implicitly does not—which is a genuinely problematic issue from the students’ perspectives. It is important to note that Ms. T still did not situate or invite relational resources to interrogate why South LA did not have “power, money, and voice” compared to Beverly Hills and therefore students were not adequately able to grapple with how to justify past actions of urbanization or to ask what should be done to achieve climate justice. Second, Ms. T’s actions embodied authority in ways consistent to past classes, situating students as undifferentiated participants in unbalancing the carbon cycle through her use of the terms we/us. For example, she said “now we have Teslas;” by “we,” she meant society, although none of the students actually had an electric car or a Tesla so they were not part of that group represented by “we.” Third, Ms. T’s actions embodied authority in a new way. In these interactions, she situated students as local authorities of their community. She elevated the students to experts of South LA by positioning them as individuals with agency who could create a better carbon cycle model than the generic diagram within the curricular resources because of their community-based, everyday experiences. Fourth, the students' actions embodied authority in ways similar to the past classes; they ascribed agency for carbon emissions and unbalancing the carbon cycles in undifferentiated ways. Tia ascribed agency to a specific social actor (the government), Sara to an undifferentiated social actor (we), Anna to an object (machines), and Jim to an autonomous action (combustion). This relationality does not differentiate participation as a function of relationships to power.

The classes on 12/1 and 12/3 focused on linking the carbon cycle to climate change through discussions of LA's Green New Deal. Student participation was mostly limited to discussions of the warm-ups and exit tickets, which nine students completed. Ms. T presented a handful of the Deal's targets for mitigation actions and engaged students in connecting the history that makes the policies of the Deal necessary to the actions proposed in the policies and the desired changes in the climate system. Ms. T launched class by showing a graph of temperature and carbon dioxide concentration over the past 800,000 years and highlighted the hockey stick curve of the last century, saying, "What we are freaking out about is the rate of increase of CO_2 in the air. This is why me and Ms. Heather are obsessed with CO_2 (laughs)." Next, she dedicated half a class to investigating LA's commitment to electric vehicles as a mitigation strategy. In describing a target to increase the city's fleet of electric vehicles, Ms. T said,

> I predict in 30 years you all will be driving electric cars. I might buy an electric car because the government gives a bunch of deals. It's not a Tesla but whatever (laugh). Yes, a Telsa is hella expensive now, but they are getting cheaper. And maybe you'll have a solar panel on your roof to power your Tesla for free! (Ms. T, 12/1)

After discussing electric cars, she continued imaging a more sustainable future by talking about my son's future and saying, "Maybe Agustín will never go to a gas station." She also addressed innovative technology when she said, "imagine if the concrete of our sidewalks could just suck up carbon out of the air." These classes included the most explicit discussions of politics and the structure of government to date. Building on the energy of President Biden's recent election sparked curiosity and elicited emotional displays from students. For example, Ms. T discussed the climate implications of President Trump's tenure and of the transition to President Biden, and two students from El Salvador asked for details on their president's stance on climate actions which Ms. T was not familiar with. Jim expressed climate anxiety during these discussions when he wrote in the chat, "I'm worrieddddddd," after Ms. T presented a series of slides from Climate Reality (Al Gore's nonprofit) on climate consequences. The activities concluded with Ms. T revisiting the guiding question of the unit and summarizing what the class had discussed so far; this was a monologue with no student participation.

During these classes, Ms. T actions embodied the principles of accountability, resources, and authority, placing an important focus on relationality embedded in resources and authority. First, Ms. T modeled the practice of scientizing in her analysis of LA's Green New Deal and held students accountable to this practice in their work. Ms. T scientized the policies of the Green New Deal by emphasizing how atmospheric carbon concentrations and temperature would change because of the actions taken by the city. For example, with more electric cars on the streets in place of gas-powered cars, combustion of fossil fuels decreases and therefore a flux of carbon into the atmosphere decreases. Second, the work of scientizing drew on the resource of bringing scientific and social dimensions of climate change into contact, such as transportation as a source of emissions and an opportunity for mitigation. Ms. T intentionally provided this as a designed resource. Third, Ms. T used two new types of resources: data on historic geochemical climate trends and relationality. Regarding relationality as a resource, Ms. T situated collective sociopolitical actions like those in the Green New Deal as necessary complements to technological solutions. Collective action represents a collaborative type of relationship—potentially a novel and transformative type of relationship—that is needed for students' intellectual work and problem solving. Ms. T projected proleptic hope for the future in her positioning of collaborative sociopolitical climate solutions. Fourth, relationality was also embodied in the principle of authority. Consistent with other classes, Ms. T did not differentiate students from a uniform group of we/us/all humans.

During the final two days of the unit (12/10 and 12/19), students worked individually to revise the consensus models of the carbon cycle and to create new models explaining how land use in LA impacts the carbon cycle. Because Ms. T mostly worked with students one-on-one, there was no student participation in the form of a discussion. A total of 17 students turned in a model, but only 10 students fully completed the activity by including text in the form of descriptive labels. Most of the text that students included on the models simply described the elements and processes of the models rather than explaining the unit's overarching question or addressing the social phenomenon of park inequality. Below, I present examples of descriptive labels written by four students that embody one or more of the principles addressed throughout unit 2.

Jessica used a clip art icon (an upheld, clenched Black fist) that Ms. T provided to represent the invisible social processes inequality and injustice. She wrote,

> There are a lot of CO_2 in the atmosphere in LA because of humans' impact on the land. Inequality impacts how we use lands because richer neighborhoods usually has more

> nicer buildings, recreational buildings, and more parks unlike low-income neighborhoods. Humans drill crude oil from fossil fuels in mostly low-income neighborhoods in LA. (Jessica, unit 2 model)

Jessica explained that she included the inequality icon to signify that wealthier neighborhoods have more parks than low-income neighborhoods, and low-income communities are burdened with more environmental harmful activities. Sara also made a classed assessment of land use in LA. She wrote, "In some parts of the city there's more money and business that's why it is clean, but it produces more pollution to the air." Sara identified wealthy neighborhoods as having the resources to maintain a clean environment and resources for luxury emissions and pollution. Lachelle wrote, "We cut down trees to make space for buildings so that takes away from our oxygen because trees can't give us oxygen if they are dead," emphasizing that urban deforestation was motivated by development. Other students also placed a similar focus on oxygen rather than carbon dioxide, but Ms. T did not address this as out of alignment with the objective of a carbon model. Jim discussed political stagnation in addressing the role of land use in causing climate change. He wrote, "Y entonces hay peleas entre los políticos, entre que uno no le importa los cambios climáticos, y otros que quieren cambiar el mundo tratando de arreglar el daño. [So politicians fight with each other because some don't care about climate change and others want to fix the damage on the planet]."

The text in the students' models embodied problematizing, resources, and authority. First, Sara and Jessica politicized inequalities in land use as a function of wealth and race. This problematizing of the causes of climate change was virtually identical to their problematizing on the first day of the unit when they identified Beverly Hills as a rich white neighborhood that had more parks because of this privileged status. This represents a lack of progress between the beginning and the end of the unit. Second, students drew on their critical awareness of social inequalities in order to make these racialized and classed arguments. Sara, for example, used her critical awareness of the power that wealthy communities have; she surfaced power dynamics by politicizing agency for emissions as a function of wealth when she described how wealthy neighborhoods engage in luxury emissions. This is more sophisticated and nuanced that the problematizing she did early in the unit. Jim identified and differentiated the government as a social actor with distinct responsibilities and power. These students used their critical awareness of social issues to problematize climate change by grappling with how to justify the actions and inactions of politicians in addressing the climate crisis. Third, the students embodied relationality in authority within their writing by using the phrases us, we, and all humans to position undifferentiated humans as members of the climate system and to position themselves as participants. For Jessica and Lachelle, "we" meant humans. This undifferentiated authority was consistent and homogenous in students' actions throughout unit 2 and matched Ms. T's actions suggesting that students reproduced rather than appropriated relationality in the principle of authority. The consistence of relationality in the principle of authority also represents a lack of progress throughout the unit.

In summary, the analysis of how Ms. T and the students grappled with the social and ecological harms of unequal access to green space in South LA shows two ways in which the CPDE principles make visible students' involvement in the concepts and practice needed to engage with climate change. First, in examining the relationship between the principles of problematizing and resources, my analysis shows that the principles were out of balance. While Ms. T problematized land use as unequal and inequitable based on race, class, and history, she positioned students as stakeholders and contributors to climate change without differentiating the power dynamics. She did not provide the relational resources needed for students to grapple with the power dynamics embedded in unequal and inequitable land use that contributes to climate change. Second, in examining the relationality in the principle of authority, my analysis shows that the principle was short-circuited. Ms. T promoted (and students reproduced) undifferentiated agency relative to the history of inequalities in urban green space and agency for carbon emissions. Without the relational resources needed to disentangle who "we/us" really is or to determine how students fit into generic descriptions of "all humans" in relation to power, the principle of authority was short-circuited. As a results, the diagrammatic models that students created at the end of the unit largely record the same version of problematizing, authority, and resources that they embodied at the beginning of the unit. The imbalance and short-circuiting of principles limited the sophistication of students' final explanations.

Analysis of Interactions in Focal Unit 4

In unit 4, Ms. T and the students grappled with actions to mitigate extreme heat in South LA caused by climate change. First, in describing the CPDE principles in this unit, I show the relationship between problematizing and resources. For unit 4, I trace Ms. T's actions and students' responses to problematizing two mitigation strategies—solar panels and electric cars—and recruiting students' critical awareness of social issues as a sensemaking resource about these mitigation strategies. Second, I show the heterogeneity in how relationality was embodied in the principle of authority. Table 9 summarizes the key interactions in unit 4.

Table 9

Summary of Key Interactions in Unit 4

Date	Summary of Key Interactions
3/2	Whole-class discussion on the ways social and physical infrastructure across the United States are inadequate to withstand climate disruption
3/18	Whole-class discussion on the greenhouse effect; Ms. T elevated and legitimized student ideas about climate solutions
3/23-3/25	Whole-class discussion and individual reflection on greenhouse effect simulation; Ms. T students positioned the wealthy/powerful as responsible for emissions AND/OR positioned themselves as responsible for emissions; Ms. T ascribes agency to undifferentiated social actors
4/6-4/8	Ms. T lectured on a) Indigenous epistemology and land ethics and b) origin of unbalanced greenhouse in the industrial revolution; created consensus model of pre-industrial greenhouse effect
4/13-4/15	Activity simulating emission reductions through global policy and whole-class discussion on how subsidies and taxes change environmental behavior at scale; Ms. T situates agency in emission reduction as limited based on power dynamics
4/22-4/29	Whole-class discussion of solar panels and electric cars as problematic mitigation solution inaccessible to low-income families of color in South LA; Argument for collective, large-scale actions to limit emissions by the powerful/government and make low-emission technology equitably accessible
5/4-5/7	Students individually revise and complete models; Solar panels and electric cars are frequently included on the models as an important but inaccessible emission reduction strategy in S. LA; Arguments for economic policies like subsides are included in the models as a strategy to make low-emission technology accessible to students and address climate injustices

Ms. T launched unit 4 on 3/2 with a discussion on heat waves and other extreme climate events as a way to introduce the overarching question: “What actions can reduce extreme heat in South LA?” The warm-up and the exit ticket asked students to reflect on personal, local experiences with extreme heat—ten students completed these tasks. Ms. T lead a whole-class discussion on the ways in which LA specifically—and the United States as a whole—is unprepared for climate disruption. In describing extreme climate events in California, New York, and Texas, she said, “We did not build LA to have so many fires, or Texas pipes to deal with freezing, or Manhattan to be flooded with a hurricane." This discussion sparked emotional displays of sadness and shock at the devastation of extreme weather. Students wrote brief comments in the chat, such as, "oh damn," "that's scary," and various emojis. When writing in notebooks, the students primarily reproduced Ms. T's presentation of extreme weather threats. These actions represent Ms. T problematizing; she grappled with the problem of extreme heat and confronted a sociopolitical reality that infrastructure in LA is unprepared to deal with climate change.

Class on 3/18 included a discussion of the mechanisms of the greenhouse effect and a brainstorming session on ways to reduce carbon emissions in order to find solutions to climate change. When Ms. T asked how electricity production in LA could contribute to a reduction in climate change, Tia, Jim, and MJ each wrote "solar panels" or "build more solar panels" as a private message to Ms. T who then revoiced their contributions publicly. She also used the student ideas as an opportunity to review the scientific concepts of albedo and combustion. Ms. T said,

> Yes, so we can change solar panels on the roofs of buildings. The city is really doing that! Change the heat from the sun into electricity and not burn any coal to make our electricity so no combustion no carbon dioxide. Has anyone seen solar panels on roofs? That is why solar panels are black because you want the sunlight to go in. If you made solar panels white, they wouldn't absorb, they'd do the opposite. (Ms. T, 3/18)

In this interaction, Ms. T's actions embodied the principle of authority. Ms. T positioned students' ideas as authoritative. By having student ideas about mitigation solutions guide the discussion and publicly documenting their thinking, she gave the students agency to play an active role in defining the problem they would explore. When Ms. T confirmed that students' ideas of solar panels were indeed part of LA's portfolio of energy, she legitimized their contribution as authoritative and valuable in the class. It is important to note that at this point, solar panels were positioned as an unproblematic, legitimate climate solution.

During classes on 3/23 and 3/25, students worked with a simulation of the greenhouse effect through the pHET website and reflected on the activity in both a guided group discussion and individual written worksheet. Ten students completed the written assignment and five students participated in the guided discussion about those reflection questions. Over these two days, the activity took place in three phases: exploring the canonical and global scale greenhouse effect; localizing the greenhouse effect by exploring experiences of extreme heat in South LA; and completing the reflection worksheet that made explicit connections to sociopolitical dimensions and equity. In explaining the global scale pHET simulation, Ms. T reminded students that carbon dioxide molecules were represented by red balls and that those molecules came from cars because people needed to drive. She said,

> We emit that carbon to the air every time we turn on the engine of our car and start up that combustion reaction. We send the carbon from the gasoline into air as CO_2. You might not pay for gas, but your parents do. Unless you're driving an electric car because there is no combustion reaction in there and no trips to the gas station. (Ms. T, 3/23)

It is important to note that here, electric cars were positioned as a legitimate, unproblematic solution. Later, in connecting the greenhouse effect to extreme heat in South LA, Ms. T said,

> Let's think back to the urban heat island we feel in LA. We are changing the land and the atmosphere. We know all this black concrete is what we built. We didn't want to drive around on dirt, so we built roads out of asphalt. (Ms. T, 3/23)

The reflection worksheet began with canonical scientific questions and ended with two sociopolitical, equity-oriented questions: 1) Does everyone in the community have access to air conditioning to adapt to heat? Who does and doesn't? If you would like to share your personal experiences, feel free to do so! 2) Are the people most impacted by the heat (the people you identified in the previous question) also responsible for releasing the most greenhouse gases? Why or why not? To elicit student ideas and connect this activity to previous brainstorming about climate solutions, Ms. T asked a series of questions including,

> Does everyone you know in South LA have AC on hot a day? Let's think about where those emissions come from and all the groups we've mentioned. Homeless people, farmers, low-income people. Are the people getting flooded in hurricanes or suffering in the heat waves the same people emitting the most carbon? (Ms. T, 3/25)

Two students wrote in the chat a simple "no" and Ms. T elaborated on these responses by saying "Yeah, AC makes your electricity bill hella expensive! Not everyone can afford that. And you have to have money to buy the AC in the first place." Below are four students' written responses to these questions,

> The people who are impacted by the heat the most might not be responsible for releasing the most greenhouse gases. Why is it because some of them can't afford food let alone a car or things that use fossil fuels. The ones responsible are the people with transportation and are able to afford homes and different things that use fossil fuels. (Tia, notebook 3/25)

> The people most impacted by heat are not responsible for releasing the most greenhouse gases since they don't even use air conditioning which costs electricity and homeless people probably don't have cars to drive which is one of the biggest factors of climate

change. In my opinion, things shouldn't be this way since everyone should at least have access to some type of shelter or AC since it can get really hot in the summer. (Jessica, notebook 3/25)

Not everyone in our community has [AC and electric car] access, the homeless people and families with low incomes do not. What I am pretty sure about is that we are all in this, there is nobody more responsible than the others, because we all use electricity, cars to move in, the public transportation, are things that we could live without. Of course there are things that we could change, no matter if they are small changes, [long term] the results are visible. Also we know the city is always building and destroying and building again and we are always trying to solve these massive acts with a mini band aid, like me putting plants in every tiny land space I see because it gives us oxygen haha. (Sara, notebook 3/25)

"I think we are all responsible for creating more greenhouse effect because we cannot blame a group of people because we all live in earth" (Juan Carlos, notebook 3/25).

Ms. T's and students' actions embodied the principles of authority and problematizing. Importantly, there was variation in the way that the causes and solutions to climate change were problematized, representing a bifurcation in politicizing. First, Ms. T's action embodied relationality in the principle of authority in ways similar to unit 2, specifically her undifferentiated use of "we" as a way position herself and students as participants in modifying the greenhouse effect. She used "we" in her utterances in three different ways: a) "we" clearly included her and the students, such as the "we" that experienced recent heat waves (a present-day, local phenomenon) or started the engine of gas-powered cars (an everyday activity), b) "we" for a generic group of present-day humans that built concrete highways, and c) "we" that could not have included herself and students, such as the "we" that lived in LA with dirt roads (a historic phenomenon that predated Ms. T and the students). Ms. T did not identify or differentiate social actors in explicit ways during these classes.

Second, Ms. T's actions embodied the principle of problematizing in two ways as she confronted the sociopolitical realities undergirding the causes of climate change. On the one hand, she began to confront the role of capitalism and power in causing climate change. She identified a gap in who is emitting carbon through luxury emissions versus who is experiencing the greatest burden of a climate changed world when she linked access to air conditioning and wealth. In this way, Ms. T began to confront the role of capitalism, wealth, and power in causing climate change, specifically positioning the wealthy—in contrast to South LA residents—as more responsible for carbon emissions. This opened an opportunity to politicize the system of capitalism as unequitable and destructive. On the other hand, she identified herself, students, and all people as responsible for engaging in activities that emit carbon dioxide and who are therefore complicit in the causes of climate change. This represents problematizing because she was making space for authentic competing alternatives in debates about climate change: one that differentiates responsibility as a function of power and one that identifies everyone's role, regardless of power.

Third, students problematized climate change—some adopting Ms. T's power-laden perspective and others adopting the universal perspective. In their writing, Tia and Jessica adopted the power-ladened perspective. Tia addressed the gap in emissions and experiences when she positioned those with wealth and power as responsible for changing their emissions, thus problematizing the cause of climate change as racialized and classed. Jessica also appropriated the politicization of climate change as linked to capitalism, ascribing agency for emissions to the wealthy and addressing how access to solutions are denied to those living in poverty. In contrast, Sara and Juan Carlos adopted the universal perspective. They did not hold the wealthy more responsible for luxury emission but instead situated everyone, regardless of wealth, as contributors of greenhouse gas emissions and able to make at least small changes for a better future. This shows how students problematized their own role in the system as carbon-emitters regardless of their lack of power in the capitalist system.

Classes on 4/6 and 4/8 were dedicated to exploring the historic moment when the greenhouse effect went from natural and balanced to anthropogenically-modified and unbalanced, leading to global warming. These classes had three components: a) Ms. T contrasted Indigenous and colonial, anthropocentric environmental philosophies, b) she situated the origin of the unbalanced greenhouse effect in the industrial revolution, and c) she created a consensus model of the pre-industrial greenhouse effect. It is important to note that this was Ms. T's first effort at including Indigenous epistemologies in her class and she acknowledged the limitations of only addressing this once. She had been inspired by the leadership of Native communities and was passionate about developing her pedagogical practices for elevating Indigenous voices in the climate justice movement. As a result of this experimental phase of her teaching, these classes largely consisted of a monologue and there was virtually no student participation. For example, Ms. T asked students, "What is our relationship to Earth?" but did not open a discussion or present an opportunity for reflection, so this was a rhetorical question. The exit ticket asked students to reflect on human's role in alerting carbon concentrations in the atmosphere; nine students completed the task.

Solar panels remained the item that Ms. T used as a concrete example of a climate solution. In Ms. T's discussion of Indigenous epistemology, she contrasted the intrinsic value of nature that is part of Indigenous' epistemologies with the extrinsic value in colonial cultures. She said, "the sun isn't there just to power our solar panels" as a way of emphasizing that in Native communities, the sun has value even when it is not monetized. Tia then asked Ms. T, "How common are solar panels for powering factories?" Ms. T did not know the answer but responded that renewable energy made up 14% of LA's energy portfolio.

Students' exit tickets focused on describing how industrial human activity changed the atmosphere. Following are five examples: "Then we came and we started to create machines we created trash we created a lot of stuff that change the greenhouse a lot" (MJ, notebook 4/8). "We took the carbon out of the land and put it on the atmosphere. We discovered the fossil fuels. We invented the machines, the ones that produces smoke" (Sara, notebook 4/8). "We have done littering. Not been respecting the water. We are using more air conditioner and more lights. Things we really don't need too much" (Monica, notebook 4/8). "The concentration [of carbon] increased a lot now. We have been hurting the world instead of taking care of it. We made greenhouse gases to increase" (Ossi, notebook 4/8). "By using gas and we are cutting down the trees, back then we didn't have all these devices to help us. But that was better for us because it's hurting us more than it helping" (Dan, notebook 4/8).

Ms. T's actions in these classes embodied the principles of resource and problematizing while the students' writing embodied relationality in authority in ways consistent with previous days. First, Ms. T invited Indigenous epistemologies as a diverse sensemaking resource. While this resource was likely not accessible to students, she did work to situate Indigenous land ethics as a resource to support students' connective-disciplinary work. Second, Ms. T politicized the human-nature divide, building on her work of problematizing from unit 2. In these interactions, she countered the dominant narrative of humans as separate from natural systems in more sophisticated, nuanced ways by opening opportunities for students to explore how Native communities live in more reciprocal relationships with the natural world. Third, students continued to use we/us in undifferentiated ways, at times without regard to temporality. For example, MJ and Sara wrote about the "we" that invented the machines, discovered fossil fuels, and drove the industrial revolution—all of which were references to humans that excluded themselves. Examples of references to people in the present were also intermixed; Monica, Ossi, and Dan wrote about actions they may engage in, such as littering and cutting down trees.

Classes on 4/13 and 4/15 were jointly dedicated to discussions of economic policies as levers of change in the climate system and to exploring a simulation called En-Roads. Students used this simulation to model how different global policies will impact carbon dioxide concentrations and temperature in the future. Student questions were procedural and the most participation occurred when two bilingual students translated the instructions for a group of three primarily Spanish-speaking students. This was the first time that neither Ms. T nor I had the language ability to do so, which highlighted the complicated nature of the En-Roads simulation. Ms. T created a set of slides in students' digital notebooks, instructing them to record observations and questions, but only four students completed the notebook prompts. Ms. T extensively described how taxes and subsidies function to change consumer behavior and environmental impacts, and she used electric cars and residential solar panels as concrete examples to explain how economic policies can increase affordability and access to technology. There was minimal participation, but Tia summarized her understanding by writing in the chat, "tax the things that hurt the earth and subsidize the things that are eco-friendly." Ms. T also reflected on her own role in the climate system, commenting, "we're not saying 'Oh Ms. T is evil with her gas car.' No, this is what I can afford and at the end of the day my emissions are nothing compared to huge companies like McDonalds."

Ms. T's action embodied the principles of authority, accountability, and resources. Importantly, she varied the way she discussed relationality and agency for emissions, representing a bifurcation in authority. First, in sharing a personal example and discussing her own use of a gas-powered car, Ms. T positioned personal, everyday experiences as sensemaking resources. This was a designed resource that she frequently encouraged students to draw on and modeled doing so herself. Second, Ms. T modeled the practice of scientizing, thus continuing to hold students accountable to this classroom norm. She scientized her use of a gas-powered car as the site of a hydrocarbon combustion reaction. In this way, she continued embodying accountability, as she had during unit 2 and throughout the whole year. Third, Ms. T addressed relationality in a new way as compared to previous classes when she positioned herself as having limited agency in her choices of vehicles. This embodied authority because it politicized her agency in addressing the causes of climate change. Ms. T voiced that she was not "evil" for using fossil fuel-reliant technology, explaining that her car choice was necessity-driven and that she had limited options because of finances. By making visible the choices that were not available to her, she hoped students would see the role of political power in their daily lives and choices. While she did not raise the question of who gets to decide what types of cars are available to whom, she did politicize the principle of authority by describing her limited agency. This embodiment of authority aligned with Ms. T's actions problematizing power dynamics in the causes of climate change.

During the next three classes (4/22, 4/27, and 4/29), Ms. T wrapped up the reflection activity from the En-Roads simulation, providing direct instruction on how various levers of change impact the greenhouse effect mechanisms. The students began an activity exploring "winners and losers" from different climate policies within a network of stakeholders. There was a high level of student participation because Ms. T designed the activity structure simply, inviting one to two word responses to targeted, accessible questions. These classes also included an important shift in the framing of solar panels and electric cars as solutions to climate change. To launch the discussion on economic levers, Ms. T asked, "How do we convince people to do what's right for the environment and right for climate change?" and clarified that it was "not your responsibility as 10th graders to convince everyone you know to buy an electric car. This needs to be large scale, and this is where the government and money come in." This opened opportunities for students to interrogate the role of specific social actors in climate solutions. was Two interactions followed that represent students stepping into that opportunity. The first interaction centered on the discussion of the climate justice video featuring the ACNTBL group. The video highlighted the role of nonprofits in providing communities like South LA with low-emission technology. Ms. T asked why ACNTBL featured South LA and JJ replied verbally, "When the [narrator] talked about solar panels, [she mentioned that the] government puts more money in to other places instead of [in to] communities of color." Ms. T repeated JJ's comment in academic language by saying, "Yes, communities of color are neglected by government investments so local groups have to help with getting solar panels to the neighborhood."

The second interaction occurred during a discussion of winners and losers in regard to the building of residential solar panels. Ms. T asked who wins and who loses when residential solar panels are built, and Anna wrote in the public chat, "homeowners win." Anna did not elaborate when prompted to explain her idea, so Ms. T invited the class to build on Anna's idea and Oscar wrote in a private chat message, "solar panels lower the electric bill for homeowners." Ms. T read this out loud anonymously and evaluated Oscar's response as correct. Ms. T also asked, "So does everyone have equal access to solar panels to make their electricity?" In response, Juan Carlos wrote in the chat a simple "no" and when Ms. T asked him to explain why not, he unmuted and said, "it's more difficult to put solar panels on apartment buildings. Where we live solar panels aren't so simple." Ms. T asked why it is not so simple for renters, and a chorus of students (Tia, Jim, Jessica, and Juan Carlos) all wrote in the chat (public and private) that renters do not have power to make decisions about their buildings and that landlords are greedy, stingy, or negligent. Tia summarized the discussion when she wrote, "communities of color will be able to have the money for [solar panels] with subsidies."

Ms. T's and the students' actions embodied the principle of problematizing in two ways; the students' actions also embodied authority and resources. First, Ms. T continued to position herself in relation to power and with limited agency in addressing climate change, and included the students in that positioning as well. When she said the "government and money" are needed to enact large-scale collective change and explicitly said this responsibility did not fall on the students' shoulders, she politicized responsibility for actions and situated agency for change with the government. Second, Ms. T and JJ problematized climate change by highlighting the uncertainty in how to address unequal access to low-carbon technology and how to move away from carbon-intensive infrastructure while humans are still reliant on it. JJ's politicization pushed against the notion that solar panels are a neutral, universally accessible solution to climate change and instead addressed complicated access to the technology based on geography, class, and race. In the climate justice video featuring the ACNTBL group, JJ saw that South LA did not have access to participation in a low-carbon future without a nonprofit stepping in to take the role that the government plays in other communities. Similarly, Tia's summary of subsidies politicized the limitations that low-income families face in accessing low-emission technologies. Most notably, the contribution from Juan Carlos was a turning point in the discussion on solar panels. He politicized solar panels as inaccessible to low-income renters. Ms. T adopted this connection between inequality of access to solar panels and the lack of power that low-income renters have in decision making in all her future discussions on solar panels, reflecting her responsiveness to students.

Third, JJ and Juan Carlos' comments also embodied the principle of resources because they drew on their critical awareness of social issues facing low-income renters and South LA residents as a sensemaking resource. Ms. T presented the opportunity for students to bring in their critical awareness of social issues from their own everyday experiences. Juan Carlos' response indicated that he used his critical awareness of the sociopolitical challenges faced by low-income renters to grapple with climate solutions. Fourth, the students' actions also embodied authority as they took up intellectual agency in the arguments for collaborative, sociopolitical problem solving. Students argued for subsidies and intervention from nonprofits (in JJ's case). This was a form of politicizing authority as they argued for collective political actions. These classes marked an important shift in the discussion of solar panels and electric cars. These items were then regarded as being somewhat problematic because of their inaccessibility to renters in South LA.

The last two classes of the unit (5/4 and 5/7) were dedicated to evaluating, testing, and revising individual models of the greenhouse effect. Twelve students completed the models, with all but one including at least two descriptive labels. Ms. T scaffolded building the models to support students with guiding questions like: "Does everyone have equal access to cars for transportation around the city?" and "Are different neighborhoods impacted differently by heat?"

In each of these scaffolds, Ms. T invited students to use their personal experiences and critical awareness of social issues in their community to localize their models and politicize climate actions. In private chat messages to Ms. T, students shared comments on their understanding of subsides that can help make low-emission technology available to low-income communities of color. For example, Juan Carlos wrote, "subsidize so we all be able to afford it," Laura wrote "you subsidize so it's affordable for everybody," and Jim wrote "No todos tienen el dinero para comprar estos autos [not everyone has the money to buy [electric] cars]." Other students wrote Ms. T private messages with questions or comment about solar panels, which were examples of spontaneous reengagement and authentic questioning. Ossi wrote, "when I go to Los Baños, almost all the houses have those solar panels" sharing her observation by contrasting another neighborhood with residential solar panels to South LA. Jim wrote "how much would it cost to place solar panels en mi casa [on my house]?" and "what if everyone would have solar panels miss?"

The students' writing on their models represented the varied ways in which they were thinking about solutions to extreme heat in South LA and the unbalanced greenhouse. Below are excerpts from the models of seven students (I have included two excepts from some students, representing two separate text boxes on their models):

> [Electric car subsides] would benefit low-income individuals because some of them don't have a vehicle so they can get to work/school easier. My model shows the fact that people with low-income most likely don't have a car to travel to school, work, etc. People with low-income would usually use the train to travel but using the train it still pollutes the air, making the air hotter and making us have more "hot days". In my model Communities of Color and low-income individuals are proven to suffer the worst when it

comes to climate change and they are barely given any resources to recover from natural disasters or climate change. (JJ, unit 4 model 5/7)

"[Subsides] would benefit low-income individuals because some of them don't have a vehicle so they can get to work/school easier" (JJ, unit 4 model 5/7).

We can save energy by using solar panels to power things in buildings and outside of buildings which will make us use less fossil fuels. The temperature won't be so hot if we use less electricity because we won't burn as many fossil fuels which will release less carbon. Grid Alternatives can help save money with solar panels because you would save energy and won't have to pay electric bills as much if you are a homeowner or own a building with solar panels. We can subsidize the cost of solar panels so some homes can afford them. With less fossil fuels to make electricity there would be more oxygen in the air instead of carbon dioxide. (Tia, unit 4 model 5/7)

Putting solar panels on our homes absorbs the sun rays and reduces the greenhouse gases. Big corporations also benefit from solar panels since more people will purchase them and they'll get more money. Workers benefit from the solar panels since there'll be more jobs to construct them. (Jessica, unit 4 model 5/7)

Factories rely on fossil fuels. And fossil fuels are what gets us the things we need. But at what cost? Fossil fuels makes the government and people in charge of factories lots of money. We burn fossil fuels and that energy from combustion makes energy and releases CO_2. We can reduce this by using solar panels and Windmills. (Anna, unit 4 model 5/7)

"Low-income individuals are able to afford electric cars because of the government subsidizing the price of the cars" (Laura, unit 4 model 5/7). "People who are in power can subsidize the price of electrical cars. Low-income individuals are now able to afford electric cars because of the government subsidizing the price of the cars" (Laura, unit 4 model 5/7). "Instead of continuing to use cars as a means of transportation, Los Angeles residents should use more buses or ecological transportation to move around the city" (Oscar, unit 4 model 5/7). "Electric cars don't make greenhouse gases so it's cooler for low-income individuals" (Dan, unit 4 model 5/7). "I think we could disconnect electronics when we are not using them" (Sara, unit 4 model 5/7). "Si tuviéramos paneles solares en cada casa que hay en los ángeles, nos ahorraríamos mucho más dinero y gastos [if we had solar panels on every house there is in Los Angeles, we would save a lot of money and expenses]" (Jim, unit 4 model 5/7).

I drew on both students' writing as well as final interviews as a proxy for engagement because they allowed me to capture their thinking about participation. Oscar reflected on the experience of creating his model during his final interview and spoke directly about why he included solar panels. He discussed laws to increase the accessibly of solar panels as an energy source for vehicles. He said,

> Puse los paneles solares y los autos eléctricos, pero lo que quería mostrar es que esta es una Telsa obteniendo su energía de paneles solares. Se necesitan leyes para regular los autos que tenemos y de dónde proviene la energía. Porque si la ley hace posible que hay más autos eléctricos y paneles solares, entonces eso significa menos contaminación porque menos consumo de gasolina y menos dióxido de carbono emitido. [I put the solar panels and the electric cars, but what I wanted to show is that this is a Telsa getting its power from solar panels. Laws are needed to regulate the cars we have and where the power comes from. Because if the law makes more electric cars and solar panels, then that means less contamination because less consumption of gasoline and less carbon dioxide emitted]. (Oscar, interview 5/21)

Student engagement throughout their creation of the final diagrammatic models embodied all four principles of problematizing, authority, accountability, and resources. Many of the excerpts above in fact exemplified multiple principles at once, at times the distinction between them was blurred, reflecting the synergy of the principles. Students problematized climate change by grappling with inequalities in access to solar panels and electric vehicles. These are authentic and fraught questions in the discipline. For example, JJ identified these inequalities as intersectional and compounding when he described that low-income people of color emit less carbon because of a lack of access to personal cars, suffer worse from extreme heat, and lack the resources to recover from disasters. In grappling with what to do, students appropriated and expanded upon Juan Carlos' contribution from an earlier class (when he politicized inequities in access to solar panels) in order to situate the mitigation solutions of solar panels and electric cars as problematic and illegitimate because they are inaccessible to low-income families in South LA. Writing by the students (Jim and Tia, for example) made it clear that they want and need access to these low-emission technologies so they can participate in the low-carbon energy transition and reap the social and ecological benefits, but are unable to participate because of their social position. Grappling with this problem embodied the principle of authority in two ways. Most students took up intellectual agency in arguing for collective, large-scale problem solving that would make low-emission technology affordable. For example, in Zoom chat messages to Ms. T, Juan Carlos, Laura, and Jim shared their understanding of how subsides make low-emission technology available to low-income communities of colors and to themselves. Laura and Dan both made racialized arguments for subsides on their models to address inequalities, and Oscar, Laura, Tia, and JJ made classed arguments for subsidies. It is important to note that subsides represent an anti-capitalist policy, therefore this politicization embodied students' appropriation of Ms. T problematizing of capitalism. In contrast, Sara argued for individual-scale action by suggesting unplugging electronics; in doing so, she did not situate herself in relation to power.

Relationality in the principle of authority was also embodied in students' descriptions of the social actors that are responsible for addressing emissions that cause extreme heat. JJ, Laura, and Jessica positioned themselves relative to power and were specific in naming social actors rather than using the undifferentiated terms of we/us. They described geographic, demographic, racial, or cultural communities that benefit from subsides. In contrast, Sara and Anna continued to use undifferentiated we/us to ascribe agency to themselves. Tia is the only student in this unit who followed Ms. T's example by embodying both variations of authority in her perspective on relationality and used both a universal and differentiated perspective in different utterances. In her model, Tia used "we" twice in undifferentiated ways, thus not identifying a specific social actor responsible for subsidizing solar panels. However, she did name the nonprofit group Grid Alternatives as an organization that needs to intervene in South LA to support equity. This heterogeneity in relationality in the principle of authority represents an important shift over time in the ways students ascribed responsibility for taking climate actions and implementing solutions.

Student actions on the models also embodied accountability in the ways explanations recognized their identity and lived experiences as low-income renters of color in South LA. Jim, Tia, and Laura wrote about their identity as low-income individuals and the relief that would come from saving money, specifically if solar panels decreased electricity bills or if electric vehicles were affordable. This embodiment of accountability indicates an important way that students displayed a responsiveness to their realities outside of the classroom through their intellectual work. It justified the legitimacy and generativity of ideas related to their personal experiences. Last, student writing embodied resources in the ways they connected the social and scientific dimensions of climate change. This was a designed resource that Ms. T embodied frequently and made the work of scientizing possible. Tia's writing is the clearest example—she established the causal process of decreased electricity use, decreased fossil fuel combustion, decreased carbon dioxide emissions, and stabilized temperature. Oscar, Dan, and Anna also made connections between the scientific process of combustion and the social structures that make low-emission technology available.

To conclude my description and analysis of unit 4, I share excerpts from the final interviews with four students that reflect their thinking across the whole of unit 4. In the final interview, I asked students to share how learning about the sociopolitical dimensions of climate change helped them learn science and vice versa. The students' responses illuminated their thinking on problematizing and authority. For example, Lachelle racialized health disparities from climate disruption and lack of education. Her response started with a story before she reached her intended point. She said,

> Like if people are taking low air quality seriously. Because sometimes with it makes older generation sick, but they don't know, they don't understand how it affect children. Although we probably have it a lot of bad air quality but I don't check the air quality a lot, which is something everybody should do though. And since we have all these oil refineries here, like the air quality might be bad a lot. So it really helps to check because it could save people's lives. Okay I think I found a good way to put it. The lack of education in colored neighborhoods about chemistry affects us. It affects us in the way that like it can possibly like kill us. (Lachelle, interview 5/17)

Lachelle shared that her experience in unit 4 helped her see science education as a tool that can save lives in her local community. Sara and Jessica also talked about different neighborhoods being impacted differently and made classed and racialized arguments. They said,

> Chem shows us, if we want to know why it's so hot in South LA and if you walk in Beverly Hills it's going to be nice. So we focus on chemistry and here there aren't parks, full of concrete, if you go walking in June on the streets of South LA at noon you're going to burn. You're not even going to find a bench to sit beneath a tree. Chem explains why it's so hot and with the colors, black traps the heat. If we go with chem to Beverly Hills or a golf course that has a lake, we'll see there are a lot more trees, everything is fresh and clean, the streets don't have trash and stuff like that. (Sara, interview 5/28)
>
> [Chem is a tool for understanding inequality because] I would say chemistry helps me to understand why different people that live in different neighborhoods are affected more by climate change, and why people that live in the richer neighborhoods have—aren't extremely affected by climate change as much. Knowing science helps me understand social because I would say that all people in lower income neighborhoods are more affected by climate change because they have less resources to help them deal with it and they also have like less parks and trees because of they're in low-income neighborhood. well yeah, and people in rich neighborhoods, or the suburbs have like more parks, and like, more resources and stuff to take care of it so they aren't affected as much as people that live in those neighborhoods. I could say because they have less resources are more affected by climate change. (Jessica, interview 5/29)

These geographic, racialized reflections on their learning in unit 4 are strong examples of their politicization of the consequences of climate change. Tia also shared a racialized perspective on the geographic distribution of pollution, specifically identifying that white communities have more resources than Black and Latinx communities to deal with pollution. She said,

> Chem is a tool for understanding inequality because well it shows that more African American and Latinos, Latinx people how they're more affected to it because of how the inequality, with payments and everything and how Caucasian people have more money easily in their areas it's less polluted than where we are because of how our areas are like redlined and everything, how all the factories are based towards like where we live and stuff, and how they just have a lot of things going on that is polluting the area. Like greenhouse gases which is causing a lot of the climate change to happen over here. (Tia, interview 5/26)

Students also discussed their understanding of the role of the government in climate action, situating the government with power, agency, and responsibility. While unit 4 only gave students a superficial introduction to laws and policies, Tia and Lachelle ascribed agency to governments for implementing environmental policies using economic levers. They said,

> [Learning science helps me understand the sociopolitical parts of climate change] because I can understand the chemical reactions happening with different things. And also different corporations, and the government and laws and stuff how, if they allow new things to happen, or keep allowing things to happen that are already happening, how those chemical reactions affect things. (Tia, interview 5/26)
>
> [Learning sociopolitical parts of climate change helps me understand the science] because going back to what I said about the masks, it will be better we had laws to set because it'll make everybody realize, 'oh this is really serious we need to do it.' It's not just a whole bunch of random people, just talking about it, it is actually the government

> and our mayor and our leaders talking about how we need to fix this. And it, frankly, makes people dig into it more when somebody high up in power talks about, if that makes sense. [Learning science helps me understand the sociopolitical parts of climate change] because it makes me understand why everybody's pushing to get a Tesla or like some type of car that doesn't need gas because frankly I thought it was just like one of those fancy cars like a Lamborghini or something where celebrity people have them. And I realized oh it's trying to make sure we have a future on earth. (Lachelle, interview 5/17)

Tia described the government's role in continuing to allow combustion reactions that emit carbon while Lachelle described the government as an authority that can change the behaviors of large groups. Lachelle also described how being more interested in "digging in" to understand laws and policies might inform her choice in selecting a car and gave the example of understanding the connections between environmental laws and climate science; bringing the scientific and sociopolitical dimension into contact was empowering for Lachelle. It was also empowering for Sara; in her interview she shared, "now I feel ready to discuss with somebody about those world problems, really, feeling like a wise grandma."

In summary, unit 4 embodied all four principles of CPDE in dynamic ways that shifted over time and were heterogenous. First, the principles of resources and problematizing were in balance. Students' intellectual work of politicizing climate change solutions in South LA was made possible by the students' critical awareness of social issues in the community. Ms. T set up opportunities for students to politicize capitalism through the concrete examples of solar panels and electric cars. She also invited students to bring their critical awareness of government neglect of low-income communities of color, life as low-income renters in South LA, and the system of capitalism. Students responded by effectively using their critical awareness of experiences of disempowerment, neglect, and vulnerability to interrogate these mitigation solutions as a function of geography, race, and wealth. JJ, Anna, Oscar, Tia, Jim, Jessica, and Juan Carlos contributed to problematizing through politicization, highlighting that renters like themselves have unequal access to solar panels and therefore cannot access the low-carbon technology needed to be part of transition away from fossil fuels.

Second, students embodied relationality in the principle of authority in ways that were differentiated over time as they established their own perspectives on their roles and responsibilities in the climate system. In contrast to the short-circuiting of the principle in unit 2, this represents a productive embodiment of authority. Relationality in authority was supported by relational resources that interrogated power dynamics. While Ms. T and students used we/us/all humans in undifferentiated ways at times, at other times they explicitly differentiated a social actor or distinguished themselves, their racial/ethnic group, or geographic community as a function of power. This work supported by the resource of students' critical awareness of local, social, and personal issues, which included relationships to power. Surfacing power dynamics and relationality shaped how intellectual agency was taken up by students as they ascribed responsibility and agency for carbon emissions in both differentiated and universal ways. The balance of the principles of problematizing and resources as well as the differentiation of relationality in the principle of authority supported significant progress from beginning to end of unit 4.

Summary and Comparison of Principles in Focal Units

Ms. T's teaching and the students' actions in unit 2 and unit 4 embodied each of the four principles of CPDE but in different ways and to different degrees in each unit. Table 10 presents high-level characterizations of each of the principles in Ms. T's actions; Tables 11 presents the same for students. Students largely reproduced Ms. T’s embodiment of principles in unit 2, while in unit 4 they appropriated and differentiated the principles. Table 11 facilitates rating the degree of embodiment of each of the four principles in students’ actions as weak, moderate, strong, or mixed for each unit. Embodiment was rated stronger to the extent that more aspects of the principle were embodied according to my definitions of the principles (see Table 4) following the model described by Engle (2012). I used the mixed designation for complex cases; for example, if one aspect of a principle was extremely strong while others were absent, or if an aspect varied over time or across learners. The rating principles allowed me to contrast unit 4 with unit 2.

Table 10

Summary and Comparison of How Ms. T's Teaching Embodied CPDE Principles in Units 2 and 4

Unit 2	Unit 4
Problematize	
Grappled with the problem of lack of green space Politicized land use as unequal and inequitable Confronted sociopolitical mechanisms of change in carbon cycle as linked to industrialism, and to universal human actions Politicized human-nature divide and relationality to situate students as part of climate system	Grappled with the problem of extreme heat Politicized heat waves as unequal and inequitable Confronted sociopolitical mechanisms of change in the greenhouse effect as linked to industrialism, capitalism, and colonialism, and to universal human actions Politicized human-nature divide and relationality to situate students as part of climate system Legitimized uncertainty in how to address unequal access to low-carbon technology and move away from infrastructure we are reliant on
Authority	
Positioned learners as experts of community Positioned self and students as participants in climate system with undifferentiated phrases of we/us/all humans	Positioned learners' ideas about community as authoritative Positioned self and students as participants in climate system with undifferentiated phrases of we/us/all humans Positioned self and students in relation to power to differentiate agency in the climate system Positioned learners' personal experiences as valuable in scientific sensemaking
Accountability	
Modeled the practice of scientizing and established as norm Urged students to use evidence from their everyday lives and communities Elevated the contribution of community organizations	Modeled the practice of scientizing and established as norm Urged students to use evidence from their everyday lives and communities Elevated the contribution of social movements and community organizations
Resources	
Brought social and scientific systems in to contact Provided and invited diverse sensemaking resources: every day and community knowledge, critical awareness of social issues, and geochemical data Situated collaborative, collective relationships and sociopolitical action as climate solutions	Brought social and scientific systems in to contact Provided and invited diverse sensemaking resources: every day and community knowledge, counternarratives, critical awareness of social issues, geochemical data computational models, Indigenous epistemologies Situated collaborative, collective relationships and sociopolitical action as climate solutions

Table 11

Summary and Comparison of How Students Appropriated the CPDE Principles in Units 2 and 4

Unit 2	Unit 4
Problematize	
Politicized land use inequality as racialized and classed	Politicized extreme heat inequality as racialized and classed Confronted sociopolitical mechanisms of change greenhouse effect as linked to capitalism, or linked to universal human actions Politicized climate solutions by advocating for sociopolitical collective change and equitable access to technology
Authority	
Positioned self as participant in climate system with undifferentiated phrases of we/us/all humans	Positioned self as participant in climate system with undifferentiated phrases of we/us/ all humans Took up intellectual agency by arguing for sociopolitical problem solving that recognized power-dynamics
Accountability	
	Justified explanations with scientizing Explanations recognized identity and history as a legitimate base for making claims
Resources	
Critical awareness of social inequalities used as a sensemaking resource	Critical awareness of social inequalities and personal/community experiences used as a sensemaking resource Brought social and scientific systems in to contact

In unit 2, problematizing was moderate while the other principles were weak. Students explored factors that create and sustain inequalities in access to urban parks and how carbon is transferred and transformed in their local environment, but they did not make new connections between these phenomena, nor did they make new connections to climate change. For problematizing, students politicized inequitable access to the social and ecological benefits of parks but did not confront the associated scientific and sociopolitical processes. Ms. T worked to present opportunities for students to justify past actions related to urbanizations, but they struggled to do so because they did not have the relational resources to grapple with the power dynamics that are central to urban land use. For resources, students used their critical awareness of racial and classed differences between neighborhoods to make sense of inequities but provided very similar explanations in the beginning and end of the unit. For authority, students positioned themselves as stakeholders and contributors to the problem of an unbalanced carbon cycle but did not differentiate that agency based on power. For accountability, students held their work accountable to the practice of scientizing but were not responsive to other norms.

In contrast, in unit 4, student engagement in problematizing and resources was strong, authority was mixed, and accountability was moderate. Students had robust, consistent, and dynamic opportunities to grapple with what to do regarding climate actions and to confront sociopolitical dimensions of climate solutions, and they had the necessary resources to do so. For problematizing, students worked through a big idea and genuine uncertainty within the discipline: how to equitably transition to low-carbon energy given our reliance on fossil fuels and our unjust social systems. Solar panels and electric vehicles were examples of low-carbon technology that elicited students' curiosity and provided concrete opportunities to politicize mitigation solutions. Notably, there was variation in problematizing amongst the students, with some addressing climate change as rooted in capitalism and others addressing universal actions that emit carbon. For resources, students used their critical awareness of inequitable systems that burden low-income renters and advocated for subsidies and nonprofit intervention, both of which represent collective actions. As unit 4 progressed, students more frequently drew on racial narratives, community-based experiences, and their identities as sensemaking resources. While students had drawn on their critical awareness of social inequalities at the beginning of (and prior to) unit 4, they explicitly used this resource in unit 4 to make significant progress in their arguments, moving from politicized arguments about the causes of climate change to politicized arguments about the solutions to climate change. For authority, the principle had a mixed embodiment because all students situated themselves as stakeholders and participants in the climate system and took up intellectual agency for addressing problems, but some did so in relation to power while others did not. Both variations of relationality in authority represented students taking up agency to address climate change, but my conceptualization of authority privileged the critical perspective. Last, accountability was moderate because students were responsive to the norm of scientizing and recognized the legitimacy of cultural and local knowledge within their intellectual work. Students recognized the generativity of their ideas to their own present and future but were not responsive to external authorities of the discipline.

Chapter 6: Findings on Outcomes

In this chapter, I present my findings on student outcomes to answer my research question focused on the ways in which a sociopolitical focus supported learning climate science and developing critical climate awareness. For each outcome, I present the quantitative analysis of pre/post assessments followed the qualitative analysis of the formative tasks and interviews.

Climate Science Learning

I drew my findings on students' climate science knowledge primarily using the pre/post assessment of disciplinary knowledge with supporting evidence from the formative critical climate awareness tasks and interviews. Results of the disciplinary knowledge assessment showed that out of 24 possible points, students scored an average of 8.2 points on the pre-test compared to 10.9 points on the post-test with a statistically significant increase of a mean of 2.8 points (t = -4.84, df = 24, p = <0.001) and a large effect size (d = 0.89) representing a large difference between the two time periods. Table 12 includes the pre and post-test means and p values from each of the five sections of the test. Improvement overall was driven by the statistically significant change in the mechanisms section of the assessment.

Table 12

Climate Science Knowledge Assessment Scores from Beginning to End of School Year (n = 25)

Test section	Max	Pre-test mean (SD)	Post-test mean (SD)	T value	Unadjusted *p*	Holm Threshold	Cohen's D
Overall	24	8.16 (3.35)	10.9 (4.11)	-4.84	<0.001*	0.006	0.89
Chemistry	6	1.61 (1.16)	2.23 (1.47)	-1.71	0.100	0.300	0.34
Mechanism	4	1.61 (1.20)	3.50 (0.51)	-1.41	<0.001*	0.006	1.60
Impacts	5	2.03 (1.50)	2.19 (1.52)	0.44	0.603	0.603	0.10
Effects	4	1.46 (1.10)	2.04 (0.99)	-0.06	0.209	0.116	0.45
Adaptation	5	1.61 (0.85)	2.12 (1.53)	0.16	0.139	0.300	0.30

As I described in the methods section, the formative critical climate awareness (CCA) tasks given after units 1, 2, and 4 (that I label CCA task 1, CCA task 2, and CCA task 4 in the text below) were intended to elicit students' understanding of the canonical scientific climate system and mechanisms of anthropogenic global warming. The task instructions, however, did not tend to elicit students' articulation of the scientific concepts, especially the first task after unit 1. Moreover, the interviews with the 12 focal students were meant to give them a chance to elaborate on their writing in the formative tasks and their thinking in general, but these also tended not to provoke much discussion from students about the canonical science concepts. I label the three interviews in the text below as follows: pre-interview (the initial interview conducted after CCA task 1), post-interview (the final interview conducted after CCA task 4) that asked identical structured questions, and document-elicitation interview (taken after CCA 2) that asked document-based questions. In the paragraphs that follow, I present examples of students' writing and verbal comments about canonical climate science made during the tasks or interviews in order to illustrate the pre-to-post gains that are shown in Table 12.

In coding for students' canonical climate science knowledge, I looked for accurate and naïve explanations of three things: the carbon cycle, the greenhouse effect, and mechanisms of anthropogenic warming. Table 13 presents the number of students that explained each concept accurately across the tasks. Three students explained all three concepts accurately (Sara, Jessica, and Tia) and 14 students accurately explained the concept of anthropogenic global warming at some point throughout the year. More commonly, students explained these three concepts with naïve conceptions. Specifically, across the three tasks, seven students had naïve conceptions of the greenhouse effect, two of the carbon cycle, and 11 of anthropogenic global warming. The other students did not include any explanation of these concepts. Two persistent naïve conceptions were most common amongst the students as they endeavored to describe the scientific, global, and physical climate system. First, students conflated climate and weather, with many students confused about differentiating long term climate patterns from their daily observations of local weather. Second, students attributed the greenhouse effect to pollution in general; they described air and water pollution as well as littering as part of the climate system, revealing confusion about general environmental systems and processes versus climate systems and processes.

Table 13

Number of Students that Accurately Explained Canonical Concepts Across CCA Tasks

	CCA task 1 (*n* = 14)	CCA task 2 (*n* = 15)	CCA task 4 (*n* = 17)	Total individual students (*n* = 26)
Greenhouse effect	0	0	4	4
Carbon cycle	0	3	0	3
Anthropogenic warming	0	10	9	14

To illustrate what students' accurate explanations looked like, below are examples from Jessica's CCA tasks. To explain the carbon cycle as related to climate change and leading to anthropogenic warming she wrote,

> Carbon goes through a lot of transformations. Examples includes trees taking in carbon during the process of photosynthesis, humans and animals breathing out carbon, and organisms dying and releasing their fossil fuels into the ground. The specific parts in the carbon cycle that impacts the climate are the factories and cars that emit carbon into the atmosphere and humans taking out the carbon from the fossil fuels to make gas to use for our cars, buses, trains, and planes. Changes to land use impacts the climate because since there are more humans than ever, more trees are being cut down to make way for more infrastructure. These trees being cut down is one way that helps us remove carbon from the air and if they keep getting cut down then more carbon would be in the air. It can also mean change in the usual weather or temperature found in a place. (Jessica, CCA task 2)

In explaining the greenhouse effect later in the year, Jessica missed an important step in the mechanism (that infrared radiation is not only released by the sun, but primarily is created when dark surfaces on Earth emit heat energy that they have absorbed) that all her classmates also missed. However, she gave a largely accurate explanation when she wrote,

> The natural greenhouse effect occurs when some of the waves emitting from the sun such as infrared waves are absorbed by the earth's greenhouse gases such as CO_2 and methane to warm up the atmosphere. On the other hand, the human-altered greenhouse effect is when too much greenhouse gases are being released into the atmosphere like CO_2 because of our daily use of electricity, driving a lot of gas-powered cars and so on. The added greenhouse gases absorb more of the sun's infrared waves which is making the earth warmer which can also be known as climate change. (Jessica, CCA task 4)

Interviews with focal students support the findings from the pre/post-test that indicate that a small group of students learned about anthropogenic mechanisms of climate change throughout the year while others had persistent misconceptions. In the pre-interview and post-interview, I asked students to share how they talked about climate change with their friends and family. Five out of the 12 students said they talked about the causes of warming outside of class; Sara and Tia gave canonical accurate explanations of the mechanisms while the others revealed naïve conceptions. For example, in her final interview, Tia said, "I talk about climate change if we're driving or something and we see a factory I'm like, 'well that's polluting the air and that's gonna cause climate change.'" Most students said that they did not talk about climate change at all outside of class (five on the pre-interview and four on the post-interview).

My findings on climate science learning drawn from the pre/post-test of conceptual knowledge, the formative tasks, and the interviews were similar. This suggests that while the pre/post-test of disciplinary knowledge is an imperfect proxy of learning, the quantitative results are likely an accurate, albeit incomplete picture of knowledge. Roughly half of the students (16 out of 30) answered at least half of the climate science concepts questions correctly after participation in this intervention (12 out of 24), with three of those students (Sara, Jessica, and Tia) responding to 17 out 24 questions correctly. While the improvement on the pre/post-test was statistically significant and the effect size of the intervention was large, the average for the post-test was 45% correct. A total of 14 students wrote canonically accurate explanations of the mechanisms of global warming on their formative tasks. The snapshot of knowledge of disciplinary concepts garnered from the tasks and interviews supports the finding that the major area of improvement for students was understanding that an anthropogenically modified greenhouse effect and carbon cycle are the mechanisms of global warming.

Critical Climate Awareness

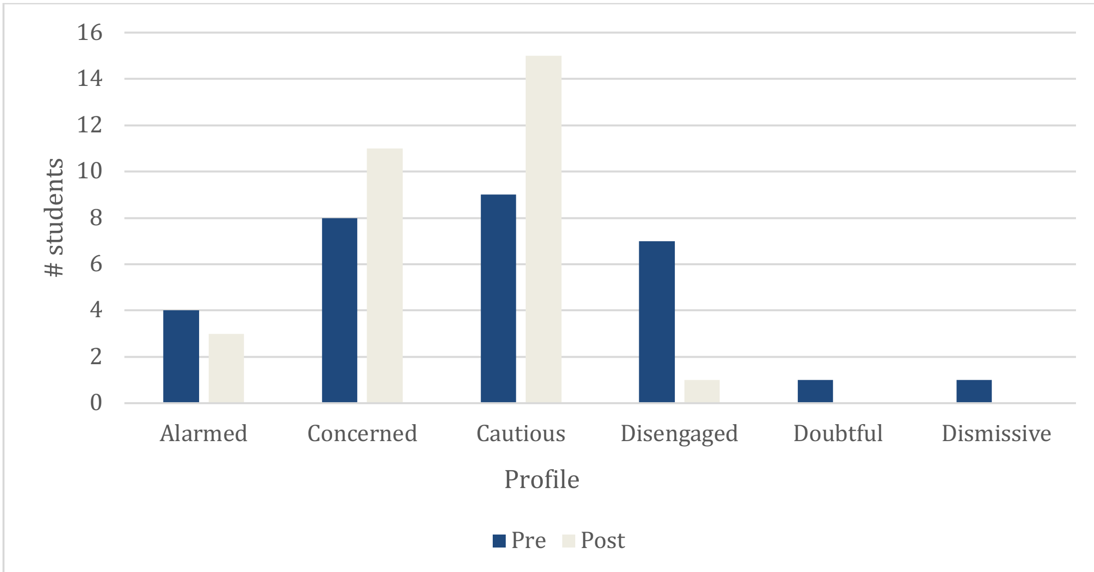
I drew my findings on the students' development of critical climate awareness from quantitative analysis of change in students' climate concern and awareness as measured in the Six Americas survey as well as from a qualitative analysis of the CCA formative tasks and interviews (Maibach et al., 2009). The formative tasks were designed to elicit student thinking in five components of critical climate awareness. Using the deductive analysis of conceptual quality described in Table 3, I examined the extent to which each component was articulated and warranted in student writing or interviews. Following the survey results below, I present my analyses of students' writing and verbal comments organized by the five areas of conceptual quality—canonical scientific systems, anthropogenic global warming, agency for emissions, distribution of disruptions, and solutions—in order to describe the features and variations in students' critical awareness of climate change.

Climate Awareness and Concern

Results of the Six Americas survey for climate concern show that all six profile types were present amongst the students before instruction while the doubtful (rank five) and dismissive (rank six) profile types were not present after instruction, reflecting an increase in concern over time (Maibach et al., 2009). Figure 11 displays the shift towards the attitudes of cautious and concerned over time. The Wilcoxon signed-rank test shows that the post-tests scores were statistically significantly lower (more concerned) than the pre-test scores ($Z = 20$, $p = 0.036$).

Figure 11

Distribution of Six Americas Profile Types in Pre- and Post-Surveys (n = 30)



Critical Awareness of Canonical Scientific System and Anthropogenic Global Warming

Prompts on the CCA tasks designed to get students thinking about the components of canonical scientific systems and anthropogenic global warming were much more successful at eliciting the sociopolitical dimensions than the scientific dimensions. Table 14 presents the number of students that explained the sociopolitical features of these systems in each task. Across the three CCA tasks, 11 total students explained sociopolitical features that impact the transfer and transformation of carbon as part of the mechanism of warming. Specifically, students made connections between the science and the politics of transportation, land use, and energy production (reliance on fossil fuels). For example, Helen described fossil fuel combustion in the transportation sector as an important source of carbon emissions and situated the reliance on gas-powered, personal cars in a complicated social system. She wrote,

> Climate change is also happening because of us using cars, we use cars so we can get to places faster which is a good thing, but the bad thing is that burning fossil fuels in cars

> releases carbon dioxide which is a greenhouse [gas] that traps heat in are atmosphere that then leads to global warming. (Helen, CCA task 1)

Helen identified that the chemical process of combustion in a gas-powered vehicle is intertwined with the social benefit of convivence. Ossi made a similar argument about gas-powered cars that she linked to the economic dimensions of transportation. She wrote,

> When fossil fuels are burned, they release carbon dioxide and other greenhouse gases, which in turn trap heat in our atmosphere making them the primary contributors to global warming and climate change. Something good that comes from burning gasoline in our cars is that fossil fuels are cheap and reliable sources of energy. Something bad is that vehicles from burning gasoline and diesel fuels contain toxic pollutants. (Ossi, CCA task 1)

Ossi's argument about affordability elevated the sociopolitical reality that transportation choices are made with constrained agency; she described "cheap" fossil fuels as positive.

In another example, Tia made connections between the scientific dimension of land use and carbon sinks with the social dimensions of urbanization. She wrote,

> Changes on the surface of land have impacted the carbon cycle because before all of the things that are built up now there was less carbon in the air because it had more plants and things to collect the carbon. Now it's less plants to collect carbon so there is way more carbon because of urbanization. (Tia, CCA task 2)

Tia described urbanization ("all the things that are built up now") as a social driver in explaining how urban deforestation ("less plants") decreased terrestrial carbon sinks and increased atmospheric carbon concentrations. The examples from Tia, Ossi, and Helen's writing tasks show how intricately interwoven the sociopolitical and scientific dimensions are in student thinking; rampant carbon emission and urban land use cannot be explained as scientific processes but are intrinsically sociopolitical.

Table 14

Components of Conceptual Quality Mentioned by Students Across CCA Tasks

	CCA task 1 (*n* = 14)	CCA task 2 (*n* = 15)	CCA task 4 (*n* = 17)	Total individual students (*n* = 26)
Scientific system & anthropogenic warming				
Sociopolitical connections	5	3	7	11
Agency for emissions				
All humans	0	9	13	10
Corporations	2	3	2	3
Government	6	6	10	11
Motivation for emissions				
Profit	2	4	5	10
Development	0	6	4	9
Who is impacted by climate disruption				
Low socioeconomic status	2	3	3	3
People of color	0	0	3	3
Me, my family, my community	3	10	5	10
Social vulnerability	0	4	7	7
Advocated for solutions				
Low-carbon transit system	9	0	0	9
Reforestation	0	5	0	5
Low-carbon electricity generation	0	0	8	8
Resilience	0	0	4	4

My interview conversations gave some students an opportunity to elaborate upon and clarify their thinking on anthropogenic global warming. I do not count the frequency of these topics in Table 14 because the interview prompts were not explicitly designed to elicit explanations of the five components of conceptual quality. Some students explained their understanding as inherently both scientific and social. For example, Lachelle described the science of climate change in social terms. My conversation with Lachelle proceeded as follows. HFC: “In writing about Grown in LA’s work planting trees, you wrote that, ‘it was great people finally realize we need to change.’ Could you say more about this idea?” Lachelle: “Well, most likely a long time ago climate change was taken as a joke. It wasn't taken seriously. But like now we [sic] realizing that changes are actually happening in the world. And people are waking up and it's like now we really got to do something about it or like, we're not going to be able to survive soon."

Lachelle originally wrote that climate disruptions are "finally" being recognized and in the interview, elaborated that they were ignored for a long time but are now obvious and serious. She explained atmospheric warming through society's perception of and reaction to that change. In another example, Sara differentiated global warming and climate change—also from a social lens. She said,

> Global warming is slow, and no one cares or pays attention because it's just a little bit hotter over time. Climate change is dramatic and impacts lives in big ways like the rainy season coming or not, or no raining coming in some parts of [my Central American country] where food is grown. (Sara, interview 2/24)

While Sara's definitions of global warming versus climate change do not align with the scientific discipline, she explained society's perception of the slow process of warming as part of her own understanding of the science. This understanding of the temporal dimensions of climate disruption is an essential characterization of anthropogenic global warming; the rate at which the planet is warming is one of the key pieces of evidence that scientists use in distinguishing the anthropogenic warming that is currently taking place from the natural warming that the planet has experienced in the past. Lachelle and Sara did not explain anthropogenic warming from the data-driven perspective of scientists, but rather drew from the social response (or lack thereof) that they had observed around them. These two examples illustrate the ways in which students understood the scientific process of anthropogenic global warming as a sociopolitical process.

Critical Awareness of Agency for Emissions

The formative tasks provided opportunities for students to ascribe agency for carbon emission and explain the motivations behind those emissions. Table 14 presents the number of students that ascribed agency to named social actors or explained motivations for carbon emissions across each task. Many students did not ascribe agency at all, and four students ascribed agency ambiguously to a disconnected action or process (such as industrialization or urbanization) rather than to specific social actors.

As shown in Table 14, students ascribed agency for emissions to three groups: corporations, the government, and all humans (described as humans, people, we, or us). The relationality embedded in students' explanations was at times unclear, but in most instances, students appeared to include themselves in the group to whom they ascribed agency. While students clearly identified the government as a responsible social actor, their writing made it clear that they did not fully understand how government functions; this understanding of government as a black box of power limited the sophistication of students' explanations about the role of the government. For example, in my document-elicitation interview with Tia, I asked her to clarify who "them" was from her writing when she wrote about "them" making decisions, and she responded, "I think it's the government. I don't actually know who does what, but I think it's the government."

While students did not fully understand the structure of government—as they might have learned in a civics course—some individuals brought in their own sensemaking resources about power structures to give sophisticated explanations of agency for emissions. During the interview conversations, students drew on their critical awareness of the power of the government. In making sense of the responsibility governments bear for climate change, they also racialized those power dynamics. For example, I asked Lachelle who she was referring to when she said she thought "they" made the choices they did around replacing trees (carbon sinks) with buildings, and she responded, "Like people higher up, like the government. And white people basically (laughs). First off, it's abuse of power, they realized they could do these things and there's nothing we can do about it." In this example, Lachelle made an important connection between urbanization, land use, and the carbon cycle by ascribing agency to an unaccountable source of power. She understood the government as a group of powerful white people that abuse their power because of a sense of immunity, and she used that understanding to make sense of decisions about land that cause climate change.

In ascribing agency for emissions, students described two types of motivation: profit and development. The profits benefited specific social actors while development (urbanization, electrification, technological advancements, and modernization) benefited a broader social group that including the students. I conceptualized the motivation of profits as critical in order to convey that this view accounts for inequality in current and historic wealth. Table 14 shows that total of 10 students wrote about development and nine students wrote about profits as motivation. For example, on CCA task 1, to ascribe agency to actions motivated by profit, Jessica wrote, "The government and large corporations make the choices and decisions about fuel, and they are motivated by the money the fuel-making is bringing them." Similarly, Anna wrote,

> The people who make these choices about land use are our city councils, community, business owners etc... The motivations for the decisions they make are to have businesses so they can get money. As well as giving us new places to visit. Just things that benefit us most of the time. (Anna, CCA task 2)

In the pre- and post-interviews, I asked, "How do you affect climate change?" which gave students an opportunity to ascribe agency to emissions. In the pre-interview, eight out of 12 students described individual actions they had taken that they believed contributed to climate change, such as driving cars and using household electronics. These eight students viewed themselves as participants in causing climate change and as individuals with agency for emissions. Naïve conceptions about the climate system and anthropogenic global warming affected the students' thoughts about ascribing agency. Of the eight students who ascribed agency to themselves, four talked about littering or not recycling—as these actions do not cause climate change, these opinions reflected a persistent misconception.

In the post-interview, it remained common for students to ascribe agency to themselves with both canonical and naïve conceptions. Six students in the post-interview mentioned their trash production and littering habits as causes of climate change, and seven students mentioned their use of gasoline or electricity. No students took a critical perspective in responding to this question which I blame on the fact that the interview prompt only elicited a narrow individual view rather than inviting students to adopt a broader systemic perspective. In these interviews, I also asked, "Whose responsibility is it to address climate change?" and the responses of the focal students were consistent with the findings for the whole class. Seven students ascribed agency to the government (specifically naming the mayor, governor, or president) and four students ascribed agency to all humans.

In summary, findings on how students ascribed agency and motivation for emissions show that about half of the students articulated explanations of conceptual quality that were aligned with critical climate awareness in this component. These students understood that greenhouse gas emissions are driven by political and social actors and motivations.

Climate Awareness of Distribution of Disruptions

Critical climate awareness includes understanding the consequences of climate disruption and how the distribution of those consequences is linked to social, economic, racial, and historic features of communities. The critical dimension of this component is that climate change disproportionally burdens low-income communities of color and therefore this dimension is explicitly linked to social justice. While most students wrote about disruptions resulting from climate change (such as warming, extreme weather, and health risks), they generally described these disruptions as placeless or uniform, and rarely wrote about the distribution of these consequences; it appears the task failed to elicit student thinking around this dimension. As shown in Table 14, a small number of students named four groups that were specifically and disproportionately impacted across the CCA tasks: people with low socioeconomic status, people of color, themselves (described as me, my family, or my community), and an emergent code that I describe as a socially vulnerable people. A total of 12 students articulated an explanation that included one of these four groups when explaining the inequalities in the distribution of climate disruption.

The 12 students who did articulate this component of critical climate awareness described that the injustices of climate consequences were linked to their understanding of racial and classed inequalities. Specifically, they explained climate disruption as disproportionately impacting people of color and low socioeconomic status communities. For example, on CCA task 2, Jessica gave a racialized explanation of disrupted climate when she wrote, “the black and brown communities are being affected most by climate change.” Similarly, Monica explained why she supports local non-profit groups like Grown in LA that are working in communities like South LA. In her document-elicitation interview, she said,

> I think it's good because I feel like white people they have white privilege. So they get in the better neighborhoods. In low income black and brown people, they're very different. And I see it now because I used to live in a white neighborhood and now I come into a neighborhood where there are more Latino folks and black people. I see the difference. I feel like it's good that Grown in LA just focusing on brown and black people, because why go help white people more when it's not them that need help, it's other people. (Monica, CCA task 2)

Monica's response shows that she drew on her critical awareness of how white privilege relates to the burden of climate change on communities like South LA.

In the students' racialized and classed explanations of the distribution of climate disruptions, a code of socially vulnerable people emerged. Four students on CCA task 2 and seven students on CCA task 4 described how disenfranchisement and neglect of communities contributes to the harm that climate change inflicts; in this way, students tapped into a narrative of social vulnerability. Specifically, students described their community as disproportionately burdened by climate change because of characteristics that created or increased social vulnerability. For example, Jessica, Laura, Helen, and Monica expressed the following opinions: "Mostly people from low-income neighborhoods are being impacted by these choices and actions. The low-income neighborhoods have less parks, trees, and sometimes less resources so the negative impacts of the land use affect us the most" (Jessica, CCA task 2). "Yes of course [energy efficient homes] would be helpful for the community because we rarely get help so it's a great opportunity to help the community" (Laura, CCA task 4).

> Yeah [energy efficient homes] are helpful for the community of South LA because I've heard my aunts and uncles talk about how expensive it is to find a nice apartment and it

> would be really nice for people to find a nice apartment. Especially because the pandemic has affected a lot of people being able to find nice place is good. (Monica, CCA task 4)
>
> Not every person of color is able to make important decisions to help the earth. With [SCOPE LA's] project not only will people of color be able to help but pretty much every race. Our whole community can help with climate change and the way we use our energy. (Helen, CCA task 4).

In these examples, students described the vulnerability of low-income communities and communities of color as linked to a lack of resources—both political and natural—that support resilience against environmental hazards. They used this critical awareness to develop their opinions about the interventions of non-profits like SCOPE LA, the community organization highlighted in unit 4 that is working to bring energy efficient apartments to South LA. The students described this intervention as necessary because of social vulnerability, either in terms of low-income status (in Jessica and Monica's examples), neglect (in Laura's example), or racism (in Jessica and Helen's examples). Ms. T consistently emphasized that climate disruptions are racialized and classed, but connections to social vulnerability were not part of her lessons. Discussions of social vulnerability provides another example of students' critical awareness of social issues that they used as a sensemaking resource. These students knew their communities were historically and currently deprived of resources, burdened with environmental hazards, and limited in resilience to emergencies of any kind, and they used this awareness to make sense of climate change as a threat multiplier.

In summary, 12 out of 26 students articulated an explanation of the inequalities in the distribution of climate disruptions and seven students explained this component in a way that revealed they drew on their critical awareness of other social issues as a sensemaking resource.

Students recruited their critical awareness of disenfranchisement and social vulnerability to explain inequalities in the distribution of warming and other climate consequences.

Critical Awareness of Solutions

Students' explanations about solutions to climate change were very contextual and linked to the prompts of the task. For CCA task 1, the solutions were related to fuel and transportation, for CCA task 2, they were related to land use and reforestation, and for CCA task 4, they were related to transitioning energy production to low-carbon fuels. In my conceptualization, a critical awareness of climate change solutions includes knowledge of approaches to adaptation, mitigation, and resilience that involve collective, large-scale, and sociopolitical actions in contrast to individual or solely technological approaches. Table 14 presents the four categories of solutions articulated in each task, including three approaches to mitigation (each contextually linked to the task) as well as arguments for resilience building that emerged in CCA task 4. In CCA task 1, nine students advocated for increased use of mass transit and decarbonization of the transit sector. In CCA task 2, five students argued for planting more trees to increase terrestrial carbon sinks. In CCA task 4, eight students articulated the need for low-carbon sources of electricity. All these mitigation strategies are inherently collective and rely on sociopolitical actions and therefore these students' articulated explanations aligned with critical climate awareness. Additionally, four students wrote about solutions that build resilience in CCA task 4. For example,

> I agree with SCOPE LA that this type of project is good for energy use, climate change, and communities because by building more affordable and energy-efficient homes that means that our usage of electricity will greatly reduce which can really have a good impact on climate change since electricity use is the second biggest factor that emits a lot

> of carbon dioxide into the atmosphere. This project will also be really helpful to communities of color since more people in these communities will be able to afford more energy-efficient homes. (Jessica, CCA task 4)
>
> The Slauson Corridor project by SCOPE LA will be helpful for my neighborhood because it allows people with low income to be provided a home. This group actually takes what people from our area have to say seriously. They provide the community with updates and allow us to vote on what we think is right or wrong. This group is making sure we have a good and safe environment. (Anna, CCA task 4)

These students argued that building resilience to climate change should involve uplifting low-income communities and making low-emission technology affordable and accessible. Embedded in these explanations of solutions to climate change is the idea that building resilience can counter social vulnerability and work against many threats, including but not limited to climate change. Both Jessica and Anna's arguments are localized (and Jessica's is explicitly racialized), as they described the unique needs of South LA and benefits for the community of building resilience around environmental decisions.

In the document-elicitation interview, the theme of educating youth emerged as a collective action solution. Four students talked about the unique position of youth in achieving climate actions. They discussed the potential of education to uplift and empower more youth to understand and engage with the climate crisis. For example, I asked Sara to elaborate on her writing from CCA task 2 in which she wrote "Grown in LA is a good example for kids." When I asked her to say more, she replied,

> Well kids are curious, and they learn from examples. It's good to show kids to take care of the environment from a young age. For climate change, this is so important because

> when they are big they are going to feel the changes and we will have more people understanding what's going on and doing things to not make it worse. (Sara, interview 2/24)

As Sara described the importance of the lived and future experiences of youth, Tia also highlighted the unique experiences of her generation to contrast with adults. She said,

> I feel like working together is clear to the children because they're learning about it and they're wanting—children are more diverse now. I feel like since the kids are more diverse with being mixed, and a lot of, like, biracial kids like me. I feel like we're more like open minded to things, and the kids are understanding what's going on, they're upset about it because we just want peace, and we're trying to fix everything, but we're noticing how our parents and our adults, which are supposed to be the role model, are doing all this chaos and acting so immature, they're babies it's embarrassing. (Tia, interview 1/13)

Education is a powerful example of a collective, large-scale, sociopolitical action that can address climate change. While Ms. T did not explicitly mention education as a solution to climate change, her actions throughout the year certainly embodied the value of this approach. In summary, although explanations of climate solutions were not prevalent in the CCA tasks, when they were included, students explained mitigation and resilience strategies that are inherently collective and rely on sociopolitical actions. While no student wrote about individual level actions as solutions to climate change on these tasks, as previously described, in interviews students did voice the need for individual-level actions to be taken collectively.

Summary of Developing Critical Climate Awareness

Critical climate awareness requires an individual to understand how, why, and by whom climate inequalities are created, experienced, and solved. Quantitative findings from the Six Americas survey suggest that the whole class generally became more aware and concerned as the course proceeded (Maibach et al., 2009). Qualitative measures from the formative tasks suggest that about half of the students ended the year with partial critical climate awareness and a small group of students (Sara, Tia, Jessica, Helen, and Anna) ended with robust critical climate awareness. A cluster of findings from the CCA tasks illustrate the critical perspective of this small group of students. First, these students articulated sophisticated connections between sociopolitical and scientific systems in explaining the mechanisms of anthropogenic global warming. Second, they drew on their critical awareness of white privilege, social vulnerability, and government neglect of Black and Brown communities to articulate explanations of who has agency for carbon emissions and why climate disruption disproportionally burdens communities like South LA. Third, these students articulated that equitable climate solutions rely on resilience building to address environmental and social injustices. Notably, Anna and Helen did not have a strong conceptual understanding of the science of climate change, but they clearly still had critical awareness of the climate crisis; this suggests that critical awareness may not be dependent on scientific knowledge. Sara, Tia, Anna, and Jessica were profiled as alarmed or concerned by the Six Americas survey at the beginning and end of the year, while Helen was cautious at both time points. Findings suggest that Ms. T's class supported them in building on the foundation they already had to develop more sophisticated critical climate awareness.

Chapter 7: Discussion

My dissertation is part of a growing body of pedagogical efforts focused on ensuring that education plays a more critical role in addressing the climate crisis (Chang & Pascual, 2017). Working in partnership with Ms. T, we designed a novel model of climate change teaching and learning to support critical climate awareness. Learning science entails appropriating discipline-specific modes of discourse and practice (Sandoval, 2003), but climate change is not just a scientific discipline. I expanded the way school science defines the "discipline" of climate change to include sociopolitical dimensions. The intervention supported many students in appropriating the sociopolitical discourses and practices needed to act on climate change. To address inequitable science learning contexts for urban students of color, this intervention removed barriers to participation and achievement in science learning with socially and culturally relevant pedagogy. Ms. T's teaching offers an example of justice-centered science pedagogy that opened opportunities to shift the outcome of learning from individual gains to social transformation that allows for all youth to thrive (Barton et al., 2021).

Throughout the school year, Ms. T, the students, and I interrogated the histories and relationships in neo-liberal and neo-colonial capitalism that drive the climate crisis, and we worked towards building the transformative, collaborative relationships necessary for climate justice (McGregor & Christie, 2021). In investigating the impact of this intervention, I aimed to answer two questions: (1) How does instruction that emphasizes the sociopolitical dimensions of climate change support the learning of climate science and the development of critical climate awareness? (2) In what ways do the sociopolitical dimensions of climate change structure engagement in climate change learning?

The 10th grade chemistry students at the Mann-UCLA Community School that participated in the study experienced immense challenges during the COVID-19 pandemic and demonstrated tremendous resilience. Ms. T faced challenges of her own and invented constructive pedagogical moves for remote teaching on the fly. I also struggled and modified my proposed methods in the shifting context of distant learning to rely on written artifacts rather than video observation of engagement. The Connective and Productive Disciplinary Engagement framework and my novel framework of conceptual quality for critical climate awareness made visible students' generative concepts, resources, and practices and allowed me to tell this story of students' engagement and learning.

In this chapter, I begin by discussing the significance and contributions of my findings. My analysis illustrates the ways in which a sociopolitical focus structured classroom engagement and supported the outcomes of learning climate science and developing critical climate awareness. First, the sociopolitical framing of the "discipline" of climate change engaged students in ways that were productive for learning science concepts and connected to their lived experiences. I documented a statistically significant increase in conceptual knowledge, specifically about the mechanisms of the anthropogenic greenhouse effect emphasized in the course. I also showed how students used their lived experiences, specifically their critical awareness of social issues, to reason about climate inequalities and imagine how they might be addressed. Second, organizing instruction to emphasize the sociopolitical dimensions of climate change developed students' critical climate awareness. I documented a statistically significant increase in climate concern. Students' written explanations of climate change showed progress in how they explained aspects of climate change, specifically in ascribing agency as universal or differentiated for the causes and solutions of the climate crisis. I conclude this chapter by discussing my methodological contributions, limitations of this analysis, possible future work, and recommendations derived from my findings for justice-centered pedagogy and teacher preparation.

Significance of Findings

In this section I answer my research questions by synthesizing across findings presented in Chapters 5 and 6. First, I explain how the sociopolitical focus engaged students in ways that were productive for learning canonical science concepts and productive relative to my connective-disciplinary conceptualization of engagement. For changes in canonical knowledge, I contextualize findings relative to the affordances and constraints of the design. Then, I draw on the CPDE framework to explain how the sociopolitical framing of climate change structured engagement around students' lived experiences. In this discussion, I explore how students used their critical awareness of social issues to reason about inequalities in access to climate mitigation solutions and to imagine how those issues might be addressed in a future that is more just. Second, I explain the ways in which engagement with the sociopolitical dimensions of climate change supported the development of students' critical climate awareness. I show the progress students made and variation in ascribing agency for the causes and solutions of climate change. In this discussion, I situate my findings relative to complexity and heterogeneity in conceptions of environmental justice and criticality. In both sections, I explore the relational dimensions of students' engagement and students' developing critical climate awareness.

Sociopolitical Focus Supported Productive Learning and Engagement

Conceptual Knowledge

The sociopolitical framing of the "discipline" of climate change engaged students in ways that were productive for learning canonical science concepts. Ms. T taught climate change as interacting systems, layering the sociopolitical and scientific dimensions in her teaching. Ke et al., (2020) argue that meaningful student learning is only achieved if teachers scaffold students' construction of climate change knowledge. Ms. T did scaffold students' construction of knowledge by helping students understand scientific systems and processes as connected to local, social, and political processes that were accessible, relevant, and meaningful to them. I documented a statistically significant increase in students' conceptual knowledge about the mechanisms of the anthropogenic greenhouse effect that were emphasized in the course. I showed that learning the sociopolitical dimensions of climate change does not limit opportunities to learn science. For science teachers hesitant to teach sociopolitical dimensions because they are concerned these themes conflict with standards-aligned teaching, I hope these data are compelling evidence otherwise.

While students' understanding of the mechanisms of anthropogenic climate change improved during the year, they displayed three misconceptions seen in related research. First, many students had persistent misconceptions that pollution causes climate change. They attributed the greenhouse effect to pollution in general, which is a common alternative conception that has been widely documented in students learning about climate change (Gowda et al., 1997; Punter et al., 2011). Students regularly lumped pollution and climate change together without differentiating underlying mechanisms (Anderson et al., 2018). Second, students relied on a common and persistent "good versus bad" heuristic to explain the carbon cycle, labeling the chemical processes of carbon dioxide as good or bad rather than relying on "pool-and-flux" reasoning to describe changes in the reservoirs and transfers of carbon dioxide (Covitt et al., 2021). The intervention focused on the scientific and social factors that impact the pools/reservoirs of carbon dioxide and students only grappled with fluxes/transfers of carbon qualitatively. Third, students' spatial and temporal reasoning were underdeveloped practices that they did not have many opportunities to use and did not use effectively for planning and assessing climate actions across scales. Temporal reasoning is using past data to make projections about the future and spatial reasoning is thinking across global and local scales to study impacts of change (Sezen-Barrie et al., 2022). While the intervention had a large effect, my findings on changes in conceptual knowledge support existing literature on the need to address persistent misconceptions, to support the development of pool-and-flux reasoning about the carbon cycle, and to teach the practices of temporal and spatial reasoning.

Connective-Disciplinary Engagement

The sociopolitical framing of climate change engaged students in ways that were connected to their lived experiences. In my findings chapters I used the CPDE framework to analyze participation and I showed how engagement embodied the four principles of CPDE to a greater extent over time. My work extends research efforts in the Learning Sciences that advocate for centering students' identities, histories, and experiences as a way of elevating the connective aspects of learning and of disciplines– that is, the political, relational, and ethical aspects - specifically for minoritized youth (Philip et al., 2018; Barton et al., 2020). In this section, I look at the three dimensions of CPDE – connective-disciplinary, productive, and engagement – to argue that student participation represents a case of CPDE. Table 15 summarizes the nature of student participation by presenting how the three dimensions of CPDE were embodied by the students. This table provides evidence for how participation represents a case of CPDE and specifically for how organizing engagement around students' lived experiences was productive. Connections to students' lived experiences allowed them to address sociopolitical scholarship and practices, and to use epistemically diverse evidence (in the connective-disciplinary column of Table 15). Specifically, students' lived experiences were the source of their critical awareness of social issues that they used to reason about inequalities in access to climate mitigation and to imagine how those issues might be addressed in a future that is more just. Connections to students' lived experiences also allowed them to make new connections between sociopolitical and scientific systems, to assert critical views on climate actions, and to make progress on modeling climate systems (in the productive column of Table 15). Below, I elaborate on these CPDE dimensions of student participation by revisiting students' engagement with the issue of solar panels as a mitigation strategy.

Table 15

Summary of embodiment of CPDE dimensions

Connective-Disciplinary	Productive	Engagement
Addressed climate science scholarship & practices: mechanisms of the greenhouse effect and carbon cycle; scientific practice of modeling; positioned students as participants in climate systems	Statistically significant increase in awareness and concern and conceptual knowledge	Made pronounced emotional displays
Addressed sociopolitical scholarship & practices: political, economic, & cultural levers of change; interrogated the harm of scientific enterprise, capitalism, colonialism, and racism on students' community; positioned students as intellectual agents of change in a more just future	Developed more sophisticated explanatory models (unit 4 only)	Asked unprompted questions/ spontaneous reengagement
Used evidence in scholarly ways: supported claims with data	New connections between sociopolitical and scientific systems, students' lives, and community	Responsiveness to peers (unit 4 only)
Used epistemically diverse evidence in critical ways: scientizing personal, cultural experiences was legitimate; practices of localizing, personalizing, and politicizing	Asserted critical views of climate actions	

Engagement with the issue of solar panels was connected to students' lived experiences through the ways in which they drew on their critical awareness of racial and classed differences in power and agency for making decisions about low-emission technologies. Students may have previously believed that this critical awareness was non-scientific, but Ms. T invited, honored, and legitimized it as valuable to make sense of climate change. Engagement with the issue of solar panels was also connected to students' imagined futures as a time when large-scale, collective sociopolitical actions, like anti-capitalist policies of subsidies, would allow them to participate in using low-emission technologies. This is proleptic imagining that worked to remediate injustices of the past when collective sociopolitical actions excluded people of color from full participation in society.

Connecting instruction to students' lived experiences, through the resource of their critical awareness of social issues and their proleptic imagination, was productive because it supported significant progress from the beginning to the end of the year in how students made critical and scientifically accurate connections between themselves, their community, and the climate system. Specifically, students identified a sort of floor in how much they could reduce their own carbon emissions. They wanted solar panels to lower their emissions from residential energy production but could not access them, so a floor was set for their emissions by the fossil-fuel reliant energy they used. Students drew on their critical awareness of limited agency as renters to assert these critical views on climate solutions.

Orienting instruction around students' critical awareness and imagined futures strongly embodied the connective-disciplinary dimension of climate change because they grappled with authentic questions about mitigation. Students' questions about solar panels mirrored intense political debate happening right now in Los Angeles. Currently, California energy policies are based on Net Energy Metering, a billing mechanism that credits solar energy system owners and has been shown to disproportionately benefit wealthier, white, single-family homeowners. Environmental justice advocates argue that by its very design, Net Energy Metering is inaccessible to California's disadvantaged communities because of the intersectional impacts of redlining, ongoing structural barriers in energy policies, and a lack of upfront capital, credit, and property ownership (Barbose et al., 2021). When students problematized solar panels and other low-emission technologies as inaccessible to low-income communities of renters, they countered the dominant narrative (in environmental policy and the NGSS) of technocentrism, a broad embrace of engineering and technology to solve all environmental problems (Feinstein & Kirchgasler, 2015). Student engagement was connective-disciplinary for the ways in which they used their identities and critical awareness of South LA to argue for sociopolitical, collective action instead of endorsing a technological fix to climate change.

Relational Dimensions of Engagement. As described in Chapter 2, relational dimensions of climate change learning are key to my conceptualization of CPDE. My methods were designed to allow me to document four types of relationality: 1) student-to-student and student-to-teacher relationships that shaped classroom collaboration, 2) students' relationships to themselves that shaped the ways they reached into their past and imagined their future, 3) students' relationships to place that shaped the way they positioned themselves as part of the environment, and 4) students' relationships to systems and institutions that shaped the way they positioned themselves relative to power and collectives. Synthesizing across my findings on the principles of CPDE, I identified three ways that students' actions surfaced relational dynamics in their thinking about climate change spanning the types of relationships described above.

First, students problematized their relationship to, and positioning in, the system of capitalism. Throughout unit 4, students explained that their identity as low-income renters constrained their ability to participate in the low-emission energy transition. In surfacing their relationship to power, they rendered mitigation solutions like solar panels and electric vehicles illegitimate in South LA because they were unaffordable. Second, students positioned themselves within the community and the climate system to take up intellectual agency. Some students took up intellectual agency with a power-laden perspective (differentiated) to argue for action by governments and corporations while others did not take power into account (universal) to argue that they personally should change their behavior to reduce emissions. In both perspectives, students positioned themselves as part of the environment, specifically as participants in the local climate system, to problematize the normative human-nature divide. Third, students' relationships to themselves and to collectives were used as relational resources in sensemaking about climate change. Specifically, students' proleptic imagination of their own future, critical awareness of injustices in their past, and positioning in collectives engaged in large-scale sociopolitical actions were resources used in arguing for climate solutions. This support for collectives represents a transformative type of relationship needed to address the climate crisis (McGinty & Bang, 2016).

When Ms. T invited and honored relational sensemaking resources, her teaching embodied justice-oriented science pedagogy. Barton et al. (2021) argue that in justice-oriented pedagogy, new types of relationality can be a pedagogical move. Ms. T worked on "critically being with" (Barton et al., 2021, p. 1242) students to direct her teaching towards shifting power. This pedagogical move involved deep engagement with youths' narratives of their lives and allowed youth to be and act as their full selves. The three relational dynamics described above – problematizing relationships to power in capitalism, positioning students with agency in the climate system, and positioning students' ideas about relationship as resources in understanding climate change - supported developing connective-disciplinary engagement. My findings illustrate the value of centering and elevating relationality to support productive engagement and extend efforts to design and understand pedagogical strategies that support minoritized students' rightful presence in science spaces (Barton & Tan, 2019). Structuring instruction around students' lived experiences, and the relational dynamics that helped students make sense of how science intersects with their lived experiences, offers a model of pedagogical moves that can catalyze academic achievement and social transformation (Morales-Doyle, 2017).

Sociopolitical Focus Supported Developing Critical Climate Awareness

The designed learning outcome of this intervention was the development of critical climate awareness. Findings from the Six Americas survey (Maibach et al., 2009) show that students became more concerned and aware of climate change over time, which I conceptualize as a part of critical climate awareness. To put the students' Six Americas profiles in context, Ballew et al. (2020) found 87% of Hispanic/Latino Americans, 77% of Black Americans, and 68% of White Americas were alarmed, concerned or cautious about climate change. While comparing youth to adults is not ideal (there are no summaries of profile distribution for youth), Mann students are aligned with the high level of concern found in their racial/ethnic community. Students' performance on the CCA tasks showed progress in how they explained the causes, consequences, and solutions of climate change. Approximately one-third of students explained the canonical scientific system and mechanisms of anthropogenic warming as sociopolitical processes; this suggests that these students' understanding of climate change was based on the social, political, economic, and cultural structures that alter climate systems. Almost half of the students explained inequalities in the distribution of climate disruptions and one-quarter of the students recruited their critical awareness of disenfranchisement and social vulnerability to explain these inequalities. Evidence that students developed critical climate awareness is most clear in two areas: how they ascribed agency as universal or differentiated for causing and solving climate change, and how they explained a range of relationships involved in those causes and solutions.

Universal and Differentiated Agency

Students ascribed agency for emissions to a diverse range of social actors. Some students differentiated these social actors while others took a universal perspective and did not clearly differentiate these actors from 'humans' generally. Neither of these perspectives involve students ascribing agency to anonymous, disconnected actions; this is a problematic assumption embedded in the NGSS that teachers adopt in their classroom discourse (Clark et al., 2020). The designed intervention helped Ms. T and her students counter this narrative.

When students ascribed responsibility for causes and solutions to social actors both in relation to power and universally, they demonstrated critical awareness of climate change. For students that elevated power dynamics, their thinking aligned with scholars of environmental justice who argue that it is unfair to ask those living in poverty today to shoulder the responsibility of undoing the damages from past carbon emissions (Cachelin & Nicolosi, 2022). To do so would ignore the historic and ongoing role of capitalism, colonialism, and racism in causing the climate crisis. For students that adopted a universal perspective, their thinking aligned with scholars of climate science who argue that all youth must learn to live low-emission lifestyles now, getting accustomed to changes that come with the low-carbon energy transition early so that they have a chance at a sustainable future. To ensure that ambitious mitigation targets are met, every person in the United States, regardless of socioeconomic status, needs to reduce their carbon footprint to 2.1 tons a year. This universal emission reduction means everyone needs to make behavior changes like having less children, eating a plant-based diet, and not owning a personal car (Wynes & Nicholas, 2017). In ascribing agency to themselves, students situated themselves as part a difficult energy transition even if they are not to blame for the climate crisis.

Students in Ms. T's chemistry class held space for both the differentiated and universal perspectives on emissions reduction and climate action as part of their critical climate awareness. Progress on the CCA tasks over the course of the year showed that more student adopted the differentiated perspective at the end of the intervention. Both the differentiated and universal perspectives became more sophisticated over time, moving from just explaining causes of climate change to later also explaining solutions to climate change.

Relational Dimensions of Critical Climate Awareness

Relational dimensions of climate change learning are also central to my conceptualization of critical climate awareness, as described in Chapter 2. Below I synthesize my findings from the CCA tasks to explore how ideas about relationality evolved over the course of intervention to support students' critical climate awareness. Ms. T and students countered the normative human-nature divide throughout the intervention to situate students as part of the environment. In unit 2, students were positioned, by themselves and Ms. T, as participating in the climate system by emitting carbon that disrupts the carbon cycle. This positioning as part of the environment was not situated in the systems of colonialism and capitalism and therefore students did not look critically at relationships that create and sustain climate inequalities in unit 2. Students positioned themselves and classmates, and in fact all humans universally and uniformly, as part of the environment and playing an active role in unbalancing the carbon cycle. Universal positioning was achieved by Ms. T and students with three different usages of the phrases we/us/all humans: to describe a group that includes themselves, to describe a group of people that may or may not include themselves, and to describe a group that cannot include themselves because the actions described took place in a historic or remote context.

In unit 4, students' positioning in the climate system did look critically at their relationships to power. This allowed some students to untangle who specifically has responsibility for causing the unbalanced greenhouse effect and to justify arguments for who has agency to fix it. Differentiated positioning was achieved when students ascribed agency to the government or corporations to exclude themselves and take a power-laden perspective. Students' progress in exploring these relational dimensions of climate change, specifically relationships to the climate system and to power, supported the development of students' critical climate awareness.

Challenges of Designing and Measuring Critical Climate Awareness

Designing and enacting a learning environment for the outcome of critical climate awareness and measuring this outcome was challenging for several reasons. First, across educators and scholars, there is no consensus on how to center or balance sociopolitical concepts in science classrooms. Second, Ms. T never discussed the concept of critical consciousness directly with students, so this outcome of critical awareness was not transparent to students. Third, Ms. T and I designed for critical awareness as a stand-alone outcome separate from the broader outcome of critical consciousness, which we found too ambitious to support in just one school year. Disconnecting critical awareness from the cycle of critical consciousness created an artificial boundary in Freire's cycle and may have constrained developing this outcome.

More broadly, my challenges of designing, measuring, and analyzing critical climate awareness are partly rooted in my own developing thinking of what criticality is in climate change learning. I continue to explore the areas of overlap and difference between what is connective, what is critical, and what is sociopolitical about learning climate change. Connective engagement gave students opportunities to think deeply about sociopolitical and critical dimensions of climate change, so in some ways the three concepts are synonymous. However, my findings suggest that for some students a sociopolitical understanding did not always recognize power dynamics and therefore does not align with definitions of critical. This is the case for students that adopted a universal perspective on agency for emissions and solutions. The other part of my challenge is rooted in heterogeneity and complexity in notions of environmental justice. Cachelin and Nicolosi (2022) assert that learning environmental justice requires "deconstruction of culturally produced narratives that uphold privilege, conceal complicity, and promote individual-level response to systemic problems" (p. 1). The most widely understood definition of climate injustice is the "asymmetrical distribution of climate impacts on vulnerable people who have contributed least to greenhouse gas emissions" (McGregor & Christie, 2021, p. 3). However, this distributive definition does not help me take account of students' lived experiences with climate change and how those lived experience shaped their developing critical climate awareness. Ms. T and I did not engage students in a discussion of what climate (in)justice means to them, and without knowing their perspectives my understanding of this outcome is limited by my own subjectivity on the issue.

Conclusions

Human-nature relationships are political, and conceptions of the environment are politically constructed to privilege or delegitimize some human and more-than-human actors over others (Demerritt, 2002; Kirsop-Taylor et al., 2021). The intervention designed for my dissertation empowered Ms. T and her students to deconstruct the power and privilege embedded in the phenomenon of anthropogenic climate change. With locally and culturally relevant activities anchored in students' wonderings and issues present in South LA, students were able to appropriate some discourses and practices of climate science as a scientific discipline and climate change as a sociopolitical discipline. This design supported learning canonical concepts, becoming concerned about the climate crisis, and explaining the causes, consequences, and solutions to anthropogenic global warming as inherently sociopolitical. Many climate change interventions study outcomes for middle class white students (c.f. Hestness et al., 2014; Stevenson et al., 2016; Breslyn et al., 2017) while my findings contribute to the growing body of literature that highlights the unique and generative sensemaking strategies of Black and Latinx urban youth when engaging with environmental issues (Morales-Doyles, 2017; Davis & Schaeffer, 2019; Madkins & McKinney de Royston, 2019). Analysis of students' engagement and outcomes shows the epistemic diversity and community-based knowledge they brought to the classroom that supported them in grappling with climate injustices and arguing for a more just socioecological future. In this section, I share two methodological contributions of my dissertation, discuss the limitations of my analysis and possible future work, and offer a set of recommendations based on my findings. I end this chapter with a reflection on my contribution to justice-centered science pedagogy.

Methodological Contribution

My work offers a case of CPDE to support Agarwal and Sengupta-Irving's (2019) conjecture that conceptualizing PDE as inherently connective is needed to fully understand the participation of minoritized students, and the role of power dynamics embedded in disciplines. I analyzed climate change as an inherently connective discipline, and the two themes of power embedded in the CPDE principles – epistemic diversity, and historicity and identity- allowed me to describe how issues of history, culture and personhood were essential to students' engagement with climate change concepts. Analyzing climate change engagement as connective-disciplinary worked to "actively disrupt epistemic fundamentalism to form expansive notions of disciplinary learning and learners" (p. 12) and to "make visible the cultural and relational terrain" (p. 13) from which students' disciplinary ideas emerge. As a set of design principles, the CPDE framework thickened "the intellectual substrate in which disciplinary curiosities and uncertainties can find root" (p.13). Student thinking was able to take root in their critical awareness of social issues and blossom into imagining a socially just and sustainable future. Agarwal and Sengupta-Irving state that the principle of resources is the least articulated in their framework, and my work contributes to a clearer articulation of this principle. I showed the ways in which the critical awareness youth have about social issues is an essential resource in scientific sensemaking and suggest that this resource be included in design principles for science learning environments that aim to support CPDE.

A second methodological contribution of my work is to Participatory Design Research. My partnership with Ms. T offers a case of PDR within the constraints of a formal school setting and a core course aligned to the NGSS. We had to navigate and negotiate this setting in ways that constrained our freedom and creativity. Many PDR studies are situated in after-school or out-of-school settings, and therefore do not contend with these limitations. This design represents one way a PDR project can take shape within the limits of a school. I contribute a case of what the "processes of partnering" (Bang & Vossoughi, 2016, p. 174) look like in this setting to expand our understanding of PDR as a generative method.

Limitations and Future Work

The constraints of remote schooling and the COVID-19 pandemic, as well as my own evolution as a researcher, limited my data collection and analysis in two ways that I will discuss here, and shape the work I hope to undertake in the future. First, the lack of observational data to document moment-to-moment interaction and artifacts to document changes in conceptual knowledge limit my understanding of the impact of the sociopolitical framing of climate change. My assessments of learning canonical climate science concepts were not well aligned with either my sociocultural understanding of competence or my connective definition of the "discipline" of climate change. If given the opportunity to do another iteration of this work, I will collect video data and use the method of Interaction Analysis to apply CPDE more traditionally to turns of talk and trace engagement with ideas through those conversations. I would also collect artifacts on conceptual knowledge to help me explore the conjecture that engaging with the sociopolitical dimensions improves learning science concepts.

Second, I was learning so much as I did this work and my own development as a researcher limited the story I tell about this intervention. Student sensemaking was more expansive, complex, unique, and messy than I could have imagined or account for. The work of measuring and analyzing the outcome of critical climate awareness made visible the "heavy lifting of expanding our own epistemic horizon" (Agarwal & Sengupta-Irving, 2019, p. 14). For example, in my findings I presented student perspectives on agency for emissions in the categories of differentiated and universal. In my original thinking, a universal approach would have been coded as uncritical and a differentiated approach would have been coded as critical. A universal positioning is out of alignment with tenets of climate justice that reject an undifferentiated 'we' because of the asymmetrical distribution of culpability, vulnerability, and agency in causing the climate crisis (McGregor & Christie, 2021). But as I observed and analyzed student sensemaking, I felt naïve and patronizing describing anything these students did as uncritical. I did not want to exclude a universal perspective from my conceptualization of critical climate awareness, so I worked to eliminate that thinking and vocabulary as I modified my methods of analysis. Critical climate awareness was personal, historical, cultural, and intensely contextual for students and the methods I implemented reflect my personal efforts to expand my epistemic horizons to honor the richness and diversity of student thinking.

Last, my dissertation does not include data or analysis of Ms. T's learning or practice. In the future, I hope to analyze my observations of her teaching, recordings of our planning sessions, and our interviews collected over four years of collaboration to understand her development. This work will contribute to extending knowledge of climate change teaching and add depth to my investigation of the affordances of Ms. T's knowledge and practices to student learning and engagement. Specifically, I want to explore Ms. T's learning about the sociopolitical dimensions of climate change and her own developing critical climate awareness. This line of inquiry will address how Ms. T's critical awareness of climate change shaped her pedagogical skills to enact culturally relevant science teaching (Jones & Donaldson, 2022).

Recommendations

Based on my findings, I can offer suggestions for justice-centered science pedagogy and teacher preparation. For justice-centered science pedagogy, I recommend teaching the political dimensions of SSIs. The well-documented pattern of teachers deemphasizing, ignoring, or neutralizing the political aspects of climate change and environmental issues needs to stop (Dawson, 2012; McNeal et al., 2017; Slimani et al., 2021). My research suggests one way to address the gap between the philosophy of environmental education, that understands environmental challenges as sociopolitical, and the practices of environmental education, that are narrowly ecological. For schools serving urban students of color, this gap can be closed by identifying real-world, local experiences of youth and connecting them to classroom activities. As shown in this design, the sociopolitical dimensions of climate change and other SSIs can be foregrounded in science courses through community-oriented and justice-centered phenomena.

To actualize this recommendation, educators and researcher need to describe a set of sociopolitical dimensions of climate change that belong in all science classes as well as advice on determining locally contingent dimensions, and more widely study what a balance of the sociopolitical and scientific dimensions might look like. My work offers a starting point for imaging those dimensions and that balance in the context of South LA.

Regarding teacher preparation, I recommend that educators be supported with resources and communities of practice to develop their sociopolitical consciousness of climate change. Teachers must learn to make visible connections between students' everyday lives and macro-sociopolitical processes of the environment (Ardoin & Heimlich, 2021). In this work, I documented the ways in which Ms. T named and elevated students' everyday experiences as situated in the scientific and sociopolitical systems of climate change. My findings show the ways in which Ms. T's sociopolitical consciousness – about education, about her students, and about climate change – allowed her to implement culturally relevant science pedagogy. To continue and expand this work, Ms. T and all teachers need sustained and systematic support in developing critical consciousness that can transform everyday actions into forces of societal change (Ardoin & Heimlich, 2021). Based on observations of Ms. T, the support teachers need should focus on a) learning the history of environmental injustices in the community, b) learning how the political history of climate change intersects with standard-aligned scientific concepts and practices, c) opening up and managing dialogue on issues at the intersection of race, identity, and the environment, and d) orienting classroom engagement towards critical hope and solutions.

Conclusion

These data on the teaching of Ms. T and learning of the 10th grade chemistry students at the Mann-UCLA Community School tell a story of what climate change education can look like and can accomplish. My findings show what was possible for a group of students during an incredibly challenging year when just one of their teachers helped them make connections between their lives and the sociopolitical and scientific processes of climate change. Imagine what is possible during a stable school year when all teachers in all subjects collaboratively work to help youth engage with the climate crisis. While I do not suggest that the engagement or outcomes that I documented represent best practices or best-case scenarios, they do show the generative, locally relevant, and culturally meaningful ways that this group of minoritized youth worked to make sense of climate change. This engagement and sensemaking illuminates the brilliance of these youth, the pedagogical wisdom of Ms. T, and the potential of foregrounding sociopolitical dimensions of climate change in science classrooms. This story contributes an approach to humanizing climate change instruction that advances justice-centered science pedagogy and moves science classrooms one step closer to becoming sites of empowerment for climate justice.

Appendices

Appendix A

Disciplinary Knowledge Assessment

Question	Category
1. The greenhouse effect can best be described as __________. a) the same thing as global warming b) pollution related to acid rain c) an increasing of the temperature of the planet d) damage to the ozone layer	Greenhouse Gas Chemistry
2. Which if the following is <u>NOT</u> a greenhouse gas. a) Carbon dioxide (CO_2) b) Chlorofluorocarbons (CFCs) c) Water vapor (H_2O) d) Oxygen (O_2) e) Methane (CH_4)	Greenhouse Gas Chemistry
3. Which is the most abundant greenhouse gas? a) Carbon dioxide (CO_2) b) Hydrogen (H_2) c) Methane (CH_4) d) Nitrogen (N_2) e) Water vapor (H_2O)	Greenhouse Gas Chemistry
4. All greenhouse gases molecules interact with what type of electromagnetic radiation? a) Visible b) Ultraviolet c) Shortwave radio d) Infrared	Greenhouse Gas Chemistry
5. What is the primary source of CO_2 contributed by humans? a) Human respiration b) Driving cars c) Pollution from factories d) Burning of fossil fuels to generate electricity	Greenhouse Gas Chemistry
6. After a molecule of greenhouse gas absorbs electromagnetic radiation it ____. a) rises into the ozone layer. b) creates other greenhouse gas molecules. c) releases energy by interacting with other molecules. d) generates a layer of greenhouse gas molecules.	Greenhouse Gas Chemistry
7. Which of the following would cause Earth's average global temperature to rise? a) Changes in the length of seasons b) Changes in the thickness of Earth's atmosphere c) Changes in the amounts of gases in the atmosphere	Mechanism of the greenhouse effect

d) Changes in the amount of heat from Earth's molten core	
8. Scientists believe that global temperatures are rising primarily because of: a) an increase in the use of toxic chemicals such as pesticides and aerosols sprays. b) increases in the amount of carbon dioxide (CO_2) from burning fossil fuels. c) a hole in the ozone layer allowing heat to enter the earth's atmosphere. d) excess heat given off from energy generation in nuclear power plants.	Mechanism of the greenhouse effect
9. What is the relationship between temperature and the Earth's atmosphere? The earth's atmosphere: a) blocks light from the Sun make the Earth cooler. b) holds heat energy from the Sun to warm the Earth. c) has no influence so Earth's temperature doesn't change. d) strengthens heat energy to increase Earth's temperature.	Mechanism of the greenhouse effect
10. Which of the following activities will lead to future intense storms? a) Ozone layer depletion b) Changes in the tilt of Earth's axis c) Variations in the energy put out by the Sun d) Heat trapped by increased greenhouse gases	Mechanism of the greenhouse effect
11. Over the past several decades, the Earth has warmed faster than any other time period. What best explains this increase? a) The sun is releasing more heat energy. b) There's an increase in volcanic activity. c) Humans are generating more air pollution. d) The Earth's orbit around the Sun is changing.	Impacts of human activity
12. There is strong evidence that there is more carbon dioxide (CO_2) in the atmosphere now than in the past several hundred years. What is most likely cause of the current increase in carbon dioxide? a) There's more toxic chemicals in the oceans and rivers. b) Plants are releasing more carbon dioxide (CO_2). c) Volcanoes are producing more ash and gases. d) Humans are using more fossil fuels	Impacts of human activity
13. Not every action taken by humans contributes to climate change. Which of the following human activities does <u>NOT</u> contribute to climate change? a) Greater use of chemicals that destroy the ozone layer b) Rises in the number of people driving cars c) Greater rates of deforestation d) Larger demand for electricity	Impacts of human activity
14. Energy can be obtained from different sources. Which of the following forms of energy production releases the most carbon dioxide (CO2) into the atmosphere? a) Nuclear plants	Impacts of human activity

b) Windmills c) Oil and coal d) Solar power	
15. How is carbon dioxide (CO_2) removed from the atmosphere? a) Factories need carbon dioxide to run a) Carbon dioxide breaks down naturally b) Carbon dioxide escapes into space c) Plants absorb carbon dioxide for food	Impacts of human activity
16. A warmer global climate will impact: a) the temperature at the center of the Earth. b) the shape of Earth's orbit around the Sun. c) the amount of fossil fuels available. d) humans and Earth's ecosystems	Climate change effects
17. Likely outcomes of climate change are: a) Ice sheets will grow larger in the Arctic areas. b) The temperature will rise equally around the world. c) Ocean levels will rise, impacting people who live on the coast. d) Earth's atmosphere will thin, especially in the Southern Hemisphere.	Climate change effects
18. Where can scientists see evidence of climate change? a) Evidence can be seen only in areas that experience droughts. b) Evidence can be seen only in the polar areas like Antarctica. c) Evidence can be seen only in coastal areas by the beach. d) Evidence can be seen in all of these areas.	Climate change effects
19. Climate change projections for the future are: a) based on available data and predict future temperature with complete accuracy. b) based on available data and may actually be lower or higher than estimated. c) relatively uncertain because they are based on scientists' opinions, which can be wrong. d) not useful because it is impossible to predict what will happen in the future.	Climate change effects
20. If humans continue to release carbon dioxide (CO2) into the atmosphere at the current rate, ecosystems may be damaged or destroyed. Which of the following actions can reduce the amount of CO2 released by humans? a) Produce less nuclear power b) Drive cars less often c) Use fossil fuel more d) Decrease littering	Mitigation and adaptation strategies
21. Which method below do you think would be the <u>most</u> effective strategy to reduce future damage from climate change to coastal communities? a) Insulate houses and buildings less. b) Switch from nuclear power to fossil fuels. c) Preserve wetlands along rivers and shorelines to absorb storm surge.	Mitigation and adaptation strategies

d) Do nothing since no idea will work because climate change is outside of our control.	
22. Data collected by scientists indicate that the average global temperature is rising and will continue to rise in the foreseeable future. What actions could people in your community take to reduce the negative impacts of climate change? a) Buy organic produce like fruits and vegetables. b) Prevent litter and pollution from entering rivers and oceans. c) Plant more trees or reduce the number of trees being cut down. d) Banning chemicals that break down ozone in the earth's ozone layer.	Mitigation and adaptation strategies
23. Human activities and technologies are being developed around the world to slow the increasing rate of global climate change. What is one direct benefit of changing human behavior and using technology to reduce the impacts of climate change worldwide? a) Coastal areas would be less likely to flood. b) Society will become more dependent on fossil fuels. c) Endangered species will be better protected by laws. d) There would be less cases of skin cancer in humans.	Mitigation and adaptation strategies

Appendix B

Six Americas Survey of Climate Change Concern

1. What do you think? Do you think that global warming is happening? Yes... ...and I'm extremely sure ...and I'm very sure ...and I'm somewhat sure ...but I'm not at all sure No... ...and I'm extremely sure ...and I'm very sure ...and I'm somewhat sure ...but I'm not at all sure Or... …I don't know	Belief
2. Assuming global warming is happening, do you think it is ... Caused mostly by human activities Caused mostly by natural changes in the environment Other None of the above because global warming isn't happening	Belief
3. How much do you think global warming will harm you personally? Not at all Only a little A moderate amount A great deal Don't know	Belief
4. How much do you think global warming will harm future generations of people? Not at all Only a little A moderate amount A great deal Don't know	Belief
5. When do you think global warming will start to harm people in the U.S.? They are being harmed now In 10 years In 25 years In 50 years In 100 years Never	Belief
6. Which of the following statements comes closest to your view? Global warming isn't happening. Humans can't reduce global warming, even if it is happening. Humans could reduce global warming, but people aren't willing to change their behavior so we're not going to. Humans could reduce global warming, but it's unclear at this point whether we will do what's needed. Humans can reduce global warming, and we are going to do so successfully.	Belief

7. How worried are you about global warming? Very worried Somewhat worried Not very worried Not at all worried	Issues involvement
8. How much had you thought about global warming before today? A lot Some A little Not at all	Issues involvement
9. How important is the issue of global warming to you personally? Not at all important Not too important Somewhat important Very important Extremely important	Issues involvement
10. How much do you agree or disagree with the following statement: "I could easily change my mind about global warming." Strongly agree Somewhat agree Somewhat disagree Strongly disagree	Issues involvement
11. How many of your friends share your views on global warming? None A few Some Most All	Issues involvement
12. Over the past 12 months, how many times have you punished companies that are opposing steps to reduce global warming by NOT buying their products? Never Once A few times (2-3) Several times (4-5) Many times (6+) Don't know	Behavior
13. Do you think global warming should be a low, medium, high, or very high priority for the President and Congress? Low Medium High Very high	Preferred societal response
14. Do you think citizens themselves should be doing more or less to address global warming? Much less Less Currently doing the right amount More Much more	Preferred societal response
15. People disagree whether the United States should reduce greenhouse gas emissions on its own, or make reductions only if other countries do too. Which of the following statements comes closest to your own point of view? The United States should reduce its greenhouse gas emissions ... Regardless of what other countries do Only if other industrialized countries (such as England, Germany and Japan) reduce their emissions Only if other industrialized countries and developing countries (such as China, India and Brazil) reduce their emissions The US should not reduce its emissions Don't know	Preferred societal response

Appendix C

Formative Tasks of Critical Climate Awareness

Unit 1 Final Project
Using chemistry to address climate inequality: transportation in LA and the Green New Deal

Introduction

As part of the City of Los Angeles "Green New Deal" to stop or slow the impact of climate change, many projects are proposed to change transportation in the city. To accomplish the goals of the Green New Deal, Mayor Garcetti is partnering with local organizations, many led by people of color.

Mayor Garcetti hopes that half of all new houses/apartments will be built within walking distance (1,500 feet) of transit (bus or train) by 2025 so that people will drive in cars less and use transit more.

One group working to make transit more accessible is called LA Más - they focus on making the walk from your home to a train and then the walk from a train to your job safer and more enjoyable. LA Más thinks that making walking and transit easier, safer and more fun is good for our transportation, good for communities of color and good for climate change.One of their projects is called "Go Ave 26." Avenue 26 is a car-centric area, is extremely difficult to navigate, and represents typical conditions throughout Los Angeles. This project features community engagement and physical design changes that make getting to and from public transit along Avenue 26 easier, safer, and more welcoming.

Part 1: Transportation, Combustion, & Climate Change

1. How is the chemistry of combustion related to transportation?
    a. Describe the chemical reaction for combustion.
    b. What are the steps of the chemical reaction and how do they make cars work?
2. How is the chemistry of combustion related to climate change?
    a. Describe what climate change is.
    b. What specific parts of a combustion reaction can impact the climate?
    c. What does having more cars do to the climate?

Part 2: Reliance on Fossil Fuels

3. Why does our transportation system rely on fossil fuels and what is the impact of that reliance?
    a. What are some good things and some bad things that come from burning gasoline (a fossil fuel) in our cars?
    b. Who is making these choices and decisions about fuels? What are the motivations for the decisions they make?
    c. Who is impacted by these choices and actions? Where is that impact experienced? You can describe both positive and negative impacts.

Part 3: Projects lead by People of Color for People of Color

4. Do you agree or disagree with LA Más that this type of project is good for the transportation system, climate change and communities?

   a. Explain what you agree or disagree with and why you think that way.
   b. Consider addressing the three areas impacted by the project

5. Do you think a similar type project would be helpful in your neighborhood?
   a. Explain what you think would be helpful and how it might change transportation choices that you or your family make.
   b. Or explain why the project would not support any change in your life.

Unit 2 Final Project
Using chemistry to address climate inequality: land use in LA and the Green New Deal

Introduction

As part of the City of Los Angeles "Green New Deal" to stop or slow the impact of climate change, many projects are proposed to change land use in the city. To accomplish the goals of the Green New Deal, Mayor Garcetti is partnering with local organizations, many led by people of color.

Mayor Garcetti hopes that 100% of the city's population will live within half a mile of a park by 2050 so that urban ecosystems can become more resilient and the benefits of parks are more equitably distributed.

One group working to increase green space is called Grown in LA - they focus on converting abandoned lots into parks. They have projects to collect seeds from trees across the city, grow the trees on vacant lots and then transplant them to parks and along streets. Grown in LA thinks that having more parks is good for land use, good for communities of color and good for climate change. One of their projects is to increase the tree canopy cover in Huntington Park from 15% to 17%. They will plant 1,400 trees in parks and along streets with the goal of reducing extreme heat and poor air quality.

Part 1: Land use, Carbon cycle, & Climate Change

1. How is the carbon cycle related to land use?
   a. Describe the chemical transformations (how carbon is changed) of carbon in the earth.
   b. What changes to the surface of land have an impact on the reservoirs and processes that cycle carbon?

2. How is the carbon cycle related to climate change?
   a. Describe what climate change is.
   b. What specific parts of the carbon cycle can impact the climate?
   c. How do changes to land use impact the climate? Give specific examples.

Part 2: Urbanization

3. Why do cities cut down trees and what is the impact of urbanization?
   a. What are some good things and some bad things that come from replacing green space with concrete or buildings?
   b. Who is making these choices and decisions about land use? What are the motivations for the decisions they make?

c. Who is impacted by these choices and actions? Where is that impact experienced? You can describe both positive and negative impacts.

Part 3: Projects lead by People of Color for People of Color

4. Do you agree or disagree with Grown in LA that this type of project is good for land use, climate change and communities?
   a. Explain what you agree or disagree with and why you think that way.
   b. Consider addressing the three areas impacted by the project (land use, climate change and communities) each individually.

5. Do you think a similar type project would be helpful in your neighborhood?
   a. Explain what you think would be helpful and how it might impact your family.
   b. Or explain why the project would not support any change in your life.

Unit 4 Final Project

Using chemistry to address climate inequality:
Extreme heat in Los Angeles and the Green New Deal

Introduction

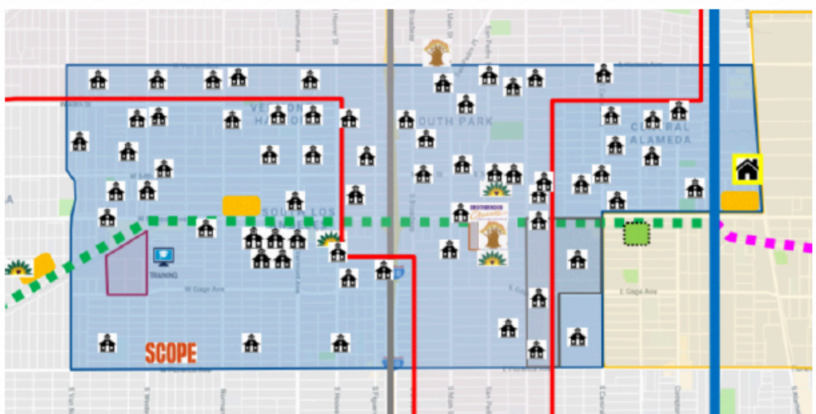
As part of the City of Los Angeles "Green New Deal" to stop or slow the impact of climate change, many projects are proposed to **change energy used in homes.** To accomplish the goals of the Green New Deal, Mayor Garcetti is partnering with local organizations, many led by people of color.

→ *LA Mayor Eric Garcetti*

Mayor Garcetti hopes that the city will use **100% renewable energy by 2045** so that urban ecosystems can become more resilient.

→ *SCOPE LA*

One group working to increase affordable and energy efficient housing is called **SCOPE LA** - they focus on empowering communities in South LA to be part of housing policy decisions. They work to slow down climate change through building affordable and energy efficient housing. SCOPE LA thinks that homes that keep us cool without burning fossil fuels are **good for energy production**, **good for communities of color** and **good for climate change**.



One of their projects is called the Slauson Corridor Climate Commons.

By improving parks, housing, access to jobs and air quality for the 8 square mile stretch of the Slauson Corridor, the **goal is to improve the health of the community and slow climate change.**

Part 1: Energy Use, Greenhouse Effect, & Climate Change

→ Reflection Questions

1. How is the greenhouse effect related to **energy use**?
    a. Describe the science of the natural and human-altered greenhouse effect.
    b. What changes to energy use have an impact on the greenhouse effect?

Type your answers in the box below (you can also use voice type), **or** record yourself talking and share the audio file with Ms. Tieu (**uclatieu@gmail.com**).

2. How is the greenhouse effect related to **climate change**?
    a. Describe the causes and effects of climate change.
    b. What specific changes to the atmosphere link climate change and the greenhouse effect?

Type your answers in the box below (you can also use voice type), **or** record yourself talking and share the audio file with Ms. Tieu (**uclatieu@gmail.com**).

Part 2: Reliance on fossil fuels

→ Reflection Questions

3. How does LA's reliance on fossil fuels to produce energy impact climate change?
    a. What are some **good things** and some **bad things** that come from using fossil fuels ***instead*** of renewable energy to power our homes?
    b. **Who** is making these choices and decisions about energy use? What are the motivations for the decisions they make?
    c. **Who** is impacted by these choices and actions? **Where** is that impact experienced? You can describe both positive and negative impacts.

Type your answers in the box below (you can also use voice type), **or** record yourself talking and share the audio file with Ms. Tieu (**uclatieu@gmail.com**).

Part 3:
Projects lead by People of Color *for* People of Color

SCOPE STRATEGIC COMMUNITY AGENDA

~Reflection Questions

4. Do you **agree** or **disagree** with SCOPE LA that this type of project is good for energy use, climate change and communities?
   a. Explain what you agree or disagree with and why you think that way.
   b. Consider addressing the three areas impacted by the project (energy use, climate change and communities) each individually.

Be detailed about how you made your decision and what influences your thinking.

Type your answers in the box below (you can also use voice type), **or** record yourself talking and share the audio file with Ms. Tieu (**uclatieu@gmail.com**).

5. Slauson Corridor is your neighborhood. Do you think this project will be **helpful** in your neighborhood?
   a. Explain what you think would be helpful and how it impacts your family's energy use.
   b. Or explain why the project would not support any change in your life.

Be detailed about how a group like Grown in LA working to change land use might impact specific features of your community.

Type your answers in the box below (you can also use voice type), **or** record yourself talking and share the audio file with Ms. Tieu (**uclatieu@gmail.com**).

Appendix D

Interview protocol

Interview 1 (pre-interview):
Structured questions:
- How old are you? Where did you grow up?
- How long have you been a student at Mann?
- Where do you hear about climate change?
- How do you talk about climate change with friends or family?
- How do you think climate change effect you personally?
- How do you effect climate change?
- Whose responsibility is it to take action on climate change?
- What kinds of stories do your grandparents or older folks shar about how weather has changed since they were young?

Interview 2 (document-elicitation interview:
With students that completed the formative task after unit 2:
- I review the students writing to identify excerpts where the students wrote about one of the areas of conceptual competencies framework in which they alluded to an idea without fully explaining it or I suspect they have more to say. These areas include:
  - Causes: linking sources of GHG to specific activities or actors
  - Consequences: Who and where climate disruptions are experienced
  - Agency: actors, activities and motivations related to emissions
  - Scale: globalized and localized differentiation of experiences
  - Solutions: mitigation, adaptation, resilience, collective, individual
- For those excerpts, I will read the students writing out loud to them and simply ask them to "tell me more about that"

With students that left the task blank:
- I will give them the task as a conversation rather than asking them to write
- I will read the questions out loud to them. I'll ask to clarify or elaborate with a "tell me more" prompt if they mention something related to conceptual competency framework

Interview 3 (post-interview):
Structured questions:
- How do you talk about climate change with friends or family?
- How do you think climate change affects you?
- How do you affect climate change?
- Whose responsibility is it to take action on climate change?

Semi-structured questions:
- We have talked a lot in class about laws, power, history and justice related to climate change. *How does* what you've learned about these topic influence how you understand the science of climate change?

- We have talked a lot in class about the chemistry related to climate change. *How does* what you've learned about chemistry affect how you understand the laws, power, justice and history of climate change?
- How is chemistry a tool for you in understanding inequality in climate change?

Appendix E

Consent and assent forms

PARENT/GUARDIAN PERMISSION FOR CHILD TO PARTICIPATE IN RESEARCH

Community-Based Climate Change Learning

Graduate student Heather Clark, with Professor Bill Sandoval and colleagues at the Graduate School of Education and Information Studies at UCLA, are conducting a research study to develop and better understand community-based climate change learning.

Your child was selected as a possible participant in this study because of her/his enrollment in a partner teacher's - Ms. Tieu - class. Your child's participation in this research study is voluntary.

Why is this study being done?

This study is intended for university researchers and science teachers to collaboratively design science curriculum that connects science instruction on climate change with students' lives and community assets in order to make instruction more meaningful to students and improve student engagement. The curriculum we design, and what we learn from the implementation and student experiences in the classroom, are expected to inform the broader science education community on how to make climate science instruction more meaningful to students.

What will happen if my child takes part in this research study?

If you agree to allow your child to participate in this study, we would ask him/her to:

- Take part in three 30-minute interviews that explore your child's learning and experience in science class
- Allow researchers to observe classroom activities and collect student work samples
- Allow researchers to video and audio record classroom activities and interviews
- Allow research to share video – with the express permission of your student – with other classmates also participating in this science class

How long will my child be in the research study?

The study will be conducted during the 2020-2021 school year. The normal course of instruction will not be impacted by this study nor will your child's normal participation in class. Your child's contribution to the study is completely voluntary.

Are there any potential risks or discomforts that my child can expect from this study?

The risks associated with the research are minimal and mirror those associated with normal educational practices. However, there is a slight risk that participants will feel uncomfortable being audio or video taped, or that the participants will feel uncomfortable having researcher writing fieldnotes.

Are there any potential benefits to my child if he or she participates?

Your child may benefit from the study as she/he:

- Gain a safe and consistent space where they can exchange ideas about the school's teaching and their learning.
- Help the school improve its science instructional practices and become active stakeholders in school's science education.

Will information about my child's participation be kept confidential?
Any information that is obtained in connection with this study and that can identify you or your student will remain confidential. It will be disclosed only with your permission or as required by law. Confidentiality will be maintained by means of applying pseudonyms to all collected digital data with the code key locked in a locked file cabinet in a locked office. Physical artifacts will also be locked in a locked file cabinet in a locked office.

What are my and my child's rights if he or she takes part in this study?

- You can choose whether or not you want your child to be in this study, and you may withdraw your permission and discontinue your child's participation at any time.
- Whatever decision you make, there will be no penalty to you or your child, and no loss of benefits to which you or your child were otherwise entitled.
- Your child may refuse to answer any questions that he/she does not want to answer and still remain in the study.

Who can I contact if I have questions about this study?
Research Team:
If you have any questions, comments or concerns about the research, you can talk to the one of the researchers. Please contact Heather Clark: (310) 699-5590 or heatherfclark@ucla.edu

UCLA Office of the Human Research Protection Program (OHRPP):
If you have questions about your rights as a research subject, or you have concerns or suggestions and you want to talk to someone other than the researchers, you may contact the UCLA OHRPP by phone: (310) 206-2040; by email: participants@research.ucla.edu or by mail: Box 951406, Los Angeles, CA 90095-1406.

You will be given a copy of this information to keep for your records.

Are you willing to allow your student to participate in this study? ________YES ________NO

SIGNATURE OF PARENT OR LEGAL GUARDIAN

____
Name of Child

______________________________ ______________________________ _____
Name of Parent or Legal Guardian Signature of Parent or Legal Guardian Date

SIGNATURE OF PERSON OBTAINING CONSENT

______________________________ ______________________________ _____
Name of Person Obtaining Consent Signature of Person Obtaining Consent Date

STUDENT ASSENT TO PARTICIPATE IN RESEARCH

Community-Based Climate Change Learning

Graduate student Heather Clark, with Professor Bill Sandoval and colleagues at the Graduate School of Education and Information Studies at UCLA, are conducting a research study to develop and better understand community-based climate change learning.

You were selected as a possible participant in this study because of her/his enrollment in a partner teacher's - Ms. Tieu - class. Your participation in this research study is voluntary.

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What will happen if I take part in this research study?

If you agree to participate in this study, we would ask you to:

- Take part in three 30-minute interviews that explore your learning and experience in science class
- Allow researchers to observe classroom activities and collect student work samples
- Allow researchers to video and audio record classroom activities and interviews
- Allow research to share video – with your express permission– with other classmates also participating in this science class

How long will I be in the research study?

The study will be conducted during the 2020-2021 school year. The normal course of instruction will not be impacted by this study nor will your normal participation in class. Your contribution to the study is completely voluntary.

Are there any potential risks or discomforts that I can expect from this study?

The risks associated with the research are minimal and mirror those associated with normal educational practices. However, there is a slight risk that participants will feel uncomfortable being audio or video taped, or that the participants will feel uncomfortable having researcher writing fieldnotes.

Are there any potential benefits if I participate?

Your may benefit from the study as you might:

- Gain a safe and consistent space where they can exchange ideas about the school's teaching and their learning.
- Help the school improve its science instructional practices and become active stakeholders in school's science education.

Will information about my participation be kept confidential?
Any information that is obtained in connection with this study and that can identify you or your student will remain confidential. It will be disclosed only with your permission or as required by law. Confidentiality will be maintained by means of applying pseudonyms to all collected digital data with the code key locked in a locked file cabinet in a locked office. Physical artifacts will also be locked in a locked file cabinet in a locked office.

What are my rights if I take part in this study?

- You can choose whether or not you want to be in this study, and you may withdraw your permission and discontinue your participation at any time.
- Whatever decision you make, there will be no penalty to you and no loss of benefits to which you were otherwise entitled.
- Your may refuse to answer any questions that you do not want to answer and still remain in the study.

Who can I contact if I have questions about this study?
Research Team:
If you have any questions, comments or concerns about the research, you can talk to the one of the researchers. Please contact Heather Clark: (310) 699-5590 or heatherfclark@ucla.edu

UCLA Office of the Human Research Protection Program (OHRPP):
If you have questions about your rights as a research subject, or you have concerns or suggestions and you want to talk to someone other than the researchers, you may contact the UCLA OHRPP by phone: (310) 206-2040; by email: participants@research.ucla.edu or by mail: Box 951406, Los Angeles, CA 90095-1406.

You will be given a copy of this information to keep for your records.

Are you willing to participate in this study? ________YES _______NO

SIGNATURE OF PARTICIPANT

___________________________________. ________________________________ _____
Name of participant Signature of participant Date

SIGNATURE OF PERSON OBTAINING CONSENT

__________________________ _________________________________ ______
Name of Person Obtaining Consent Signature of Person Obtaining Consent Date

Appendix F

Scope and Sequence of Focal Units

Unit 2 Scope and Sequence

Date	Daily question	Activities	Sociopolitical dimensions	Scientific dimensions
10/20	How is land used in LA?	Guided discussion on land use comparison by neighborhood; guided discussion on abundance and prevalence of carbon everywhere	Humans as part of the environment	
10/22	What is carbon?	Direct instruction on how to use periodic table and defining elements		Performance expectation (PE): use periodic table to predict properties of elements
10/27	How does carbon bond with other elements?	Direction instruction on electrons and bonding		PE: Explain the outcome of chemical reactions based on electron state, periodic trends, and patterns in chemical properties
10/29	What are some chemical reactions that use carbon?	Individual activities on bonding notation, counting atoms; Guided discussion on combustion reactions		PE: Explain the outcome of chemical reactions based on electron state, periodic trends, and patterns in chemical properties
11/3, 11/5	What are some chemical reactions that use carbon?	Carbon cycle choose your own adventure game; direction instruction on photosynthesis reaction	Humans as part of the environment	PE: Explain the outcome of chemical reactions based on electron state, periodic trends, and patterns in chemical properties; Explain

				why atoms and mass are conserved in a chemical reaction
11/10	How does carbon cycle in South LA?	Whole-class consensus model on pre-industrial carbon cycle	Inequality in disrupted climate system	PE: Develop a quantitative model to describe the cycling of carbon Disciplinary Core Ideas (DCI) on weather & climate and Global climate change
11/12, 11/17	How have humans changed the carbon cycle?	Individual activity exploring data on how the carbon cycle has changed; Whole-class activity to localize model for present day	Humans as part of the environment; Sociopolitical driver of greenhouse gas emission	PE: Develop a quantitative model to describe the cycling of carbon; Explain why atoms and mass are conserved in a chemical reaction
12/1, 12/3	What is climate change and what can we do about it?	Guided discussion based in Climate Reality and discussion on local climate changes and LA's Green New Deal	Sociopolitical driver of greenhouse gas emission; Ascribe agency to social actors; Inequality in disrupted climate system; Localize and personalize phenomenon	PE: Analyze geoscience data to make the claim that one change to Earth's surface can create feedbacks that cause changes to other Earth systems
12/8		Critical climate awareness tasks		
12/10 – 12/19	How does land use impact the carbon cycle in my community?	Final model revisions	Sociopolitical solutions to reduce emission	Disciplinary Core Ideas (DCI) on weather & climate and Global climate change

Unit 4 Scope and Sequence

Date	Daily question	Activities	Sociopolitical dimensions	Scientific dimensions
3/2	What aspects of our lives can be affected by heat waves?	Whole-class activity investigating data on heat waves and organizing evidence at different stations	Humans as part of the environment; Inequality in disrupted climate system	Disciplinary Core Ideas (DCI) on weather & climate and Global climate change
3/4	What is the difference between climate change and global warming?	Guided discussion on climate verse weather, climate change verse global warming, and examples of how climate has changed	Humans as part of the environment; Inequality in disrupted climate system	Performance Expectation (PE): Use a model to describe how variations in the flow of energy result in changes in climate DCIs on conservation of energy, weather & climate and global climate change
3/9	How does the sun impact life on earth?	Direct instruction on electromagnetic spectrum		PE: Use a model to describe how variations in the flow of energy result in changes in climate DCIs on conservation of energy, electromagnetic radiation and weather & climate
3/11	Why do some places get hotter than others?	Direct instruction on albedo and urban heat island	Inequality in disrupted climate system; Localize and personalize phenomenon	DCIs on conservation of energy and global climate change
3/18	How are humans making LA warmer?	GHE mechanism guided discussion; Whole-class activity exploring data on what changes increase and decreasing carbon emissions; whole-class activity using Jamboard to document	Sociopolitical driver of greenhouse gas emission; Ascribe agency to social actors	PE: Analyze geoscience data to make the claim that one change to Earth's surface can create feedbacks that cause changes to other Earth systems

		brainstormed climate solutions		
3/23	How are humans making LA warmer?	pHet GHE simulation and worksheet	Sociopolitical driver of greenhouse gas emission	PE: Analyze geoscience data to make the claim that one change to Earth's surface can create feedbacks that cause changes to other Earth systems
3/25	Does inequality play a role in how LA deal with warmer temperatures?	Guided discussion on climate resilience and changes in climate; Whole-class activity answering the years and unit's driving questions; Jamboard documenting personal experiences with extreme heat	Inequality in disrupted climate system; Localize and personalize phenomenon	
4/6	When and why did the GHE change?	Guided discussion on anthropocentrism and indigenous environmental philosophy; problematize "humans" & "all humans" to blame	Sociopolitical driver of greenhouse gas emission; Ascribe agency to social actors	PE: Use a model to describe how variations in the flow of energy result in changes in climate; Use a computational representation to illustrate the relationships among Earth systems and how those relationships are being modified due to human activity
4/8	When and why did the GHE change?	Direct instruction on parts per million as a unit of measurement for atmospheric concentration; Whole-class activity on ways to change domestic energy use; Whole-	Sociopolitical driver of greenhouse gas emission; Ascribe agency to social actors	PE: Evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources; Use a computational

		class activity creating consensus model of GHE		representation to illustrate the relationships among Earth systems and how those relationships are being modified due to human activity
4/13, 4/15, 4/22	How can we slow down climate change?	Direct instruction on tax, subsidy, incentive, discourage; individual activity with EnRoads simulation and worksheet on winners and losers	Sociopolitical solutions to reduce emission; Ascribe agency to actors	
4/27, 4/29	Can climate action really make a difference?	Guided discussion on winners and losers when put two climate solutions in place; direct instruction on causal sequence action to GHE	Sociopolitical solutions to reduce emission; Ascribe agency to social actors	PE: Analyze geoscience data and the results from global climate models to make an evidence-based forecast
5/4, 5/7	What climate actions can lower GHG in LA?	Revise models with electricity lever	Sociopolitical solutions to reduce emission	DCI on global climate change
5/11, 5/13	What climate actions can lower GHG in LA?	Revise models with transportation lever	Sociopolitical solutions to reduce emission	DCI on global climate change
5/20	What climate actions can lower GHG in LA?	Test models with micro-climate data	Sociopolitical solutions to reduce emission	DCI on global climate change
5/25, 5/27		Critical climate awareness task		

References

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