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Critical climate awareness as a science education outcome

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Abstract

This paper presents the argument that climate change should be taught in schools as a sociopolitical and scientific process, and that students should be able to use their science knowledge to think critically about climate change as a social justice issue. A necessary and achievable outcome of science education is critical climate awareness—an understanding of the systems and structures that create and sustain climate change inequities. Through a participatory design research partnership, a high school chemistry course was designed and studied that focused on this outcome. Data from a single group, mixed method pre/postdesign show how a group of Black and Latinx urban youth appropriated critical climate awareness from the curriculum they experienced and how they used this awareness to explain climate change as a scientific and sociopolitical process. The findings show that students became concerned about climate change, if they were not already, and that they improved their knowledge of scientific concepts specific to climate change. In their explanations of climate change, students foregrounded sociopolitical processes that result in changes to physical systems, assigned agency for carbon emissions to diverse social actors in ways attentive to power dynamics, and articulated differences in consequences and solutions based on the racial and socioeconomic demographics of communities. This work has implications for transforming science classrooms into incubators for climate justice.

KEYWORDS

climate change, critical awareness, design-based research, justice-centered science pedagogy, participatory design research

1 | INTRODUCTION

Earth's climate is warming at an unprecedented rate due to carbon-fueled industrial capitalism (UNESCO & UNFCCC, 2016). The resulting disruptions to global climate systems are causing a socioecological crisis that has disproportionate consequences for marginalized and vulnerablized communities (Hickel, 2020). Science education has an obligation to help children and youth understand what is going on in their lives and what is going on with this crisis. Current approaches to climate change education are failing to help learners know what to do with the knowledge and skills they develop in school (Drewes et al., 2018; Holthuis et al., 2014; Neas, 2023). Part of this failure is because the climate crisis is not just a scientific issue—it is a sociopolitical one—but is not taught as such. Climate change education must be recalibrated to align with the reality of inequities and to support action and justice (Sover & Walsh, 2022).

This paper presents an argument that the reason to learn the science of climate change in schools should be to explain climate change as it is experienced and solved in the real-world, that is, as a crisis with sociopolitical and scientific dimensions. I present critical awareness of climate change—or critical climate awareness—as a science education outcome that supports youth in understanding both the scientific and sociopolitical dimensions of climate change. Building on Freire's (1970) general notion of critical awareness, I conceptualize critical climate awareness as an understanding of the systems and structures that create and sustain climate change inequities. Learning environments oriented to critical awareness of socioscientific issues are valuable for all youth but are particularly important for marginalized youth from nondominant backgrounds. This is because problematizing normative science education through attention to power dynamics can support epistemic diversity and justice for these marginalized youth (Birmingham et al., 2017; Davis & Schaeffer, 2019; Morales-Doyle, 2019). Data are presented here on how a group of Black and Latinx urban youth developed critical climate awareness through their engagement in a curriculum oriented to developing this outcome.

1.1 | Challenges of equitable and actionable climate change education

Calls for critical and justice oriented frameworks that teach climate change as a scientific, technical issue as well as a social, economic, cultural, historical, and ethical issue are not new (Kagawa & Selby, 2009; Schlosberg & Collins, 2014; Sharma, 2012). But the demand and momentum around these calls is now the focus of extensive efforts, rising to match the urgency of the climate crisis (Borgerding et al., 2024; Leve et al., 2023; Trott et al., 2023). Balancing efforts to address the climate crisis and ensure equitable science education present distinct challenges. Here I introduce five challenges that motivated me to re-imagine the outcomes of climate change education in the context of schooling and cities in the United States.

First, minoritized students are historically and currently under-served and underestimated in school science classrooms, where deficit perspectives are pervasive (Calabrese Barton, 2003; Medin & Bang, 2014). Many of these youth live in low-income urban communities of color that are hit first and hardest by disrupted climate

(Benevolenza & DeRigne, 2019). Therefore, school-based opportunities to explore this crisis are most absent where they are most needed.

Second, while geophysical data on disrupted climate tell one story of cities, climate change may not be perceived as a reality for urban residents relative to other social and environmental threats (Levinson, 2012). Climate change is identified as a pressing issue by Latinx and Black Americans (Ballew et al., 2020) and youth engagement in climate activism has rapidly increased (Mayes & Center, 2023; Neas et al., 2022), but some youths may not identify climate change as an urgent concern relative to issues like immigration or gun violence (Garcia et al., 2020). Education systems do not yet consider their power in driving public engagement with climate change (Reid, 2019) or their ethical role in bringing "natural systems back to order through compassionate and transformative actions that students can be part of" (Windschitl, 2023, p. 79).

Third, there are difficult questions about who should address the climate crisis through behavioral and lifestyle changes. Should all youth learn to live low-emission lifestyles to ensure a sustainable future? Should youth living in poverty be asked to shoulder the responsibility of undoing damange? Or instead should these youth learn how to change the systems that caused damage (Henderson et al., 2017; Wynes & Nicholas, 2017)? In standardized learning environments, differentiating climate change education by taking into account the diverse identities of students and the histories of their communities presents a signifant challenge.

Fourth are questions of how prepared and empowered teachers are, specifically urban teachers working in underserved communities, to provide the school-based opportunities youth need to engage with climate change in their lives. Teachers often present climate change objectively (Plutzer et al., 2016), while the issues are social and emotional (Burke et al., 2018; Pihkala, 2022) and inextricably intertwined with issues of power and politics, including capitalism, racism, and settler-colonialism (Bang et al., 2022; Ghosh, 2021; Henderson et al., 2017). Frameworks, rationales, and tools to prepare teachers with the pedagogies and perspectives to teach climate change as a trans-disciplinary issue of social justice are emerging but not widely adopted (cf. Beach, 2023; Carman et al., 2021; Learning in Places Collaborative, 2021).

Last, climate change is politically divisive and perspectives on the nature of and solutions to climate change are dominated by worldview (Kahan et al., 2012; Stevenson et al., 2016). This makes addressing just the canonical science concepts contentious for some teachers (Plutzer et al., 2016). During instruction, teachers have been found to deemphasize the political aspects of climate change (Herman et al., 2017). Remediating these cumulative challenges requires critical approaches to climate change education. It is within this context that I conceptualize critical climate awareness as an outcome of science education to address the challenges of the climate crisis and inequitable science education.

1.2 | Science standards as necessary but insufficent to address challenges

Disciplinary, conceptual knowledge is one valuable outcome of schooling and evidence from environmental education suggests that a basic understanding of the scientific concepts behind an issue (e.g., the mechanisms of the greenhouse effect) is important for taking effective environmental action (Robelia & Murphy, 2012). Research has extensively documented students' confusion and misconceptions about the scientific mechanisms of climate change (Breslyn, 2017; Chang et al., 2018; Leiserowitz et al., 2011; Lombardi et al., 2013). 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. Systematic reviews of research (cf. Bhattacharya et al., 2021; Monroe et al., 2017) suggest several strategies to support students in learning canonical climate science concepts such as making climate change relevant through school or community based projects and addressing students' misconceptions through discussions of theirs and others viewpoints.

The Next Generation Science Standards (NGSS) are the first standards to offer teachers the opportunity and incentive to discuss human impacts on the environment, including climate change (NGSS Lead States, 2013). While science education standards inclusive of environmental issues are necessary for teaching climate change, they are insufficient to support transformative education outcomes to match the urgency of the crisis. The persistent and narrow focus on a mastery of disciplinary knowledge as the desired outcome of school science ignores the evidence that simply understanding the scientific principles of the climate system is not enough to support action (Henderson et al., 2020; McNeill & Vaughn, 2012; Stevenson et al., 2016). For all 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 focuses on economic mobility, or preparing youth to participate in science related jobs, over other educational goals (Hoeg & Bencze, 2017). They also prioritize access to educational opportunities as a pathways to equity without interrogating structural inequity to access or representing diverse perspectives (Rodriguez, 2015). The standards also perpetuate neoliberal ideological commitments that ignore the harms that can result from scientific enterprises as well as the unequal distribution of those harms (Morales-Doyle et al., 2019). These features maintain the status quo of science education by ignoring epistemological diversity essential to supporting students from nondominant communities (Bang & Marin, 2015).

Second, the demands of the NGSS pose significant challenges for teachers. Shifting to the new standards entails radical changes, such as organizing curriculum around natural phenomena that require explanation and reorganizing discursive practices within the classroom (Reiser et al., 2017; Reiser et al., 2021). For example, an intervention to support NGSS-aligned learning of the carbon cycle was implemented at 94 schools and researchers found that the schools with the most resources were the most successful and that all partner teachers required substantial investment in material, human, and social resources (Anderson et al., 2018; Covitt et al., 2021). Even with extensive resources and professional development, teachers struggle to make these radical changes, such as supporting productive student dialog needed for authentic engagement in NGSS science practices (Sandoval et al., 2018).

Third, the NGSS are flawed in their conceptualization of environmental issues. The NGSS omit 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 an ontological stance of universalism and an epistemic stance of scientism which combine to exclude the sociopolitical dimensions of issues (Feinstein & Kirchgasler, 2015). Hufnagel et al. (2018) identified how the NGSS include problematic themes in performance expectations, such as the environment existing as an entity separate from humans and ascribing agency to autonomous actions or processes (like combustion or industrialization) rather than to specific social actors. My previous work found that when teachers strive to learn and align their instruction to the NGSS, they can promote these themes in their teaching and disconnect agency for carbon emissions from social actors (Clark et al., 2020). The NGSS do not give teachers and students opportunities to confront the sociopolitical realities of climate change as part of science education. Hodson (2013) warned of the senselessness and harm caused by depoliticized science education because it fails to engage students, as young citizens, in looking “critically at the society we have, and the values that sustain it” and in asking “what can and should be changed to achieve a more socially just democracy” (p. 654). I conceptualize science education for critical climate awareness as building on the NGSS's phenomenologically oriented approach while disrupting the themes in the standards that perpetuate socioecological inequities.

1.3 | Defining critical climate awareness

Critical climate awareness is understanding of the systems and structures that create and sustain climate change inequities. Freire (1970) proposed that critical consciousness develops through a three-part cycle: critical analysis or awareness (gaining knowledge about the systems and structures that create and sustain inequity), sense of agency (developing a sense of capability), and critical action (committing to act). Critical consciousness helps people engage in broader collective struggles rather than experience oppression in isolation and self-blame (El-Amin et al., 2017). Critical climate awareness represents the first part in Freire's cycle. This awareness requires understanding how inequities in climate disruptions form, and linking this with an understanding of how and by whom those inequities are experienced today. Making these connections requires attention to power dynamics across the causes, consequences, and solutions to climate change. Youth with critical climate awareness will understand climate change as a large-scale collective action dilemma (Lundholm, 2019). This study designed for the outcome of critical awareness rather than critical action or consciousness. As contextualized in the next sections, the design team decided that more time and attention would be needed to design for the outcomes that follow awareness in Freire's cycle.

Critical climate awareness is distinct from the range of generative constructs of climate literacy (cf. Azevedo & Marques, 2017; Leve et al., 2023; McNeal et al., 2014; Niepold et al., 2007) partly for its roots in critical pedagogy (Freire, 1970) that firmly orient this outcome towards justice. This orientation is aligned with a distributive view of climate justice that is focused on the disproportionate climate-driven harm experienced by communities that have contributed the least to greenhouse gas emissions but are at the greatest risk of harm due to overall exposure risk and lower adaptive capacity (Ogunbode, 2022; Tayne et al., 2021). I conceptualize critical climate awareness as a building block to critical action while literacies more broadly comprise knowledge, skills, and attitudes that are valued for society as a whole (Leve et al., 2023; Roth, 1992; Valladares, 2021). Marginalized communities face unique climate risks and hazards that are compounded by deep-rooted systemic inequalities. Critical climate awareness was designed to remediate educational inequities experienced by students living in just such a marginalized community.

Science education for critical climate awareness challenges presentations of climate change that lack political context. Understanding the social and political complexities of climate change is a necessary precondition for understanding and addressing the climate crisis (Kagawa & Selby, 2009). Like McGinty and Bang (2016), I agree that climate change education based solely on normative ways of knowing and doing science are “deeply problematic and will serve no one” (p. 474). Climate change education must be epistemically diverse including knowledge and practices from a wide range of interacting disciplines, communities, and systems, including the sociopolitical and biogeochemical. Table 1 summarizes how I conceptualized critical climate awareness in five components that combined represent a scientific and sociopolitical explanation of the climate crisis. Below I explain first the systems and structures of climate change in these components, and then the connections to inequities.

A student with critical climate awareness will understand the systems and structures of climate change inequities, which are scientific (biogeochemical) and sociopolitical (societal influence of culture and norms; political structures and governance; economic systems and conditions). For scientific systems, this definition includes the carbon cycle and the greenhouse effect. The concepts that explain these systems are included in the NGSS. Learning about these two natural systems is represented in “canonical scientific systems” in Table 1.

For the sociopolitical systems, the economic and political conditions and structures that contribute to climate change involve carbon-intensive, extractive infrastructures controlled by capitalist corporations and governments to pursue development and profit-driven agendas. Societal norms that contribute to climate change involve the cultural routines, lifestyles, and structures dependent on cheap carbon-based energy. These sociopolitical dimensions are included in “anthropogenic global warming” and “agency for emissions” components in Table 1. The “anthropogenic global warming” component emphasis that human actions are the primary cause of rising surface temperatures, the key driver of climate disruption. This counters the problematic assumptions of the NGSS that suggest climate change can be disconnected from human behavior and systems (Hufnagel et al., 2018). The “agency

TABLE 1 Five components of critical climate awareness.

Component	Description
Canonical scientific systems	Carbon is transferred to and transformed through the spheres of Earth in biogeochemical cycles, and in the atmosphere carbon dioxide is a greenhouse gas and warms Earth
Anthropogenic global warming	Humans are rampantly emitting greenhouse gases through industrial activities to unbalance the carbon cycle and these emissions trap more infrared radiation to unbalance the greenhouse effect and accelerate atmospheric warming
Agency for emissions	Emissions of greenhouse gases are driven by political, economic, and social motives; systems of power perpetuate a reliance on fossil fuels and limit alternative forms of energy production; all modern-day activities have a carbon footprint, but subsistence emissions are embedded in this fossil fuel-reliant system and luxury emissions are associated with wealth
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 greenhouse gases
Climate change solutions	Urgent, large-scale collective actions can address climate disruptions; prioritizing justice in climate solutions can remediate socioecological inequities

for emissions" component foregrounds thinking about power and privilege by differentiating responsibility for rampant emissions among groups rather than attributing it uniformly to all humans.

The last two components of critical climate awareness address how the consequences of climate change and the responsibility for solutions are unevenly distributed among different communities and social groups. "Distribution of disruptions," the fourth component in Table 1, addresses the distribution of the consequences of climate change. These consequences include (among others) extreme heat, the spread of disease vectors, and sea level rise. Inequality in the distribution of disrupted climate patterns are not explored as simply a geographic issue but as corresponding with socially and economically marginalized populations (IPCC, 2022; Morello-Frosch et al., 2009). I take an intersectional approach in this study to view power as a multidimensional phenomenon encompassing a community's racial and socioeconomic composition (Collins, 2015). Finally, the "solutions" component emphasizes sociopolitical and collective actions rather than technological and individual actions. Collective sociopolitical solutions counter recommendations given in U.S. curricular resources that are low-impact, individual climate mitigation activities, such as recycling (Meehan et al., 2018). Collective strategies, like investing in green energy sources or youth activism (Neas et al., 2022), and justice-oriented actions, like supporting Indigenous land sovereignty and cultivating reciprocal human–nature relations (Marion Suiseeya et al., 2022), can be more high-impact and transformative. The "solutions" component in this study is limited to awareness of solutions as this design did not support students in engaging in actions. This guiding definition is based on the needs, demands, and assets of my context, as described in the next section, and is not necessarily comprehensive or appropriate for all contexts.

In this paper, I describe the high school science course designed to help students develop critical climate awareness and the outcomes of students' participation in this course. The outcomes include learning canonical climate science concepts, becoming concerned about climate change, and becoming critically aware about climate change. I ask: how did students appropriate critical climate awareness from the curriculum they experienced? And how did students explain climate change as a scientific and sociopolitical process?

2 | METHODS

2.1 | Research context and positionality

This research was conducted during the academic year of 2020–2021 while all instruction was remote due to the COVID-19 pandemic. I worked at the Mann UCLA Community School, a Grades 7–12 Title 1 public school located in a low-income neighborhood of South Los Angeles in Los Angeles, California, United States. In the context of Los Angeles, the political divisiveness of climate change was not an issue, and there was strong support at the school, district, and state level to teach climate change science as well as the sociopolitical dimensions. The school follows a community school model and has been in a partnership with UCLA since 2016. The participants in this study were 33 tenth grade students in two sections of chemistry class. Demographically, the students were 52% African American and 48% Latinx with 22% bureaucratically designated as English Language Learners; all students were from low-income families qualifying for the federal free and reduced-price meal program. The logistics and dynamics of remote learning resulted in less instructional time than a typical school year and fewer disciplinary core ideas being included in the curriculum. Forms of engagement were also different with students preferring to participate via the Zoom chat.

My methodological approaches were design-based research (DBR, Brown, 1992; Gravemeijer & Cobb, 2006; Sandoval & Bell, 2004) and participatory design research (PDR, Bang & Vossoughi, 2016). From the DBR tradition, I was simultaneously committed to a constellation of research outcomes: the production of an innovative climate change learning environment, knowledge about how the environment worked in the urban classroom setting serving minoritized youth, and more fundamental knowledge about learning and teaching climate change as political and ethical endeavors. I also engaged in iterative analysis to refine the design followed by a retrospective analysis to construct the findings (Cobb et al., 2003).

From the PDR commitments, I attended to how “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). I worked in a research-practice partnership (Penuel, 2017) to co-design the chemistry class with my teacher-partner, Ms. T, who is a young Vietnamese American woman and was in her third year of teaching during this study. When I refer to “we” in this paper, I am including myself and Ms. T as we conceptualized the design and outcomes together. Ms. T and I collaboratively redesigned her chemistry course over 3 years, starting with designing one unit on climate change science during the 2018–2019 school year, and iteratively refining and expanding the design to eventually develop a year-long curriculum. During the 2020–2021 school year of this study, we met weekly to plan activities, debrief implementation, and revise activities. As aligned with PDR, we developed a reciprocal process of partnering by explicitly positioning us both learners and investigators to share power (Kyza & Agesilaou, 2022). Through these efforts, we built a shared community of practice with stable roles, norms, and language that elevated Ms. T's perspective in deciding what counted as a good activity or learning outcome.

My positionality shapes my work to remediate issues of power and privilege that are re-produced in science education and that perpetuate environmental injustice. I am part of communities that have emitted the most greenhouse gases but have the greatest resilience and resources to adapt. As a White[1] child and now woman in schools and communities with such resilience and resources, I share few lived experiences with the youth at Mann UCLA Community School. The spark for my thinking about critical climate awareness occurred while reading Naomi Klein's (2015) “This changes everything: Capitalism vs. the climate” and preparing my own high school students to take the AP Environmental Science exam. My students lamented that some colleges gave social science credit for the exam instead of science credit because the course was seen as too heavy on history and policy concepts relative to science concepts. But Klein's powerful argument for thinking about the roots of climate change in the histories of inequitable social systems made me want to teach these dimensions more. Over the years before I met Ms. T and then throughout our partnership, I solidified my commitment to politicized, interdisciplinary climate change education. I now work as an outsider and ally in underserved schools, listening to, learning from, and amplifying the voices of students and teachers. I am committed to leveraging my privileges as a White academic and my training as a Learning Scientist to pursue environmental justice and educational equity. My designs and research are anchored in the perspective that learning science concepts and practices can and should open generative and joyful ways of making sense of the world. To make that possible, classrooms must be spaces of epistemic diversity and intellectual respect (Rose, 2014) and all adults need political clarity (Vakil & de Royston, 2019). Working in the PDR framework helps me foreground these commitments as I continually develop my own political clarity.

2.2 | Design overview

This research is based on a year-long study of the co-designed chemistry course that engaged students in the overarching question of "How can we use chemistry to explain inequities in climate change?" Table 2 presents a summary of the curricular sequence for the year. There were five units, with unit zero representing a 2-week period of community building, framing of the academic year, and elicitation of student wonderings. The next four units are modified versions of the instructional segments in the California NGSS Framework (Science Framework for California Public Schools, 2016). Specifically, we modified the units with localized phenomena informed by students' questions and wonderings.

I focus on Units 2 and 4 as the focal units that addressed climate change-specific phenomena (see Supporting Information Materials SA for the complete activity sequence of both units). The guiding question of Unit 2 was, "How does land use in Los Angeles impact the carbon cycle?" The phenomenon of investigation was the lack of parks in Los Angeles, which decreases carbon reservoirs. 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. Conceptually, the unit addressed the chemistry of the natural and disrupted carbon cycle, carbon's chemical reactions, and land use strategies for mitigation. Students worked throughout Unit 2 to create and revise models that layered land use changes, issues of equitable access to greenspace, and the mechanisms of the carbon cycle.

TABLE 2 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 phenomena (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 neighborhoods	Why aren't we using used vegetable oil to fuel our cars?
2. Carbon is transformed and transferred and is always conserved (Oct–Dec 2020)	Land use in Los Angeles, including the lack of parks, decreases the carbon reservoirs of the city	How does land use in Los Angeles impact the carbon cycle?
3. Energy change in chemical reactions shows the change in chemical bonds (Jan–Feb 2020)	Different chemical reactions produce different temperature changes	What chemical reactions are happening all around me?
4. Human activity has altered climate systems (Mar–May 2021)	Carbon-dependent infrastructure has unbalanced the greenhouse effect	What are the impacts of Los Angeles getting hotter?

The guiding question of Unit 4 was, "What are the impacts of Los Angeles getting hotter?" The phenomenon of investigation focused on how Los Angeles' dependence on carbon-based fuel for transportation and electricity has disrupted the greenhouse effect, leading to more frequent and intense of extreme heat events that disproportionally affect marginalized communities. The unit was oriented to students' lived experiences with extreme heat and the technologies they use everyday that directly or indirectly emit carbon. Conceptually, the unit focused on the mechanisms of the greenhouse effect, greenhouse gas chemistry, and the causes and solution to extreme heat. Students worked throughout Unit 4 to create and revise models that layered emission-reduction actions in their neighborhood, experiences with extreme heat, and the mechanisms of the greenhouse effect.

2.3 | Data sources

I used a single group pre/postdesign (Shadish et al., 2002). Students took three types of assessments or tasks, two given at the beginning and end of the year and one as a formative end-of-unit task given after Units 2 and 4. First, I assessed conceptual disciplinary knowledge using two previously validated instruments. The first instrument was the Climate Science Content Knowledge Assessment designed for middle and high school age students (Drewes et al., 2018). This consists of 18 multiple-choice questions across four scales: mechanisms of the greenhouse effect, climate change effects, impacts of human action, and mitigation and adaptation strategies. The second instrument is a subset of six questions on energy trapping properties (radiative forcing) of greenhouse gases from the Visualizing the Chemistry of Climate Change Project (Versprille et al., 2017). These instruments were administered to students as a single assessment, given at the start and end of the school year. Twenty-five of the 33 students completed both pre- and posttests, which is the sample used for statistical analysis.

The second assessment was the Six Americas survey that measured climate change concern and beliefs (Maibach et al., 2009). I used the 15-question version of the survey that has been widely used nationally and tested for reliability with a representative sample of over 15,000 Americans, and has been validated with adolescents (Holthuis et al., 2014; Shea et al., 2016). Questions are on four topics: global warming beliefs, issue involvement, climate-related behavior, and preferred societal response. The survey results describe student views on climate change on a spectrum of six profile types that include alarmed (highest belief in global warming, most concerned, most motivated), concerned, cautious, disengaged, doubtful, and dismissive (lowest belief in global warming, least concerned, least motivated). Thirty of the 33 students completed both pre- and postsurveys, which is the sample used for statistical analysis. We informed students that these were an ungraded and anonymized surveys to guard against them feeling compelled to provide unauthentic responses.

Third, we developed a formative task as an end-of-unit assessment to assess critical climate awareness. For each unit, the task was tailored to the specific concepts and themes of the unit (e.g., carbon cycle vs. greenhouse effect) but the tasks were isomorphic (see Supporting Information Material SB for the task given after Unit 2). The task was an opportunity to explain climate change with prompts to elicit student thinking about the scientific, sociopolitical, and critical dimensions of climate change. The prompts asked students about Los Angeles' Green New Deal and the activities of various organizations working to meet the targets in that proposal. Fifteen of 33 students completed the Unit 2 task, and 17 students completed the Unit 4 task. Eight students completed both tasks and 26 completed at least one.

Given the multilingual student population and challenges of participation during the pandemic, several multimodal options were implemented to support students in completing assignments. First, the formative task was translated to Spanish and bilingual students were invited to respond in Spanish. Second, all students were given the option to type or record a voice memo of their responses. Third, students were given the opportunity to meet after class and complete the task as a conversation in which Ms. T or I read the question and then typed the students' response for them, clarifying prompts when needed ($n = 2$ students opted for this modality). In addition, for students that assented to participate in interviews as part of the broader study ($n = 12$, with parental consent), I conducted document-elicitation interviews on the Unit 2 task ($n = 9$ participated). In these interviews, the student and I reviewed their writing on the task together and using the simple prompt of "please tell me more about this" I asked them to elaborate on parts of their writing that touched on a component of critical climate awareness. I used these interviews as an extension the tasks, adding interview transcript to written responses, and therefore interview data were analyzed as part the formative tasks.

2.4 | Analytical approach

The pre- and postassessments of conceptual knowledge were scored for the number of correct responses for the total assessment and for the 5 sub-sections. Change in the mean score between the pre- and posttests was measured with a paired *t*-test in the Statistical Package for the Social Sciences (SPSS). Holm's sequential Bonferroni procedure was employed to correct for familywise error due to the testing of multiple hypotheses (i.e., the multiple subsections) which sequentially calculated alpha significance values for each sub-subsection of the assessment (Holm, 1979; McLaughlin & Sainani, 2014). Effect sizes for paired samples were generated in SPSS and interpreted via Cohen's *d* guidelines for instructional effects (Cohen, 1992).

The pre- and post-Six Americas surveys were scored with a SPSS syntax for discriminant analysis based on the guidelines provided by the original authors. This analysis assigned each student a numerical value that ranged from 1 (alarmed) to 6 (dismissive) to identify their profile type (Maibach et al., 2011, 2009). To identify change over time in the profile types, I used a Wilcoxon signed-rank test. This statistical test was ideal because the variables are ranked in order of strength of belief and engagement with climate change issues, and because the data were non-normally distributed.

The formative task was the instrument used to assess students' explanations of climate change and how they expressed critical climate awareness in those explanations. Student responses were analyzed with a coding framework that organized the major components of critical climate awareness (Table 3). This framework assessed the extent to which each component of critical climate awareness was articulated and warranted in students' tasks, adapting a framework for assessing the conceptual quality of science explanations (Sandoval, 2003; Sandoval & Millwood, 2005). Coding with this framework took place in three phases. First, in NVIVO I created a high-level code for each of the five components of conceptual quality and then used structural coding to index students' responses into these five components (Saldaña, 2014). Second, I printed out all the coded excerpts and sort them by hand based on the topics and themes that students mentioned. The goal of this step was to move from the a priori categories to a more inductive approach to understand the forms of student thinking within each component of critical climate awareness. The assessment task demanded the coordination of the scientific and sociopolitical dimensions of climate change, so analysis focused on how students coordinated claims, evidence, and justification to articulate relations between human actions, power dynamics, and biogeochemical processes involved in climate change. I wrote interpretations of the students' work on the printed excerpts and interpreted data with grounded theory (Charmaz, 2006; Glaser & Strauss, 1967). Through an iterative process, I compared excerpts to generate, collapse, and expand codes. These findings were discussed with Ms. T in conversations oriented to interpretative validity (Johnson, 1997). Her contribution refined how I interpreted the students' appropriation of classroom experiences. Ms. T's review principally shaped the "agency for emissions" component by helping to refine the three codes. Third, I finalized the codebook presented in Table 3 and input these final codes into NVIVO to facilitate code comparison and data visualization.

TABLE 3 Codebook for conceptual quality in formative task.

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 influences and political structures modify climate systems; description of emissions can be localized and specified with sources	Canonical description of the physical mechanisms of global warming, including emissions and land use; identifiable sources of emissions Sociopolitical mechanisms of global warming, including influence of cultural and societal norms, governance and policy making, economic conditions Naïve description of global warming
Agency for emissions	Human decisions, actions and structures modify climate systems; agency is ascribed to specific actors; motivations for emissions can be linked with specific benefits to those actors	Ascribe agency to an actor including corporations, government, scientists, humans/all people, we/us, and powerful individuals Ascribe agency to an action Describe a motivation for emissions including development, power, and profits
Distribution of disruption	There are inequalities in the distribution of consequences; there are a wide range of consequences; inequities 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/groups that experience consequences including humans/all people, we/us, low socioeconomic, me/my family, people of color Describe locations/communities that experience consequences including our community, polluted communities, socially vulnerable
Solutions	Describe how to address climate change; climate change is a large-scale collective dilemma; adaptation, mitigation, and resilience building are all possible in communities; co-benefits of climate action for social justice	Describe mitigation solutions including zero-carbon electricity production, reforestation, and zero-carbon transit system Describe resilience building solutions Describe actors engaged in solutions

3 | FINDINGS

Findings are presented in three parts to reflect the outcomes of interest. First, descriptive statistics on the Six Americas survey show the extent to which students became concerned about climate change. Second, descriptive statistics on conceptual knowledge show improvements in climate change science knowledge. Third, and most importantly, the outcome of critical climate awareness is described with evidence on how students used their science knowledge to think critically about the sociopolitical dimensions of climate change.

3.1 | Changes in concern about climate change

Results of the Six Americas survey show that all six profile types were present among the students before instruction. Attitudes of doubtful and dismissive were not present after instruction, reflecting an increase in concern over time (profile types are based on the original survey authors' suggestions, see Maibach et al., 2009). Figure 1 displays the shift towards the attitudes of cautious and concerned over time. The Wilcoxon signed-rank test shows that the posttest scores were statistically significantly lower (more concerned) than the pretest scores ($Z = 20$, $p = 0.036$).

3.2 | Changes in conceptual knowledge

Results of the conceptual knowledge assessment show that out of 24 possible points, students scored an average of 8.2 points on the pretest compared to 10.9 points on the posttest with a statistically significant increase of a mean of 2.8 points ($t = -4.84$, df = 24, $p \leq 0.001$). Results also show a large effect size ($d = 0.89$) representing a large difference between the two time periods with a large percent of the pretest scores below the mean of the posttest scores. Table 4 includes the pre- and posttest 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.

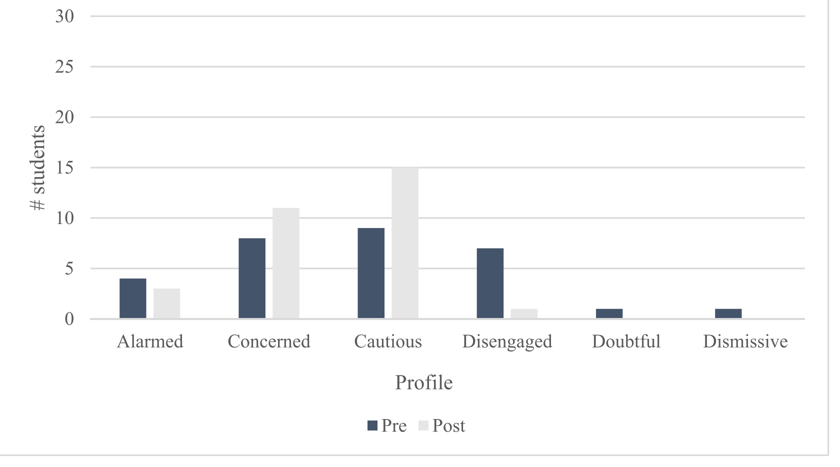

FIGURE 1 Distribution of Six Americas profile types in pre- and postsurveys ($n = 30$).

TABLE 4 Climate science knowledge assessment scores from beginning to end of school year ($n = 25$).

Test section	Max	Pretest mean (SD)	Posttest 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*	0.008	0.89
Chemistry	6	1.61 (1.16)	2.23 (1.47)	−1.71	0.100	0.013	0.34
Mechanism	4	1.61 (1.20)	3.50 (0.51)	−1.41	<0.001*	0.010	1.60
Impacts	5	2.03 (1.50)	2.19 (1.52)	0.44	0.603	0.013	0.10
Effects	4	1.46 (1.10)	2.04 (0.99)	−0.06	0.209	0.013	0.45
Adaptation	5	1.61 (0.85)	2.12 (1.53)	0.16	0.139	0.013	0.30

Note: Holm threshold is a sequentially calculated alpha significance values.
*Unadjusted *p* values are statistically significant.

3.3 | Articulation of critical climate awareness components in the formative task

Table 5 presents the number of students who articulated various dimensions of each component of critical climate awareness on Task 2 and Task 4. Many of the codes associated with the various components were rarely identified while others were identified in about a third of the students. In the following sections, I present excerpts to show the three most common ways students addressed these components. First, from the "anthropogenic global warming" component, seven students explained how social and political processes change physical system. Second, from the "agency for emissions" component, students ascribed agency in two broad ways with 13 students ascribing agency universally to all humans and 11 students differentiating agency based on power. Third, from the "distribution of disruption" and "solutions" components, 12 students explained differences in climate consequences and solutions based on racial and socioeconomic demographics of communities. I start each section below with a description of designed activity structures that students engaged in as context for how and why they came to explain climate change in these ways.

TABLE 5 Components of conceptual quality mentioned by students across critical climate awareness tasks.

Components of conceptual quality	Task 2 ($n = 15$)	Task 4 ($n = 17$)	Total students[a] ($n = 26$)
Canonical climate systems			
Canonical greenhouse effect	NA	4	4
Canonical carbon cycle	3	NA	3
Anthropogenic global warming			
Physical mechanisms	10	9	14
Sociopolitical mechanisms	3	7	7
Agency for emissions			
Actor: All humans (universal)	9	13	13
Actor: Corporations (differentiated)	3	2	3
Actor: Government (differentiated)	6	10	11
Motivation: Profit	4	5	8
Motivation: Development	6	4	9
Distribution of disruption			
Low socioeconomic status	3	3	3
People of color	0	3	3
Me, my family, my community	10	5	10
Social vulnerability	4	7	7
Solutions			
Reforestation	5	NA	5
Low-carbon electricity generation	NA	8	8
Resilience	0	4	4

[a]The number of unique students who articulated a component of conceptual quality in at least one of the tasks and thus is not simply a sum of the other two tasks. Twenty-six students completed at least one task.

3.3.1 | Foreground sociopolitical mechanisms of change to physical change

Students made connections between the biogeochemical, social, and political dimensions of transportation, land use, and energy production in causing global warming. As an example of a classroom experience that engaged students in thinking about these connections, here I share an interaction from Unit 4 when students learned about the greenhouse effect. Ms. T facilitated participation structures that put students in the role of predicting global temperature change. In a series of lessons using two simulations—Climate Interactive's En-ROADS simulation of global temperature (Climate Interactive, 2023) and PhET's simulation of the greenhouse effect (PhET Interactive Simulations, 2023)—students explored government decisions about energy production that changed atmospheric carbon dioxide concentration and global temperature. For example, how investments or economic policies like subsidies or taxes could increase or decrease the use and production of different sources of energy. While engaging with the simulations, Ms. T introduced political and social levers of change in energy production that students could "pull" to change projected temperature. In these interactions, she directed students' attention to the power dynamics relevant to the levers. For example, Ms. T politicized fossil fuel reliance and greenhouse gas emissions from combustion. She named economic and social motives, like the profits of corporations or savings for governments, that restrain transitions to alternative energy use. As students worked through the simulations and explored "pulling" various levers, their role of predicting temperature change required that they consider these social, political, and economics dimensions in various scenarios. In making visible the scientific and sociopolitical processes in anthropogenic warming, she encouraged students to appropriate this classroom norm as they learned about the causes of global warming.

I now present excerpts to show how students explained climate change drawing on their critical awareness of anthropogenic global warming. These students came to understand scientific processes of change in biogeochemical systems as linked to societal norms and political structures. For example, Destiny (all student names are pseudonyms) described fossil fuel combustion in the transportation sector as a key source of carbon emissions that causes global warming, and she situated the reliance on gas-powered, personal cars in a complicated social system. She wrote,

> Climate change happens based on what is happening on earth, such as the heat increasing because of us using fossil fuels. Climate change is also happening because of us using cars. We use cars so we can get to places faster but burning fossil fuels in our cars releases carbon dioxide a greenhouse gas that traps heat in the atmosphere and leads to global warming. *Destiny, task 2*

Destiny explained the chemical process of combustion in a gas-powered vehicle contributing to climate change. She linked this process with the social benefit of a convenient transportation system that she values. In another example, Elle outlined pros and cons of fossil fuel reliance. She wrote,

> Fossil fuels are very beneficial for humans. With fossil fuels we get electricity and things that we need. Although fossil fuels are very beneficial it is causing more harm than good to our environment. It has increased the amount of carbon dioxide going into the atmosphere which is causing temperatures to rise. As the temperature rises it is causing climate change to ruin our Earth. *Elle, task 2*

Elle linked the mechanism of warming to a reliance on fossil fuels for its benefits like electricity but argued that the cons outweigh the pros. In another example related to fossil fuels, Zuri 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 carbon dioxide 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. *Zuri, task 4*

In Zuri's definition of climate change, she explained “our daily use” of fossil fuel reliant technology as part of modern life and the mechanism of change to the physical systems of the atmosphere. These excerpts represent appropriation of the designed focus on how social systems and norms are part of the mechanisms of change in climate systems.

Students also foregrounded the sociopolitical mechanisms of change that decrease carbon reservoirs through land use. For example, Vicki described the negative impacts she sees from anthropogenic changes to the carbon cycle when 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 [the land] 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. Things that are being built are homes, jobs, stores, schools, highways, streets, etc. Climate change is where it impacts extreme heat, more hurricanes, huge storms, more fires, more diseases, and it affects our water and food supply. The carbon cycle affects it all because it causes most of this because there is too much carbon in the air. The greenhouse effect is happening because with the carbon, water, and methane being trapped in the atmosphere it causes Earth to heat up which causes climate change. Changes in land use like factories, cars, human population, etc. that use carbon impact us in a great way. It affects us horribly and will cause these things to get worse. *Vicki, task 2*

In this explanation, Vicki described land uses changes that built the urban infrastructure she knows and relies on shifting carbon from the biosphere to the atmosphere with deleterious effects. Her writing links societal decisions about urbanization and deforestation to the processes of global warming. In another example, Zuri described the carbon cycle when 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 impact 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 impact the climate because since there are more humans than ever, more trees are being cut down to make way for more infrastructure. These trees not 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. *Zuri, task 2*

Zuri explained that the carbon cycle includes canonical, scientific components like the processes of photosynthesis, respiration, and decomposition, but she also wrote that factories, cars, deforestation, land use, and fossil fuel extraction are part of the carbon cycle. Zuri's use of evidence from anthropogenic processes in social and political systems positions the scientific, social, and political dimensions of climate change as linked. These students foregrounded social and political processes as mechanisms in anthropogenic global warming, forming a foundational layer of understanding the systems that create climate change inequity.

3.3.2 | Assign agency for emissions as both universal and differentiated

Students explained the causes of climate change by ascribing agency for carbon emission to specific social actors and to human decisions, actions, and systems. There are two ways that students described who emits carbon and why: some students adopted a power-laden perspective to argue that agency lies with governments and corporations, which I describe as a differentiated perspective. Other students explained that all humans—including themselves—are responsible for emissions, which I describe as a universal perspective.

Ms. T's instruction embodied both universal and differentiated agency, and below I present examples of her discourse patterns to illustrate students' engagement with both variations. A universal perspective was the most common narrative adopted by Ms. T in Unit 2 while exploring the carbon cycle, and the differentiated perspective became more prominent in Unit 4 while teaching the greenhouse effect. In Unit 2, while facilitating students' modeling of the carbon cycle, Ms. T consistently positioned herself, students, and all humans uniformly as altering fluxes of carbon (emitting carbon through activities that require energy) and reservoirs of carbon (cutting down trees thereby decreasing photosynthesis). She launched a day of revising explanatory, diagrammatic models of present-day Los Angeles by saying, "Today we are going to add to our model what humans are doing" and then "You all live here, and you all live in the present day, so you know what this model needs to be better." Ms. T then used an activity structure designed to elicit participation in the Zoom chat; she asked targeted questions about the carbon cycle which students responded to in the chat, and she evaluated and revoiced with elaborations and in academic language. For example, Ms. T asked for human-driven changes to carbon fluxes and reservoirs and students responded with "we pollute," "we eat plants," "we extract crude oil," and "fossil fuels we dig them up." Ms. T responded by saying, "Yes, we need energy, so we use fossil fuels to power our cars and cook and heat our homes." In these interactions and others, Ms. T used the phrases we, us, our, people, humans, and society to position herself, students, and all humans as part of the carbon cycle, and in students' responses they used "we" universally as well.

In contrast, in Unit 4 Ms. T's discourse patterns also included the differentiated perspective that more often named specific social actors, contextualizing and historicizing emissions. For example, she facilitated a class discussion exploring the question, "The greenhouse effect has only recently changed, but humans have been around for a long time, so what changed?" In this class, Ms. T shared differences between anthropocentric relationships with nature and Indigenous, reciprocal environmental philosophies. This discussion engaged students in differentiating agency as a function of history, culture, and power to position responsibility for emissions in colonial-capitalist systems rather than with all humans uniformly. In another example, Ms. T reflected on her own role in the climate system to problematize her personal emissions. She said, "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." This comment worked to position her choices in a constrained system where some actors, like large corporations, are responsible for rampant emissions. In contrast, individual decisions, like driving a gas-powered vehicle, are made based on limited economic options. These discourse patterns illustrate how the curriculum provided students opportunities to consider roles and power dynamics in greenhouse gas emissions.

Of the 26 students that completed at least one of the tasks, 13 assigned agency for emissions to humans universally and 11 ascribed agency to the government, corporations, or other wealthy entities thereby differentiating based on power. Below are examples from Julia, Elijah, and Laila in which they take a differentiated perspective:

> The people who make choices about land use are city councils and business owners. The motivations for the decisions is to have businesses so they make money and to give us places to visit. *Julia, task 2*

> The government makes choices about land use. I don't really know who is in charge like with everything that has been going on since we got a new president. I mean, it might change now. *Elijah, task 2 interview*

> The mayor is in charge and he does what he thinks is best. He might think fossil fuels are the best choice. In government, people do things that are bad for the planet because those choices are cheaper. I don't want to be rude but people do stuff like that. *Laila, task 4*

In these excerpts, the government and businesses represent entities of power and students are differentiating agency in causing climate change by ascribing blame for greenhouse gas emissions based on that power. While Julia and Laila described the local government, Elijah spoke to the federal governments' power as he described his own confusion about decision making following the presidential election in 2020. In another example, Zuri named several actors and explicit motivations around fossil fuel reliance and emissions when she explained,

> I can't really think of the good things that come out of using fossil fuels instead of renewable energy to power up our homes because since fossil fuels are non-renewable, we have to keep fracking the ground to keep on getting more which is really bad for the environment. The government, big corporations, and people with a lot of influence make the choices and decisions about energy use and they are mostly motivated by the amount of money and power those decisions could bring. However, mostly people of color living in low-income neighborhoods are impacted by these actions since there are less parks or trees or even resources to help and protect them against the excessive amount of carbon dioxide being released into the atmosphere. *Zuri, task 4*

This example of critical climate awareness in the component of agency for emissions linked specific benefits of carbon emissions to actors with power, and explained the inequities experienced by marginalized communities as perpetuated by the profit-driven motivations of those in power.

In contrast, other students took a universal perspective. For example, Lucia wrote on Task 2, “We take carbon out of the ground which is fossil fuel and it ends up being released into the atmosphere,” and Matthew wrote on Task 2 “We use a lot of energy on a day to day basis and that causes CO_2. Using gas and fossil fuels and energy creates more CO_2.” These students used “we” in undifferentiated ways. Matthew's use of “we” may include himself since he certainly does use energy everyday, but Lucia's use of “we” cannot include herself since she does not personal extract fossil fuels from the ground. These examples of universal agency broadly implicate all humans uniformly in greenhouse gas emissions. In another example of a universal perspective, Vicki wrote,

> Some good things about concrete [are] we use it to build shelter and places to work and walkways and places to travel on. Some bad things are we take away plants and grass and animal[s'] habitats and replace it with concrete. Some good things about buildings [are] that they provide us shelter and places to eat, work, sleep, etc. some bad things are again it takes away plants, trees, grass, and habitats. *Vicki, task 2*

It is unclear in Vicki's writing who are the actors making those decisions and what she thinks about her own relationship to and within decision-making systems. These examples of critical climate awareness in the component of agency for emissions illustrate the diversity of student thinking about the causes of climate change and responsibility for emissions.

Ms. T's discourse patterns included universal and differentiate perspectives and she modeled ascribing agency in both ways. A universal perspective did not problematize relationships to power underlying emissions but in adopting this perspective, students did position themselves as part the climate systems. A differentiated perspective surfaced power dynamics that constrain the agency of marginalized individuals or groups in decision making about emissions.

3.3.3 | Surfacing race and socioeconomic status in consequences and solutions

Critical climate awareness includes describing local variations in the consequences of global warming, the inequities of those local variations to marginalized communities, and possible remediating actions. Twelve students explained inequities in the distribution of climate disruption by describing the disproportionate burden on people of low socioeconomic status, people of color, themselves (described as me, my family, or my community), and socially vulnerable communities. These explanations embody the "distribution of disruptions" component of critical climate awareness as they make explicit links between the geographic location of climate change's consequences and inequities experienced by communities in those places. In addition, some students named actors involved in addressing these disparities, part of the "solutions" component. These explanations link the need for mitigation actions to the community's racial or socioeconomic characteristics.

A series of activities were designed to draw students' attention to inequalities in climate change consequences, and relevant solutions, at the end of each unit. Ms. T engaged students in exploring the work of local non-profits addressing disparities in Los Angeles as part of the city's Green New Deal partnerships. These groups focused on issues like turning abandoned lots into parks, advocating for affordable, energy efficient housing, and addressing "first mile, last mile" transportation issues to ensure walkability around transit hubs. The activity structure at the end of each unit included: Ms. T describing a target in Los Angeles' Green New Deal that a local non-profit's work supported, students exploring what specific aspect of the climate system was impacted by the work, and students reflecting on the impact of the non-profit's work in their neighborhood. These activities then connected to the formative tasks that asked students to discuss the impact of these groups on their neighborhood. For example, Ms. T facilitated a discussion on a non-profit called Grown in LA and their work focused on the social and environmental impacts of having more abandoned lots than parks in Los Angeles. In another activity, Ms. T introduced the impact of the non-profit SCOPE's (Strategic Concepts in Organizing and Policy Education) on affordable, energy-efficient housing.

As students explained climate change in the formative tasks, they described the burden of climate disruptions in their community and the lack resources to be resilient during extreme climate events like heat waves. Students' explanations of the consequences of climate change described who, where, and why disruptions were experienced. Below are examples from three students that argued the work of the local non-profits was needed because the burden of climate change is disproportionately experienced in communities of color:

> I think [helping our community plant more trees is] 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 is 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. *Sonia, task 2 interview*

> I agree with SCOPE because it can be of good use to the environment. Not every person of color is able to make important decisions to help the earth. With this 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. *Destiny, task 4*

> Seria una buena idea ya que tienen pocos recursos y las malas condiciones por estas zonas. Como por ejemplo la contaminación. En las zonas gringas hay muchas cosas que se merecian en las zonas afroamericanos y latinos. ([Planting trees] would be a good idea since there are few resources and bad conditions in [urban communities]. For example, pollution. In the [English speaking-American/

White] areas there are a lot of things that deserve to be in the African American and Latino areas). *Samuel, task 2 interview*

In these examples, Sonia drew on her first-hand experiences living in different neighborhoods in Los Angeles to describe how power, specifically White privilege, partially explains the burden of climate change on communities like South Los Angeles. Destiny described disenfranchisement and social vulnerability of people of color in climate change mitigation decision making. And Samuel argued for environmental justice in remediating exposure to hazards and access to greenspace. Sonia, Destiny, and Samuel identified the centrality of race and systems of racial inequities in describing why communities of color are disproportionally burdened by climate change consequences and limited in mitigating actions.

In addition, students regularly drew on their local knowledge and personal experiences to explain the distribution of disrupted climate such as the two examples below:

> The Slauson Corridor project by SCOPE 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. *Elle, task 4*

> The trees and plants in my neighborhood would be helpful to help collect carbon. It'll help with shading so it won't be so hot and it will help birds and other animals live. It will impact my family in a good way by helping collect carbon so we don't get sick as often and so we can see more of the sky. *Vicki, task 2*

Elle and Vicki are drawing on their knowledge of socioeconomic and public health issues relevant to climate change mitigation as justification for the work of local non-profits. These excerpts are representative of the twelve students that explained how climate change unequally and unjustly burdens low-income communities of color like their own.

In addition, Vicki, Sonia, Samuel's writing connects urban reforestation as a mitigation solution to community characteristics. These students described large-scale collective action as appropriate mitigation for their community based on the racial and socioeconomic demographics. Ms. T's activity structures helped students to connect histories and marginalization experienced by low-income communities of color to their personal experiences with climate change. These examples show how students explained climate disruptions and solutions as a function of the race and socioeconomic status of their community.

4 | DISCUSSION

The outcomes of student participation in our design illustrate how this group of Black and Latinx urban youth learned scientific concepts about climate systems, developed a sense of concern about the climate crisis, and used their critical awareness of sociopolitical dimensions to explain climate change. After experiencing a year-long chemistry curriculum oriented to developing critical awareness of climate change, students appropriated three aspects of the curriculum from Ms. T's instruction. First, students linked human actions to biogeochemical processes. Students commonly related human actions to the consequences of those actions on naturally occurring processes such as the clearing of trees for urbanization removing carbon reservoirs from the carbon cycle. Second, students used their understanding of relevant chemical processes to argue for the value of specific climate change mitigation actions. We saw students justify their argument for more urban greenspace because that will increase carbon reservoirs which will then reduce the amount of carbon in the atmosphere. These two outcomes reflect that the students in Ms. T's class developed a canonical, NGSS aligned understanding of the mechanisms of anthropogenic warming through classroom activities aligned to performance expectations relevant to the greenhouse effect and the carbon cycle.

Third, students drew on their experiential knowledge to explain the value of collective sociopolitical action in addressing climate change in their community. Continuing the urban greenspace example, students drew on their experiences in communities with environmental hazards to argue for government intervention to build more parks. Combined, these three outcomes show that the students' learning experience pushed beyond the NGSS to politicize climate change and the causes of climate inequities. Through linking human actions to chemical processes and drawing on lived experiences to explain the value of sociopolitical action, students rejected the scientism and technocentrism embedded in the NGSS (Feinstein & Kirchgasler, 2015) and problematized the lack of collaborative transformative action needed to address the climate crisis (McGinty & Bang, 2016).

4.1 | Implications

An implication of this study is that designing climate change learning for critical climate awareness is one possible way to align with the NGSS and push beyond the standards for a more equity and justice-oriented outcomes of science education. Specifically, critical climate awareness is an science education outcome aligned with justice-centered science pedagogy (Morales-Doyle, 2017). This pedagogy has roots in critical and culturally relevant pedagogies and aims to ensure minoritized youth succeed academically—which is to say, learn the concepts of the NGSS—while also developing sociopolitical consciousness. Students in this study both succeeded academically and developed a building block of sociopolitical consciousness, specifically critical awareness. I understand that many teachers are constrained by mandates to align their instruction to the standards, and therefore offer critical climate awareness as an objective that allows teachers to work within and push beyond mandates. Orienting instruction to critical climate awareness allowed Ms. T to support canonical sensemaking while making power dynamics visible. In this way, she supported students in constructing explanations that critically examine the sociopolitical dimensions of climate change.

This study also contributes to the growing body of literature that highlights the unique and generative sensemaking strategies of Black and Latinx urban children and youth when engaging with environmental issues (cf. Davis & Schaeffer, 2019; Madkins & McKinney de Royston, 2019; Morales-Doyle, 2017). Davis and Schaeffer (2019) showed that when elementary age children were introduced to water-shutoffs as a systemic issue with sociopolitical and racial dimensions that they shifted from a seeing shut-offs "through a lens of personal shame or irresponsibility" towards connecting their "daily lived experiences to systemic issues" (p. 381). Similarly, here data show how students drew on experiential knowledge as a sensemaking resource to explain climate change inequity as a systemic issue. Students' explanations surfaced racial and socioeconomic (counter)narratives that politicize climate change.

Methodological, I contribute a case of a long-term, participatory partnership between one teacher and one researcher. A strength of this approach is that Ms. T helped me see how I was vulnerable to "erase or assimilate ideas" that seemed distant from my design (Agarwal & Sengupta-Irving, 2019, p. 362). To illustrate this strength, I return to the example from the methods section about Ms. T's contribution to analysis. I struggled to code students' ideas in the "agency for emissions" component. While Ms. T and I discussed what "counted" as critically aware, we analyzed examples where students did not disaggregate responsibility for emissions based on a characteristic of a person or group. I considered the code of "uncritical" for these excerpts, but Ms. T was troubled by this label of students' ideas. Over the following weeks, we worked together to develop the codes of universal and differentiated that were more dignifying of students' ideas. Ms. T ensured that the design and analysis expanded as we learned from and with the students about climate change in their community. This is one of the many ways that Ms. T "showed up" (i.e., acted in solidarity with) for me beyond what was required of the research collaboration to actualize this justice-oriented research (Tolbert et al., 2018, p. 814).

4.2 | Limitations and future work

The findings of this study should be interpreted considering the context and research limitations. I outline two challenges and limitations below along with opportunities for additional future work. First, remote instruction limited data collection and therefore limits the story of student experiences that I can tell. More robust and multidimensional assessments of student sensemaking to further elicit students' range of thinking may better demonstrate their competencies. Additional work can explore what assessments in a place-based, critically oriented learning space might look like.

Second, across educators and scholars, there is no consensus on how, or how much, to grapple with sociopolitical concepts in science classrooms, or what the "right" sociopolitical dimensions of a given socioscientific issue are. Resources for teachers and teacher educators can include a rationale and guidance on how to integrate policy literacy and political perspectives in climate change education (Beach, 2023; Kranz et al., 2022; Selin et al., 2017). To make this possible in classrooms where interdisciplinary instruction is not the norm, science teachers would benefit from a conceptual map of the landscape of the "points of contact" between scientific systems and sociopolitical or everyday processes (Brown & Sadler, 2018; Duncan et al., 2018; Morales-Doyle et al., 2019). For example, how can we teach distributive justice with the cross-cutting concept of energy and matter? Instruction exploring that communities that emit the least greenhouse gases but experience the most climate consequences could overlap with instruction on the conservation and transfer of matter and energy in earth systems. Additional work can develop this conceptual landscape and study how teachers learn to make visible the connections between students' everyday lives and macro-sociopolitical processes of the environment (Ardoin & Heimlich, 2021).

I do not claim that this design is the only or best way to teach for critical climate awareness, or that the five components we conceptualized as making up critical climate awareness are the only or best. I expect and hope that teams of researchers and teachers inspired to pick up this work will design interventions that fit their contexts and will expand on complexities that Ms. T and her students did not. Below I describe four areas of problematization that Ms. T and I had in the front of our minds but that did not include in this design.

First, the logic that underlies extractive capitalism, and the causes of climate change rooted in colonialism and carbon-based industrial development (Ghosh, 2021), can be problematized as part of sensemaking. The ontological and epistemological frameworks that underlie the nature-culture relations of setter-colonial dynamics can be interrogated and dismantled in climate change education (McGinty & Bang, 2016). This can extend to the technology being advanced as climate solutions like electric vehicles (which are also extractive) and to relationality within and to systems of capitalism and colonialism.

Second, building on the differentiated perspective of agency for emissions documented in this study, classroom communities can do more to problematize the generalization of responsibility for greenhouse gas emissions. While we are all entangled in the problems of climate change, we are unevenly entangled (Roane et al., 2022). For teams working in schools and communities that hold more power and privilege, it will be fascinating to reimagine critical climate awareness as an outcome for students with variable relationships to climate change. This work could also include unpacking responsibility for emissions at the systemic, institutional scale, not just differentiating based on the power of individuals and groups.

Three, teachers can scaffold students' imagination of alternative futures. One way to do this is through the integration of the voices and practices of Black and Indigenous leaders and communities. As Roane et al. (2022) said, the everyday practices and ways of knowing of Black and Indigenous people hold "seeds of a different world" (p. 136) that are generative for imaging futures of vitality. Another way to do this is through solution-focused phenomenon that engage students in explaining how mitigation and adaptation support a range of co-benefits for equity and justice (Foley et al., 2020; Windschitl, 2023).

Forth, in building from critical awareness towards critical action, future work can support students in committing to and engaging in action that addresses the climate crisis. Science education for action has strong frameworks (cf. Bazzul & Tolbert, 2019; Roth & Désautels, 2002; Valladares, 2021) and instructional practices like youth participatory action research (cf. Morales-Doyle, 2017) make these learning spaces possible. I conceptualize critical awareness as a building block for critical action and future work can support youth in developing critical consciousness of climate change.

4.3 | Recommendations and conclusions

These findings support three recommendations for pedagogical strategies and teacher learning. First, teachers can explicitly name and model using students' everyday, local, racial, and cultural experiences as sensemaking resources in explaining, modeling, and investigating socioscientific issues. Ms. T's routines invited these experiences into the classroom, positioned them as belonging, and framed them as valuable. Teachers can legitimize critical awareness of social issues as useful for scientific sensemaking through these practices. Second, in designing instruction, sociopolitical dimensions of climate change and other socioscientific issues can be foregrounded in science courses through community-oriented and justice-centered phenomena that grapple with youths' real-world, local experiences (Ballard et al., 2023; Clark et al., 2024; Gyles & Clark, 2024; Lee & Grapin, 2022). Third, regarding teacher learning and professional development, it is important to call out that Ms. T's instruction was based in her sociopolitical consciousness (Ladson-Billings, 1995) and political clarity (Bartolomé, 1994; Beauboeuf–Lafontant, 1999; Madkins & McKinney de Royston, 2019) of both educational inequities and climate change inequities. Ms. T had a deep understanding of how schools, societies, and climate change operate to reproduce inequities and she had a desire to remediate educational and socioecological inequities. For teachers and researchers aspiring to support critical awareness or consciousness of socioscientific issues, cultivating political clarity of both the educational and socioscientific issue can ensure that power dynamics across systems and scales are interrogated.

In conclusion, the findings of this study support efforts to normalize politicized instruction of socioscientific issues like climate change and show that this instruction is compatible with the normative outcomes of learning disciplinary concepts. Teachers deemphasize, ignore, and neutralize the political aspects of climate change and environmental issues for countless reasons (Slimani et al., 2021; Henderson, 2019), but one does not have to be fear that the science learning will be "lost." I have shown that when students are given the chance to think about the critical dimensions of climate change, they can explain the crisis as they experience it in the world—as a scientific and sociopolitical process that is power-laden, locally relevant, personally meaningful, and possible to address. My sincerest hope is that students in today's classrooms can experience a sense of liberation and collectiveness as they learn about climate change, and that their teachers feel like they are an essential part of the solution to the climate crisis. In striving to transform science classrooms into incubators of climate justice, I offer critical climate awareness as an outcome that can be part of our collective work of striving for educational and socioecological justice.

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CONFLICT OF INTEREST STATEMENT

The author declares no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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ENDNOTE

[1] In addition to aligning with APA seventh edition guidelines, I capitalize White to disrupt the normalization of Whiteness, to call out Whiteness as a social construct that perpetuates oppression, and to invite other White people into conversations about race.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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