Received: 27 August 2022 | Revised: 12 July 2023 | Accepted: 22 July 2023

DOI: 10.1002/sce.21824

RESEARCH ARTICLE

Science Education WILEY

Incorporating investigations of environmental racism into middle school science

Allison Bradford[1] | Libby Gerard[1] | Erika Tate[2] | Rui Li[1] | Marcia C. Linn[1]

[1]Berkeley School of Education, University of California, Berkeley, California, USA

[2]Bluknowledge, Savannah, GA, USA

Correspondence
Allison Bradford, Berkeley School of Education, University of California, Berkeley, CA, USA.
Email: allison_bradford@berkeley.edu

Abstract

To promote a justice-oriented approach to science education, we formed a research-practice partnership between middle school science teachers, their students, curriculum designers, learning scientists, and experts in social justice to co-design and test an environmental justice unit for middle school instruction. We examine teacher perspectives on the challenges and possibilities of integrating social justice into their standards-aligned science teaching as they participate in co-design and teach the unit. The unit supports students to investigate racially disparate rates of asthma in their community by examining pollution maps and historical redlining maps. We analyze interviews and co-design artifacts from two teachers who participated in the co-design and taught the unit in their classrooms. Our findings point to the benefits of a shared pedagogical framework and an initial unit featuring local historical content to structure co-design. Findings also reveal that teachers can share similar goals for empowering students to use science knowledge for civic action while framing the local socio-political factors contributing to the injustice differently, due in part to different institutional supports and constraints. Student interviews and a pre/postassessment illustrate how the unit facilitated students' progress in connecting socio-political and science

ideas to explain the impacts of particulate matter pollution and who is impacted most. Analyses illuminate how teachers' pedagogical choices may influence whether and how students discuss the impact of systemic racism in their explanations. The findings inform refinement of the unit and suggest supports needed for co-design partnerships focused on integrating social justice and science.

KEYWORDS
design-based research, middle school science, research practice partnership, social justice, technology-enhanced learning

1 | INTRODUCTION

Recently, there has been increased attention to the necessity of designing science units that center social justice and highlight the political nature of science teaching and learning. Typical science instruction, by neglecting issues of social justice, reproduces social inequities (Dimick, 2012). Integrating social justice requires science teachers to reconceptualize their role and reimagine science teaching as supporting the social, political, and academic empowerment of students (Dimick, 2012; Morales-Doyle, 2017). In doing so, teachers need to attend to the political nature of teaching and the power dynamics, local histories, and issues of justice within the content they teach (Agarwal & Sengupta-Irving, 2019; Madkins & McKinney de Royston, 2019; Morales-Doyle, 2017; Vakil & Higgs, 2019). Teachers continually develop and reformulate these understandings in new teaching contexts (Philip, 2011). This study focuses on the activities of a research-practice partnership (RPP) that was initiated by two teachers who were called to action by the inequities laid bare as a result of the COVID-19 Pandemic and the increased attention to racial injustice following the murder of George Floyd. We examine the perspectives of teachers who were eager but new to designing and teaching curriculum materials that foreground social justice science issues (Morales-Doyle, 2017) rather than using their science department's typical curriculum. We explore how they navigate issues that arise while connecting their existing science teaching practices and pedagogical approach with their goals to foster social justice.

Specifically, the partnership explored how curriculum materials could be designed to build students' integrated understanding of science and social justice, including by integrating ideas about racial inequities. The partners viewed science curriculum as a space to both broaden notions of what counts as science and to make visible and address racial injustices. While engaging in the designed units, students fostered connections between racial inequality and scientific understanding, and imagined solutions for their communities. The partners designed opportunities for students to identify factors that lead to social inequities, like the disparate impact of environmental issues on marginalized communities and generate ideas for bringing about positive societal change.

The partners engaged in a process of co-design that elicited and respected the contributions from each partner, supported both teacher and student learning, and grounded the investigation in localized data that illustrates disparities or inequities within and across communities (e.g., Foster, 2020; Morales-Doyle, 2017). We report on the co-design process and how partner perspectives were incorporated into the unit. We analyze teachers' perspectives on their experiences while enacting the unit. We also examine the impact of the unit on students' progress in connecting their understanding of social justice issues and science. We investigate the following research questions:

- What are science teachers' perspectives on the challenges and possibilities of integrating social justice into standards-aligned science instruction?

- How do the co-designed materials and the teacher enactment of the unit impact students' progress in integrating ideas about social justice and science?

2 | DESIGNING AND TEACHING FOR SOCIAL JUSTICE IN SCIENCE

The partnership began with a commitment to center justice in science (Morales-Doyle, 2017) and to promote the integration of the rich ideas each student brings to science class (Linn & Eylon, 2011; Linn & Hsi, 2000). Our conceptualization of social justice in science envisions science education that provides students with access to an academically rigorous curriculum that centers counter-hegemonic narratives and opportunities to interrogate the political nature and inequitable impacts of scientific advancement. It supports students to leverage their community knowledge and resources toward just futures for themselves and their communities (Dimick, 2012; Morales-Doyle, 2017). One productive avenue toward achieving social justice science curriculum is to ground traditional science teaching in local social justice science issues. Many have argued that students can learn state-required disciplinary content through learning tasks that engage students in political struggle and address issues of injustice in their local communities (e.g., Barton & Tan, 2010; Buxton, 2010; Calabrese Barton & Tan, 2020; Corburn; Dimick, 2012; Morales-Doyle, 2017). Morales-Doyle (2017) clarifies that social justice science issues go beyond the exploration of local, socioscientific, or "real-world" issues because they "cannot be understood or addressed apart from understanding and addressing oppression" (p. 1036). Addressing such issues necessitates that both students and teachers learn about the historical and political intersections with traditional science content.

Integrating social justice into science courses provides opportunities for students to make sense of issues impacting their own communities and raises issues around inequality and racism (Morales-Doyle et al., 2019). Students might combine typical science ideas that help them interpret how an environmental phenomenon impacts people with social justice ideas that help them determine why the impacts are different across racial groups. Developing such science units can involve a lengthy design and iterative refinement process because it requires attention to existing curriculum standards and demands nuanced depictions of social justice issues (Kraig-Turner, 2016; Marks-Block, 2011). For example, Morales-Doyle (2017) reports on a chemistry unit that supported students to succeed academically and learn standards-aligned content while also identifying instances of environmental racism and seeking ways to enact positive change for their community. It took more than 7 years to design the unit in partnership with teacher colleagues, community policy advocacy organizations, and university-based scientists (Morales-Doyle, 2017).

Students often perceive the salience of race when examining data, whether or not teachers take up race or racial discrimination as an important factor for making sense of data (Philip et al., 2016). In the designed unit, data visualizations and interactive models comparing the distribution of harmful pollutants and frequency of asthma can illustrate factors impacting students' lives (Bichler et al., 2021). Interactive models can help students explore the disproportionate, negative impact of these environmental phenomena on marginalized communities. They can support students to investigate ways that communities have taken action to disrupt injustices and help students envision solutions needed for change (e.g., Morales-Doyle et al., 2019). Students can interact with visualizations, explore how the factors play out in their local neighborhoods, and connect community dilemmas to historical events. Students can draw on the visualizations to jointly form and debate conjectures about what is happening and why.

In this study, we combined social justice science pedagogy (Morales-Doyle, 2017), which grew out of Culturally Relevant Pedagogy (Ladson-Billings, 1995, 2009) and critical pedagogy (Freire, 1970), with Knowledge Integration (KI) design principles (Linn & Eylon, 2011), which grew out of constructivist theory (e.g., Inhelder & Piaget, 1958). Social justice science pedagogy highlights the importance of grounding science instruction in issues that cannot be understood without interrogating and challenging systems of oppression and positioning students as transformative intellectuals (Morales-Doyle, 2017). KI centers making science accessible, making thinking visible, helping students learn from others, and promoting autonomy and lifelong learning (Linn et al., 2004). Taken together, these frameworks inform the design of a unit, our co-design process, and the assessment of student learning.

The unit supports students to identify and understand the factors contributing to inequities and to generate strategies for effecting social change in their communities. We began by surfacing social justice science issues, focused instruction on taking action (Morales-Doyle, 2017), and centered the unit on racially disparate health effects of particulate matter (PM) pollution in the local community. To design instruction that supports students to connect their ideas encompassing science and environmental racism, we drew on KI to design and sequence the learning activities. KI articulates four research-based pedagogical moves for guiding students to develop integrated understanding: *elicit* student ideas and experiences, provide opportunities to *discover* new perspectives, *distinguish* among their ideas, and *form connections* among ideas (Linn & Eylon, 2011). Taken together, justice-centered science and KI instructional design support science teachers to elicit all their students' ideas, to value each students' views, to provide opportunities to discover evidence in relevant and meaningful contexts, to help students distinguish among their ideas about societal inequities, and to reflect on ways to use their insights to advocate for actions that create a just world (Linn & Eylon, 2011). While justice-centered pedagogy provides strategies for incorporating the political nature of science, KI provides a framework to design and assess instruction that guides students to link ideas concerned with race, power, and history with ideas from typical science instruction.

The designed unit *elicits* students' observations of the causes and impacts of an environmental hazard (PM pollution) by drawing on varied forms of evidence including videos illustrating concerns of community groups. The unit guides students to *discover* new evidence and perspectives using models and visualizations of local data that enable students to explore connections among core science ideas, and their personal and cultural lives (Polman & Hope, 2014; Rubel et al., 2016). The unit prompts students to *distinguish* who in the community is impacted and which factors (policy and environmental) contribute by combining evidence from these sources. The unit supports students to *form connections* to explain causes and to combine ideas to identify actions that might ameliorate the inequities they unearth. These activities support teachers to introduce issues of environmental racism while making each student feel that their questions, concerns, and experiences are welcome and valued in the science lesson and that they are empowered to use science to benefit their community.

2.1 | Implementing justice-oriented pedagogies

To incorporate local justice issues in the science curricula, teachers need to develop and enact justice-oriented pedagogies. Studies of inservice and preservice teachers reveal the importance of political clarity to avoid reinforcing racialized power dynamics (Madkins & Nazar, 2022; Sheth, 2019). Since teacher preparation programs rarely address racial bias (Sleeter, 2017) and issues of equity, diversity, and justice are neglected in the Next Generation Science Standards (NGSS; Morales-Doyle et al., 2019; Rodriguez, 2015), developing justice-oriented pedagogy is essential. Brown and Crippen (2017) took a grounded theory approach to characterize how inservice teachers develop expertise in enacting culturally responsive science pedagogy. Their study revealed that teachers were most successful when identifying science topics relevant to their students' lives, taking an asset-oriented view on students, positioning students as authorities in the classroom, and building community (Brown & Crippen, 2017). We seek to build on these accounts by documenting the experiences and challenges of experienced science teachers who are eager but new to addressing racial justice in their science classroom, as they co-design and enact a unit featuring an issue of environmental racism, racially disproportionate rates of asthma.

3 | METHODS

This study used design-based research methods to develop and study a curriculum unit that integrates racial justice with standards-aligned science topics using KI pedagogy. Our goals were to develop (a) a curriculum unit that teachers would continue to use, refine, and share, and (b) new knowledge of science teachers' entry points into

integrating a social justice perspective into their science teaching practice. Further, we explored how this approach to science teaching influenced the students' justice-oriented KI.

3.1 | Partner participants

The data for this paper were collected as part of a research project focused on the co-design of open-source science curricula to make visible and address issues of racial justice in local communities. The partners participating in this project included university-based science education researchers, designers, middle school science teachers, and their students. The project also had an advisory board composed of three researchers who identify as scholars in antiracism pedagogies for STEM classroom contexts.

The authors of this paper include four university-based researchers and one member of the advisory board, a scholar in an independent research organization. The university-based researchers identify as White (three authors) and Chinese (one author). The project advisor identifies as Black. We do not all identify as experts in antiracist education but rather hold a commitment to justice and to learn from the expertise of others. As researchers and curriculum developers, we are in a position of power to decide how standards-aligned topics are addressed in the units we develop and refine with our partner teachers. With that power, we feel responsible for foregrounding the justice issues that are part and parcel of "typical" disciplinary content. This approach requires critical interrogation of the intersecting power dynamics and justice issues inherent in these topics. As a majority-White team designing a unit focused on environmental justice issues that disproportionately impact Black and Latinx communities, and as outsiders to the local community featured in the unit, we relied heavily on video testimony from members of those communities and insights from partner teachers and their students to inform the structure of the unit. We sought out input from a specific project advisor who is an author on this paper because of her prior experience designing curriculum about asthma with members of the community featured in the unit in this study (Tate, 2009). We acknowledge that developing our understanding of the issues and how to present them in a unit is an ongoing process that depends on mutual trust and regular revisiting of the design. In this paper, we capture our first steps toward a partnership that centers racial justice in science learning.

Data for this study were collected from the teachers and students who participated in the initial iteration of co-design and implementation: Taylor and Sam, teachers at School A, and Alex, a teacher at School B. This study primarily focuses on two of these teachers, Sam and Alex. As shown in Table 1, the two teachers from School A taught the first iteration of the curriculum, Air Quality and Asthma v1, with all their 8th-grade students ($N = 288$). The teacher from School B taught the second iteration of the curriculum, Air Quality and Asthma v2, with all their 7th-grade students ($N = 98$). The analysis of teachers' perspectives is drawn from Sam (School A) and Alex

TABLE 1 Teacher and student participants with school demographics and data collected.

School	Demographics	Teachers, grade	Unit	Number of students	Data collected
A	33% White, 28% AAPI, 18% Hispanic, 18% 2+ Races, 3% Black; 22% Free/Reduced Lunch	Taylor, 8th	Air Quality and Asthma v1	144	Digital artifacts, student written work, student interviews
		Sam, 8th	Air Quality and Asthma v1	144	Digital artifacts, teacher interview, student written work, student interviews
B	75% Hispanic, 9% Black, 6% AAPI, 7% 2+ Races, 3% White; 92% Free/Reduced Lunch	Alex, 7th	Air Quality and Asthma v2	98	Digital artifacts, teacher interview, student-written work

Abbreviation: AAPI: asian american and pacific islander.

(School B). Taylor (School A) was unable to participate in interviews due to time constraints associated with teaching remotely during the COVID-19 pandemic and union responsibilities. The three teachers have worked in partnership with the research team in previous curriculum design research projects for at least 5 years, which included multiple curriculum customization workshops guided by the KI framework. The web-based inquiry environment, underlying KI pedagogical framework, and co-design process were hence familiar to these teachers.

3.2 | Co-design process with curriculum visualizer and web-based inquiry science environment platform

To enable each partner to contribute to the co-design process and to ground design in a pedagogical framework, we used the Curriculum Visualizer (Figure 1). The Visualizer makes the KI and social justice pedagogy of the unit visible and captures the insights of each partner during the design process (Bichler et al., 2021; Bradford et al., 2021). Teachers' past participation in the RPP supported the development of a shared understanding of the KI processes among all partners which supported the co-design process. Partners elaborated the unit design and refinements in the Visualizer.

To support the co-design process, the partnership takes advantage of an open-source authoring environment, designed to support KI pedagogy. The environment makes it possible to combine open education resources (OER) to engage students in KI processes. The easy-to-use authoring system allows for customization of the curriculum for each teacher's needs, and rapid refinement based on partner input and logged student responses. The university-based researcher used the authoring environment to create the unit using the final design from the Visualizer.

3.3 | Data sources and analyses

3.3.1 | Teacher interviews

After teaching the unit, Sam (School A) and Alex (School B) participated in a semi-structured interview with researchers to reflect on their experience. In each interview, we asked questions such as (a) why did you decide to

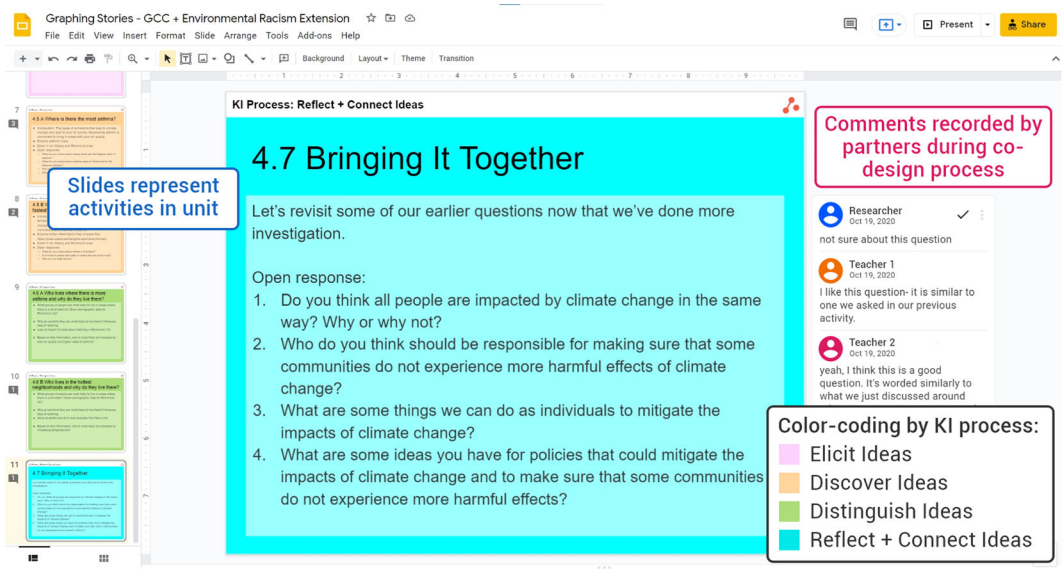

FIGURE 1 Curriculum visualizer for an activity in the Air Quality and Asthma unit.

integrate topics of social justice into your science teaching, (b) what parts of the unit did you feel were most engaging or challenging for your students, (c) how did you approach the discussion of sensitive topics, like racial discrimination, in your classrooms, and (d) what support do you believe other teachers need to address issues of racial justice in their science classrooms. Interviews were approximately 45 min, audio recorded and transcribed.

3.3.2 | Description of the interviewed teachers

Below we describe Sam and Alex in greater detail to provide information about their identities, teaching contexts, teaching experience, and history of partnership with the authors. This provides additional context to guide interpretation of the themes that emerged from their interviews. While sharing a history of partnership with the researchers, the two teachers interviewed hold different racial identities, work in dissimilar school contexts, and hold different reasons for joining the partnership. Because of these differences, our analysis of the convergences and differences in their perspectives might yield additional insight into the range of support and development needed by teachers embarking on integrating discussion of racial justice into their science classrooms. We use gender-neutral pronouns to describe each teacher to withhold gender identity with the intention of preserving each teachers' anonymity.

Sam

Sam is a White science teacher at a racially and ethnically diverse middle school. At the time of this study, they had been teaching at this school for over 9 years. Sam had been working in partnership with some of the university researchers for the same length of time: teaching units from the web-based platform for 9 years and attending professional development workshops focused on curriculum customization and supporting student KI for 8 years.

Sam was often an eager collaborator to pilot new units and activities in their classroom. For example, in the year before this study, Sam partnered with the first author to pilot a newly designed activity that scaffolded students' self-directed inquiry into a topic related to climate change. After Sam "spent quite a bit of time reading some books and trying to think about ways I can integrate these issues into science" (Interview statement) during the summer of 2020, they approached us, along with their colleague Taylor, with a desire to connect the climate change unit they had previously taught with an exploration of environmental racism. After this communication, Sam met with the first author to discuss the new unit. After the meeting, Sam, along with colleague Taylor, shared news articles and other resources to inform the content of the unit activities. We used the Curriculum Visualizer and Google docs to co-design activities and scaffolds for the unit. Sam routinely met with Taylor to plan their enactment of the unit.

Alex

Alex is a Latinx science teacher at a middle school that serves a majority Latinx student population. At the time of this study, they had also been teaching at their school for over 9 years. Alex had been teaching units from the web-based platform for 8 years and participating in professional development workshops focused on curriculum customization and supporting student KI for 7 years. This teacher frequently sought out additional opportunities to collaborate with the university researchers to customize and design science units using the web-based platform. Whereas School A had the same principal who had voiced social justice as a part of the school's mission, School B had frequent turnover in the administration. Also, the district recently adopted a new science curriculum which teachers in School B were heavily encouraged to adhere to.

At the time of this study, Alex was focused on developing ways to better support their emergent bilingual students' learning in the context of the web-based units. They partnered with one of the authors to integrate more opportunities for students to see and use their everyday language in the units they were teaching using the web-based platform. Alex had previously customized a version of the unit taught in this study to include videos of Greta

Thunberg, a young climate activist, and a culminating activity where students wrote letters to local officials calling for reduced use of fossil fuels. Because of their interests in connecting the science content in their classroom to social issues and supporting their students in taking action with the knowledge they are developing, we invited them to participate in the present study. They expressed interest in partnering to attend to their goals to connect the science to the real-world issues youth and families are facing. After sharing our version of the unit, Alex created an additional, modified version of the unit to use with their students with IEPs and other accommodations. They taught the two versions of the unit over the course of 4 weeks. They reported making real-time customizations to the unit by chunking videos, providing sentence starters, and doing whole-class reviews of some of the activities in the unit.

3.3.3 | Analyzing teacher interviews

We used an inductive coding approach (Saldaña, 2013) to capture the range of perspectives about the opportunities, challenges, and purposes expressed by the teachers interviewed. We sought to identify (a) areas of uncertainty (where teachers expressed internally conflicting views or alternate views from each other), (b) the desired and provided supports described by the teachers, and (c) teachers' perspectives on their commitments or motivations. This would provide insights into the needs of teachers who are embarking on integrating topics of social justice into their science instruction.

To analyze the transcribed interviews, first, the two university-based authors who conducted the interviews independently highlighted both transcripts to identify statements the teachers expressed about the above topics. The two researchers discussed what they each identified until reaching agreement about which interview segments corresponded to each topic. Segmentation was done using color shading so as to keep the full interview transcript in-tact to preserve context for each segment.

Second, with the other university-based authors, we jointly reviewed the segmented transcripts and identified themes in each of these topics. We further coded the interview transcripts using the themes.

Third, we shared the themes with researchers on our larger team including some who are not working on this project directly. The researchers (three pairs) used the themes we had identified to also code the interview transcripts and raise questions about the coding. The authors refined the themes once more based on this process and re-coded the transcripts, resulting in the themes: *supporting a partnership for social justice*, *centering racial justice in environmental science*, *leveraging local relevance to achieve teaching goals*, *empowering students to use science to advocate for change*, *monitoring student engagement and well-being while discussing injustices*, and *connecting school and broader community dialogue*.

Last, to further check our interpretations, we discussed the segmented interviews (uncoded) with the project advisor-author to engage in the same process of identifying themes. Doing so resulted in refining some of our existing themes. For example, the project advisor noted that when the teachers expressed concern about their students' well-being while introducing topics related to environmental racism, they seemed to assume they are imparting new knowledge about race and racism to their students, rather than drawing from and acknowledging students' experiences with these topics. This provided nuance to the meaning of the existing theme, "monitoring engagement and well-being." The advisor also noted that teachers expressed differing clarity in their motivations for teaching the unit and that teachers had a different emphasis when articulating how the unit served their teaching goals. This clarified our theme of "leveraging local relevance" by highlighting that teachers expressed different motivations for and emphases in teaching the unit. While they both expressed the value of localizing, other motivations emerged when interview questions made other facets of their context more salient. We integrated the advisor's insights to articulate the final themes (See Table 5 in Section 5 for Final Themes). We used these final themes to refine our analysis of the interview transcripts.

3.3.4 | Co-designed artifacts

The Curriculum Visualizer, Google Docs, the web-based authoring platform, and emails generated digital artifacts that we used to inform our interpretation of the teacher interviews. The Curriculum Visualizer contains the original outline of activities in the Asthma & Air Quality unit as well as comments that document the exchange of ideas between the researcher and the two teachers involved in the initial unit design (School A). Two Google Docs were also used, one to segment portions of OER to include (e.g., excerpts of news articles) and one to collaboratively design prompts to support students' engagement with the selected OER segments. We also used information from previous email communications, workshops, and collaborations during the duration of our partnership to deepen our interpretation of the teachers' perspectives.

3.3.5 | Student pre/posttest assessment

The web-based platform logs students' responses as they engage with the unit, and we collected the pre/postassessment responses for all students in each teachers' classroom (Table 1). At the start and the end of the Air Quality and Asthma unit students are prompted to explain, "Do you think climate change (or the impacts from gasoline combustion, depending on the iteration) impacts all people the same amount?" During the unit, students gather evidence about how climate change and emissions from combustion impact human health and historical policies motivated by racism and classism that contribute to unequal impacts on particular groups. This question targets students' KI about the health impacts of combustion emissions and the social and place-based factors that influence how likely someone is to experience the impacts. It calls for students to link ideas about how proximity to sources of pollution impacts health and how historically racist policies like redlining influence where pollution sources are located and where people live.

3.3.6 | Analyzing student pre/posttest assessment

We developed a KI rubric (Liu et al., 2011) to score student responses to the pre- and postassessment question, as shown in Table 2. The rubric enumerates targeted ideas that were generated through a combination of a priori ideas that were introduced in the unit and other ideas that emerged from student responses. The scoring prioritizes links between ideas and does not penalize students if they hold a combination of accurate and inaccurate ideas.

The responses are scored on a scale of 1–5 as shown in Table 3. Not all students reached the postassessment in the class time allotted by the teachers, so those students' work was dropped from the data set (final $N = 211$). We examined the ideas expressed by students in the assessment item to understand the impact of the co-designed materials, enactment choices, and perspectives expressed by their teachers. We conducted a paired t-test to evaluate changes in students' scores from the pre- to postassessment and counted the frequency of student responses that discussed race and that discussed socioeconomic status and used two proportion Z-tests to examine differences from pre- to posttest and between teachers.

3.3.7 | Student interviews

We interviewed all students who returned student assent and parental consent forms: seven students from Taylor's classroom and six from Sam's classroom (both School A). Alex (School B) was unable to distribute interview consent forms to the students' parents during remote instruction, so they were unable to participate in interviews. Students participated in semistructured interviews after they completed the Asthma & Air Quality v1 unit.

TABLE 2 KI rubric for pre/postassessment.

Item Prompt: Do you think climate change (or the impacts from gasoline combustion, depending on the iteration) impacts all people the same amount?

Target Ideas: Impacts depend on proximity to a source of pollution/low air quality, different areas experience different impacts, current/historical policies have a role (redlining, or other policy), social factors like race, ethnicity, or SES have a role, an individual's health is impacted by exposure to air pollution

KI Score	Criteria	Example responses
1	No answer; irrelevant; I do not know	idk
2	On topic, but nonnormative: all people are impacted the same; normative but vague (without explanation)	No, not ALL humans are affected by Climate Change in the same way but most are.
3	Partial link: one target idea	Yes, because if you have more freeways or factories where you live you could have more of the effects of incomplete combustion than places without many. If you live near refineries and places with fewer trees, you will also be impacted more, though everyone is impacted to some extent.
4	Full link: links two target ideas	I think that people who are lower income are impacted by climate change more than people who are not. I think this because they sometimes have to live closer to factories and other places where there could be harm.
5	Full links: links three or more target ideas	NO! Racially oppressed groups are affected more by climate change. These groups are in redlined communities which are put near industrial areas which produce greenhouse gases. These greenhouse gas emissions give you a higher chance to have asthma.

Abbreviations: KI, Knowledge Integration; SES, socioeconomic status.

TABLE 3 Summary of refinements of Air Quality and Asthma v1 to create the second version. Refinements were made to improve learning about social justice issues and to adapt the unit to a new disciplinary context.

Unit refinements
Began unit with videos featuring local activists and community members making a change.
Added activities to investigate asthma hospitalization rates disaggregated by race.
Incorporated multimedia resources to help students unpack redlining policies and their lasting impacts.
Introduced the reactants and products of the incomplete combustion reaction.
Incorporated analysis of PM pollution along local freeways.
Added multimedia resources to explore the impact products of incomplete combustion (PM pollution) have on the lungs and other body systems.

Abbreviation: PM, particulate matter.

The interview questions focused on students' perceptions of the unit and how they felt while engaging with it. We asked students to pull up their work from certain activities in the unit and to explain their responses and whether their thinking had changed. We also asked them what they felt surprised to learn, what they were proud of in their work, and what role they believe science plays in understanding social issues.

3.3.8 | Analyzing student interviews

Using an inductive coding approach (Saldaña, 2013), each interview was read by one of the authors to identify categories that represented common themes in students' thinking related to the ideas students had frequently articulated in their written explanations in the unit. The two researchers discussed what they each identified until reaching agreement to generate a set of emergent themes. Ideas that came up in multiple student utterances and that yielded insight into the student experience, the unit, or elaborated on ideas we had observed in student written responses were counted as themes. These emergent themes were used to inform refinements to the unit and to understand the impact of the unit on students' ideas about social justice in science.

3.4 | Limitations

This research included two schools and three teachers. The exclusion of teacher interview data from Taylor in School A and student interviews from School B due to additional challenges of remote instruction limited the diversity of the teacher and student population with whom the unit was tested. Other teachers and teachers from different schools might encounter different reactions to our unit. We also only examined one pre/posttest item to triangulate student progress with their teachers' perspectives, orientations, and goals. This was the only pre/postitem that directly prompted students to express the integration of their canonically disciplinary ideas with their understanding of the environmental justice issue.

4 | AIR QUALITY AND ASTHMA UNIT DESIGN ITERATIONS

In this section, we describe the activities and refinement of the Air Quality and Asthma unit. Taylor and Sam incorporated the Air Quality and Asthma v1 unit into an eighth-grade unit on data analysis and climate change. For the second iteration, Alex incorporated the Air Quality and Asthma v2 unit into a seventh-grade unit on chemical reactions. We describe the co-design process and analyze the impact of the unit in these two disciplinary contexts.

4.1 | Air Quality and Asthma v1

The initial design of the unit, Air Quality and Asthma v1, emerged from a meeting including the university-based researchers and the teachers from School A, Taylor and Sam, where we exchanged ideas about connecting the students' exploration of the causes of global climate change to inequitable health impacts from air quality. The researchers proposed connecting these issues to the historical practice of redlining to explain some of the origins of the inequitable impacts. After the meeting, one researcher and the teachers exchanged OER such as news articles, publicly available data sets, and data visualizations to inform the design of the unit. The researcher used these OER and the KI framework to create an initial version of the unit in the Curriculum Visualizer which all partners used to iterate on and refine the unit design.

The Air Quality and Asthma v1 unit follows the KI design process to support students to develop an integrated understanding of the intersecting impacts of climate change and redlining. The unit begins by engaging students in a brainstorm to *elicit* their prior ideas about whether they think all people are impacted by climate change in the same way. Students then *discover* new ideas by using a discussion board to add their own ideas about how climate change impacts people and to comment on the ideas shared by their peers. Next, students engage in a sorting activity to *distinguish* which effects of climate change they believe impact all people the same and which impact some more

than others. After the sorting activity, students conduct an investigation into the effects of climate change on air quality and asthma.

In the next part of the unit, students use an interactive map to compare asthma rates in their city to other cities nearby. More of the students' ideas are elicited when they make predictions about why the asthma rates differ across cities. Students are introduced to Refinery City (a pseudonym for a city nearby the schools) where the Local Refinery (also a pseudonym) is located. Students learn more about the conditions in Refinery City and are then introduced to the historical practice of redlining to *distinguish* reasons why sources of air pollution like freeways and oil refineries might be located in Black and African American communities. Students then examine two maps to explore the relationship between the areas that were historically redlined and those that have the highest rates of asthma hospitalization. Students are prompted to *form connections* by explaining the ways historical policies have impacted who lives nearest to the Local Refinery and how that has impacted those residents' health. The unit ends with students investigating how local residents are bringing about change. Students *connect* their ideas by revisiting the question from the beginning of the unit: "Do you think all humans are impacted by climate change in the same way?" In keeping with justice-centered science pedagogy, students critically evaluate and brainstorm possible solutions that would improve equitable access to clean air and make claims about who is most responsible for ensuring there is a solution.

4.2 | Curriculum refinement

Observations from the initial enactment of the unit and teachers' reflections motivated the partners to seek additional input to refine v1 of the unit. We asked our advisory board members to review the Air Quality and Asthma unit v1 and help us further integrate racial justice into the unit. We also interviewed students to learn about their experiences with the curriculum and how to improve it for other middle school students. See Table 3 for a summary of the refinements.

4.3 | Air Quality and Asthma v2

The second version of the Air Quality and Asthma unit begins by introducing the Refinery City Case Study. This version included new images of the refinery and videos of scientists and activists from the local community who are concerned about the impact of the refinery on their community. These changes ground the science in the social justice issue from the start of the unit. They localize the issues in the faces and voices of community members and activists who are using their understanding of asthma and air quality to advocate for changes in their community. They expand notions of what counts as science by positioning the stories and testimony of members of the community as valuable evidence for understanding phenomena related to air quality (Corburn, 2005). Students are then asked to predict the impact of living near the Local Refinery, freeways, and railroads on Refinery City residents' health.

The second major change was to connect the impact of the Local Refinery and of traffic on the local freeways to incomplete combustion to better suit Alex's instructional goals to address 7th-grade chemistry standards. Building on instruction about the combustion reaction, we added a video about incomplete combustion to support students to learn about the products of a combustion reaction that occurs with insufficient oxygen.

The mapping activity was strengthened to increase students' opportunities to make connections between the pollution produced by incomplete combustion and health impacts, like asthma. To do so, students engage with diagrams that illustrate the impact of the products of incomplete combustion, like diesel particles and PM pollution, on the lungs and other body systems when inhaled. Then students explore a map of the local area surrounding Refinery City with cities and freeways labeled and different-sized triangles to indicate the quantity of PM pollution in a given area. This activity is designed to help students develop ideas that link the pollution from refineries and freeways to health impacts.

Next, an activity was included to support students to use their graph analysis skills, to notice the racial health disparity and to investigate why this disparity exists. In this activity, students engage with two data visualizations. The first shows the rates of hospitalization due to Asthma in Refinery City and the rates for the county where the city is located. The second shows the rates of Asthma hospitalization in Refinery City by racial group. While exploring these visualizations, students should discover that the higher rates of asthma in Refinery City exceed those in the rest of the county. They also discover that in Refinery City Black and African American populations have much higher rates than other racial groups.

This version also included two new videos to support students to understand redlining and the lasting impacts of redlining today. We aimed to support students to grapple with the complexities of a practice like redlining and to provide evidence to support students in distinguishing factors that might contribute to the racial health disparities they have observed. One of the videos features a local scientist describing the demographics of the neighborhoods nearest to the Local Refinery. The other video provides a historical overview of how redlining occurred and the racist motivations that underlaid the ratings given to various neighborhoods. It details the lasting impacts and continued use of redlining maps today. Finally, students engage in the same reflection activity as in the first version of the unit.

5 | RESULTS

5.1 | RQ1: Teachers' perspectives on their experiences and needs when integrating justice into science

In the sections that follow, we describe the themes that emerged from the teacher interviews and explore the areas of alignment as well as different emphases shared by Sam (School A) and Alex (School B) within each theme. As shown in Table 4, the teachers both felt supported by engaging in partnership to create and refine a science curriculum unit featuring issues of racial justice. They both valued localizing the curriculum and recognized the potential for their students to feel empowered by the activities. They reported interest in additional collegial support including opportunities to work with other teachers enacting the same unit.

The teachers had different priorities for centering race. Sam centered race, emphasizing impacts of environmental pollutants on specific populations and viewing the unit as a way to build classroom community. Alex viewed the unit as a way to strengthen engagement in NGSS practices, especially by connecting the practices to the students' communities.

5.1.1 | Supporting a partnership for social justice

Access to curriculum resources and professional collaborations made teachers feel able to address issues of racial and environmental justice in their classrooms. When asked what teachers need to address antiracism in the science classroom, Sam (School A) voiced that having access to a curriculum where issues of social justice are integrated was essential:

> "I even think like you know if you're making a [web-based platform] unit or with any kind of curriculum with this, it is helpful to see an example like how you can phrase things like what could you say, even so you know for people who are feeling nervous about it."

Sam believed that providing teachers with a starting point like we did during the co-design process, could support them to overcome nervousness about bringing issues of justice into their classroom. Specifically, Sam

TABLE 4 Summary of findings from teacher interviews.

Theme	Teacher perspective and emphases
Supporting a partnership for social justice	The partnership supported teachers by providing an example curriculum and historical content.
Connecting the school and broader community in dialogue	Connections with other teachers, parents, and community members supported integrating science and local justice issues.
Empowering students to use science to advocate for change	The unit supported students to view science as a lens for identifying injustices in their communities and envisioning solutions. Sam appreciated the support for students' future civic engagement; Alex valued support for students to communicate their ideas to their communities and to people in power.
Leveraging local relevance to achieve teaching goals	The co-designed unit made the science content more relevant to students. Sam emphasized a personal interest in understanding the connections between race, racism, and science. Alex emphasized building science and engineering practices like constructing arguments relevant to their community.
Centering racial justice in environmental science	Centering race in class discussions led to concern and discomfort. Sam nevertheless centered race to foster trust with students. Alex centered socioeconomic status and ethnicity.
Monitoring student engagement and well-being while discussing injustices	It was challenging to support students' emotional well-being while discussing the injustices raised in the unit. It was difficult to gauge student engagement during remote instruction.

thought that teachers benefited from support to think about how to introduce these topics in the classroom and how to respond to students. Alex (School B) expressed a similar view, reporting that teachers are supported by having information about social justice issues and access to data that students could analyze:

> "I think as soon as we're armed with some facts, then we can feel confident as teachers to go in there and say, look, these are the facts, by the way, that you should know about because you live in this community. And this is the science behind it. And now we need to start talking about and discussing how we can maybe address these issues or even try to make a change, suggest changes be made."

Both teachers expressed that science teachers could be more confident about how to integrate issues of social justice once they had data that allowed students to draw on science practices to make injustice visible. Their perspectives indicate that teachers need support and time to understand the historical foundations of the injustices present in their school communities and that doing so will require developing content expertise outside of their science discipline. Having the information in the unit and discussing it with the university-based researchers facilitated Alex raising the issue of disparate impacts of air pollution with their students. Alex said, "When it came down to this poor air quality issue, you know, it was kind of like in the back of my brain. Like oh, yeah, I wonder if the kids know about this." Having access to the unit supported Alex to move from wondering if their students knew about the issues to enacting a unit about them.

5.1.2 | Connecting the school and broader community in dialogue

Sam (School A) and Alex (School B) both expressed the importance and amount of support that would be provided by connecting with a broader community of teachers, parents, and community members. Sam mentioned, "I think

the redlining stuff is very relevant to science in environmental racism stuff, but you know I think it is hard. You know a lot of science teachers just … want to do the science." They added that, "I think it would be awesome if there were a group of teachers so they could meet with and talk about it, especially if there were other science teachers. I do have that at my school; it's been something that we've been focused on for a while." Additionally, Sam sought connections with their students' families by sending an email to share what students would be learning about and received primarily positive feedback: "I kind of gave my reasons and people were either supportive or didn't respond." Sam felt fortunate to have partner teachers and families to connect with as they try to integrate social justice into their science teaching and thought other science teachers might feel more willing if they had the same.

Alex also believed that a community of support to discuss dilemmas and concerns would be valuable. They expressed this information would enable teachers to identify and address locally relevant issues:

> "Depending on where the teachers live, and you know, where their population resides, then teachers can be informed of some of these social issues that could be addressed through science, or discussed through science, like water quality, you know, soil fertility, depending on where you live."

Alex reported that having a community to work with supports teachers to consider ways to integrate social justice into their science curriculum. Sharing ideas about local issues that connect to the science curriculum would support other teachers to do this integration as well.

5.1.3 | Empowering students to use science to advocate for change

Another theme that emerged was that teachers saw the Air Quality and Asthma unit as an opportunity for their students to recognize their power to use science to advocate for change. In Sam's (School A) words:

> "I don't expect all of my students to become scientists, but I hope they learn about how to use science, or graphs, or read something to understand why and defend why they should have certain policies and or vote in a certain way."

Sam felt that students are best served by a science education that enables them to be civically engaged citizens who can use science to address issues that affect them and make the connection between scientific understanding and policy decisions.

This perspective was also reflected during the partnership design of the unit. Sam incorporated a question at the end of the unit that asked the students who they think should be responsible for making changes that ensure that some communities do not experience unfair impacts of climate change. Sam built on prior conversations with students during a unit on scientific ethics featuring the Tuskegee Syphilis Experiment where students were encouraged to consider the social responsibilities.

Alex (School B) also voiced that integrating the social issues of disparate impacts from combustion pollution into the curriculum was a,

> "Positive thing, positive move towards their self-empowerment. Especially when they get to communicate some of these things. Like, okay, that's empowering to me to say something to someone to do something about it."

To Alex, it was particularly important that the students would have the opportunity to communicate their learning and see that they could advocate for changes in their community once they had learned about the science behind the issues they were exploring. Alex was hopeful that the culminating activity of writing a letter to the

president would provide students with this opportunity and enable them to connect their learning to what they were hearing in the news about the 2020 presidential election.

Teaching the Air Quality and Asthma unit provided teachers with an invitation to position science as a lens for identifying racial injustice in their local communities, the factors that contribute, and policy-level changes that create a more just society for marginalized peoples. The teachers viewed this as a way to empower their students to develop a deeper understanding of scientific phenomena and use that information to affect change within their communities. Their reflections reveal a common starting point that might motivate teachers to integrate justice issues into their science teaching. They also indicate the importance of creating additional opportunities within the unit for students to take action based on what they have learned.

5.1.4 | Leveraging local relevance to achieve teaching goals

The partner teachers valued introducing the issue of asthma rates and air quality in Refinery City as a powerful approach to make their science content more relevant to their students. This served as one factor to motivate these teachers to teach the Air Quality and Asthma unit. For Sam (School A), increasing relevance and creating a more welcoming science classroom was a key motivator for integrating the Air Quality and Asthma unit. They reported:

> "I want to try to make science more relevant to all my students' lives. I think that's something that is lacking the most. I am not saying I am achieving it, but I do think that by addressing racism and making it something you speak about, you make a space for all people to feel to be part of your classroom."

From this teacher's perspective, addressing racism within the science topics raised in their classroom made the science more relevant to their students. Further, they believed that doing this in their science classroom communicated to their students that they valued them and that what they learned in their class should help them address issues that matter to our society.

Alex (School B) felt that including the Air Quality and Asthma unit would make the science of chemical reactions more relevant to the students because they are directly affected by disproportionately high asthma rates. During the interview, Alex commented that integrating the Air Quality and Asthma unit into the Chemical Reactions unit made the science important to the students. They believed students were more engaged because it helped them to understand impacts that they were directly or indirectly experiencing:

> "I mean … because they thought it was important, they formulated some pretty direct statements there about what should be done. Because, you know … at our school there are a lot of, there's a pretty high percentage of kids with asthma. Right? And so, I guess when we started to make that connection, they realized oh, okay, so maybe this is why we have asthma or a lot of kids in our school have asthma."

Because asthma is an issue that directly affects Alex's students, they reported that investigating the role of air pollution from combustion and the lingering impacts of redlining enabled students to make conjectures about what they are experiencing in their daily lives and identify solutions. Interestingly, Alex did not explicitly express concern about students investigating an injustice they experienced, although they did avoid situating that injustice as a consequence of racism.

Despite having aligned perspectives on the value of localizing the unit, Sam and Alex expressed differing emphases when asked how the unit supported their teaching goals, a question that might evoke more formal responses or cue thinking related to their school's priorities. Sam shared that they had a personal interest in better understanding race-related topics and integrating them into science and that their school was focusing on racial

justice. Sam also shared that they had spent the summer reading books about racial justice and had "realized how many connections there are actually in science of miscommunication and propagation of racist ideas." In response, they began their school year with a unit about the Tuskegee Syphilis Experiment to illustrate that scientific advancement has often come at the expense of harm to marginalized communities. They viewed the Air Quality and Asthma unit as a way to continue integrating race-related topics into science and addressing racism in science. Relatedly, Sam expressed a focus on teaching the unit as a means of building classroom community, personal relationships, and creating safe space for students. Sam shared:

> "I think that's [student engagement] one of the biggest goals for me … I just think that if you bring everybody in, they might think of science as something that could be for them, not something that is only for a certain group."

Sam believed that using science to investigate justice issues and addressing issues of racism within the scientific community would support the students to engage in the classroom learning community and support a sense of belonging within the field of science.

Alex expressed a strong focus on using the unit as a means of addressing NGSS standards. When asked whether they felt it was important to address social justice within the science classroom, they shared:

> "Yes, I think it is important. And in fact, it does fall under another standard, or performance expectation, right. And that's the human impact, and human activities do affect our planet, and the environment we live in."

Alex felt that the content of the environmental justice issues was aligned with the standards they are required to teach. The administration had previously asked Alex to justify how units from the web-based platform aligned with the state standards, so it is not surprising that asking about teaching goals cued an explanation about how the unit helps cover the required standards. Alex further elaborated that activities like writing a letter at the end of the unit was also well aligned with the NGSS goals:

> "You know, also in the standards, there are the science practices [NGSS SEPs] too, to argue for this, right, and the cross-cutting concepts that students, you know, state claims that are backed up by facts, and then try to explain them through scientific reasoning."

Alex believed that grounding the unit in the context of disparate asthma rates would provide students with an opportunity to engage in a core scientific practice: engaging in arguments from evidence. Sam and Alex emphasized different priorities for integrating a justice perspective to a science unit—promoting belonging in science and increasing student engagement in using science practices. This illuminates how justice-oriented science curriculum can offer multiple avenues to broadening who belongs in science and how doing science can make visible and remedy injustices in the community.

5.1.5 | Centering racial justice in environmental science

Both of our teachers were unsure of the best approach and what language to use to introduce the discussion of race in the Air Quality and Asthma unit. In Sam's (School A) words:

> "One of the things that came up for us with sort of this idea … like is it too harsh and are we worried about what this could bring up things for kids and like how do you kind of help kids with that."

Sam and their colleague, Taylor, were concerned that their choice to center race would bring up challenging emotions for their students and were not sure that they would be able to support students through those emotions. Sam did not express concern about the emotions that could be raised by choosing not to center race. Ultimately, Sam decided to directly address race and make clear that discussing racism would be an expectation in their class:

> "I just kind of came out and said it. I'm like it's going to be a part of this class to understand how racism has been affected and somewhat influenced by some people in science and it's important for us to address that … I do think that by addressing racism and making it something you speak about … I think it makes it safer to have students feel that you understand and have empathy for them."

Afterward, Sam still wasn't sure if this was the best approach but voiced in an email communication that they thought it was better to try it out and learn how to do it better next time rather than waiting to figure out a perfect approach. They believed that speaking about race and racism directly, particularly in the context of this unit, would be more likely to create a supportive classroom environment than being indirect or decentering race.

Alex (School B) expressed discomfort and concern about what talking about racial justice would bring up for their students:

> "I didn't want to see the word race in there. So yeah, there is race in there. And I think I pivoted away from that as much as I could, because I didn't want this to become something of, you know, like a race discussion … So just talking about different groups in the community. And then yeah, naming those groups, by ethnicity, you know, the African American group, the Hispanic group, or Latin American group, I think that facilitated, you know, this entry point into some disparities that we see."

When probed further, Alex did not elaborate on the difference between discussing the impacts on different ethnic groups rather than the role of race in general. Alex later added that talking about race directly could create more emotional discomfort for the students than talking about impacts on specific ethnicities: "So, I was concerned about that. And so that's why I think not using, sort of avoiding this word race, I think helps. But we're still addressing different communities, different ethnic groups." Alex was particularly concerned because the students were likely to be experiencing the racialized impacts explored in the unit and did not want the discussion of race leaving students in a place where they felt helpless. Alex wanted to focus on students thinking about how to use their science knowledge to make an impact. This connected to a sentiment students had previously expressed when introducing climate change in the Chemical Reactions unit. Like Sam, Alex did not mention any harm that might arise by neglecting discussions of race in this context. Alex's decision to emphasize ethnicity and socioeconomic status as social determinants and actively avoid use of race and racism suggests a view that discussions of race are inherently unproductive. This is a perspective that needs further attention and interrogation. Distinguishing among the impacts of environmental racism on specific ethnic groups may facilitate awareness of the nuances around these issues. It is worth noting, too, that Alex is also a member of a minoritized group and did not have a supportive community of teachers or administrators to engage with while grappling with their discomfort.

5.1.6 | Monitoring student engagement and well-being while discussing injustices

Related to their explorations of whether and how to center race in their classroom conversations, the teachers expressed concern about their students' engagement and well-being while bringing issues of environmental racism into their classrooms. Both teachers discussed a notion of finding balance in introducing the racial injustices, so that students wouldn't be emotionally overwhelmed. They both wanted students to conclude the unit feeling positive and capable of taking action. Sam (School A) shared worries that frequently centering race or racism could feel negative for students:

> "One thing that I don't do is have it super negative all the time. I think it can be hard for kids to hear all the time about this happening, the most horrible thing, like basically killing people, people in our community who are mistreated."

Relatedly, Alex (School B) shared,

> "Yeah, I think it's an age where they should become aware of these … this reality, I suppose. And at the same time, we don't want to have them get depressed over it. Like that they can't do anything about it."

This framing by both teachers suggests that they thought the unit advanced students' knowledge about race, racism, discrimination, and justice. However, their students might have experience with and knowledge of these topics as members of the community disproportionately impacted by the issues raised in the units. The unit could be strengthened by expanding opportunities for students to express their existing ideas about race, racism, discrimination, and justice. Further, the students' well-being might be affected if their experiences are not acknowledged, addressed, and built upon in the classroom.

The teachers' concerns about the emotional consequences of raising these issues were exacerbated by the nature of teaching over Zoom during the Covid-19 pandemic. They both recognized that it was more difficult to build relationships with students in the online learning environment and that it was much harder to gauge student reactions as many students had their cameras off. Both teachers had ideas about how it would have been different if they were able to be in person with their students. Sam (School A) said,

> "And I think in the classroom it could be a lot better and you know I didn't think too much about what you're talking about like how to make it so that there is sort of a more mild build up where kids kind of feel like you build some community and like you have some similar language to talk about things. And I think that that could really make this a lot better."

In addition, the limited classroom time to develop community relationships, trust, and a common language to respectfully and openly discuss issues of race made teaching the unit challenging. Sam shared a sense of uncertainty about how students were affected by the unit, despite previously expressing a sense that students would feel a sense of empowerment from engaging in the unit:

> "Maybe it was really powerful for some kids. I don't … I can't really tell. It's so hard to tell. But I think in the classroom just like it could be so much better because you have so much richer conversation, you can stop the [web-based platform] project, you can bring things up, kids can ask questions, you can actually see their actual, even just seeing their reactions, their facial reactions, and knowing what they're thinking it, overhearing discussions between students."

Alex also felt it was especially challenging to engage these topics in the remote environment because it was so much harder to sustain dialogue between students. During remote instruction, they also had fewer opportunities to talk directly with their students, and for students to talk with each other, compared to face-to-face instruction. Alex shared that it was:

> "Challenging to interpret the questions, come up with some responses, because maybe they don't have someone discussing these questions with them out loud, you know, paraphrasing them, or giving them ideas about what they could talk about, or how they can respond. I'm thinking that's … so that's the challenge that students have, right, responding to these questions when they don't have someone else to talk to about [it]."

When asked specifically about whether the unit was having an emotional impact on their students, Alex reflected how hard it is to tell in the virtual classroom environment: "So I have … I can't say for sure that someone can put something in there that might indicate … yeah." Alex felt like it was possible that the content had disturbed the students but was not able to gather enough input from students to tell.

The two teachers highlight the importance of fostering student–student and teacher–student relationships when teaching a justice-oriented science unit, as a means for students to recognize and express their emotional response to the issues. Both teachers expressed concern about their students' well-being, especially since they assume they might be imparting knowledge of racism and discrimination by raising issues of environmental justice. This raises questions that can be addressed in future work that welcomes students' experiences as resources for learning and community building.

5.2 | Variations across contexts

Variations reported in this work may be due to the instructional contexts. Sam is in a school with much support from the principal to teach about racial justice in science and these students are not personally experiencing the high rates of asthma due to air pollution. Alex on the other hand is in a school where teachers are expected to adhere to the teaching of the performance expectations as described by the NGSS and many of the students have asthma due to air pollution in their community. This may relate to Alex's focus on the standards as a way to justify the choice of curriculum. Alex may also need more time to plan how to teach this topic in a way that respects the students' experiences, acknowledging the racial injustice that is occurring and providing concrete steps for students to take action to care for themselves, their families, and community.

5.3 | RQ2: Impact of co-designed materials and teacher enactment on student ideas

5.3.1 | Student pre/posttest assessment

A goal expressed by our partner teachers was to co-design materials that improve students' ability to use their scientific understanding to identify inequitable impacts. To gauge the effectiveness of the materials, we used a paired *t*-test to examine the change in KI score and in the ideas expressed by students in the pre/postassessment. Across all teachers, students made significant preassessment to postassessment gains in their understanding of the differential impacts of effects of climate change and pollution from combustion (mean difference = 0.336, $t = 5.55$, $p < 0.0001$, $d = 0.38$). The mean score at postassessment was 3, indicating that a majority of students had reached the understanding that not all people experience the effects of climate change or combustion in the same way.

Looking more closely at the types of ideas students used in their explanations, we found that at pretest 14% of students explained that the disparate impacts resulted from factors such as past policy decisions, socioeconomic status, and race. By posttest, a significantly higher proportion of students (28%, $Z = 3.46$, $p < 0.001$) were using such social factors to explain that not all people are impacted to the same degree. Thus, the curriculum combined with their teachers' enactment choices supported students to integrate evidence about social factors into their explanations of differential impacts on specific populations.

To explain why some groups experience greater impacts than others, students were more likely to attribute the difference to socioeconomic status than to race at pretest. Only one student (0.5%) across all three teachers mentions race in their initial response. By posttest, however, 28 students (13.3%) discussed race or racial discrimination as playing a role, a significantly greater proportion ($Z = 5.12$, $p < 0.001$). By comparison, 26 students (12.3%) mentioned socioeconomic status at pretest and a comparable proportion of students, 30 (14.2%) mentioned it at the post. Given the greater number of students discussing socioeconomic status than race at the

beginning of the unit, it seems that it was easier for students to express the connection between disparities in impact and differences in socioeconomic status. Eleven of the 27 students who mentioned race at posttest also discussed socioeconomic status at posttest. This suggests the value of building from students' initial ideas about socioeconomic inequities to connect to racial injustice.

Taylor and Sam (School A) expressed that they wanted to address racial injustice directly with their students, had school support to discuss racial justice in science, and aimed to center race in their discussions of the unit, while Alex (School B) expressed that they preferred to focus on socioeconomic and ethnic group differences. Consistent with these preferences, a greater proportion of Sam and Taylor's students (15.2%) than Alex's students (5.1%) discussed race in their posttest responses. These findings suggest the importance of supporting teachers to consider how they will frame the inequities raised in the unit.

The relatively low percentage of students discussing socioeconomic status and race overall (28%) indicates the need for future iterations of the curriculum to provide additional scaffolds to support students to integrate ideas about race and class into their thinking, speaking, and writing. The mirroring between student and teacher framing also suggests that the partnership will benefit from further exploration of ways to address these issues within their current school contexts.

5.3.2 | Building on students ideas to shape curriculum refinement

Student interviews (School A) revealed three main themes after they engaged with the Air Quality and Asthma unit (Table 5). First, students expressed a sense of urgency about climate change as a problem that all people need to take seriously. For example, one student said, "everyone is or will be impacted by climate change no matter where you are located. It's a really big problem." Another student said, "I think we should devote more time to climate change. We usually only spend like a couple weeks doing it, and I think it warrants more of our attention." These statements reflected the student perspective that climate change is a wide-reaching, pressing issue. These statements align with what we saw in many students' written responses to the pre/postassessment, particularly

TABLE 5 Student ideas about the curriculum from interviews after students completed the unit and possible revisions for the next iteration of the curriculum.

Theme	Curriculum revisions for next iteration
Urgency of climate change	Add activities that reinforce students' understanding of the magnitude and urgency of climate change issues and then build on these commitments to help them distinguish differential impacts.
Attribution to SES more than race	Build on students' understanding of the role of SES to introduce the idea of intersectionality. Design activities that guide students to ask questions about which racial identities were targeted by redlining policies. Support students to investigate intersections of race and class in the United States. Add activities to strengthen student understanding of the impact of cycles of disinvestment in neighborhoods. Support students to distinguish the racial identities of groups experiencing the lasting impacts of historical policies.
Curriculum relevance	Build on the perceived relevance of the unit by designing activities where students can explore additional connections between their own experience and the scientific and historical content in the unit (such as proximity to sources of PM pollution or additional policies that impact distribution of PM pollution such as local highway regulation). Support teachers to include or strengthen final projects that enable students to communicate learning and advocate for change within their spheres of influence.

Abbreviations: PM, particulate matter; SES, socioeconomic status.

the inclination at pretest to write that climate change is a problem that will eventually affect all people and the call for all people to take action.

Furthermore, during the interviews and in their written responses, students rarely distinguished groups that are more impacted than others by environmental issues like climate change and combustion pollution. This indicates a need to provide space within the next iteration of the curriculum for students to acknowledge how important it is for all people to take climate change seriously while supporting them to distinguish that the impacts of climate change are disparately distributed.

Second, when discussing differential impacts in interviews and written work, students at both schools talked about socioeconomic status more than about race, neglecting the intersectionality of these issues. Students tended to express that a person's socioeconomic status would increase their likelihood of exposure to the effects and limit their options for moving away from or dealing with the consequences. During interviews, students said things like: "where they live can affect it, or money. That can affect health. With worsening air quality people can be affected if they don't have the money to deal with health" and "I think a lot of people are impacted because it depends on your circumstances or privilege too, honestly. Like if they don't have a lot of money and have to buy a cheaper house." Students' emphasis on socioeconomic status, despite the foregrounding of race in the curriculum, reflects a need to unpack the intersections between race and class in the United States and support teachers to navigate discomfort around discussing race and class.

Third, interviews revealed the relevance of the curriculum for the students and their emerging understanding of environmental racism. For example, one student connected the curriculum to their own experiences and indicated that it supported their understanding: "I had asthma too and it was the worst. I would cough so much. So, I could recognize how people would not like that. Especially if you can't control anything." Students also felt that topics like environmental racism belong in science, even if doing so brought up challenging emotions. When asked about this, one student shared, "I feel like the role of science has changed to sort of think of ways to solve these issues that we built," and another student said "I find it surprising, I feel a little upset that this area that I might or my family or this city might have, might relate to redlining and stuff like that" when reflecting on what they had learned during the unit.

6 | DISCUSSION AND IMPLICATIONS

Informed by justice-centered pedagogy and KI design processes, the partners developed curriculum materials and teaching strategies to support students to deepen their understanding of disciplinary science and issues of social justice. Each partner contributed essential information, respected the views of the other partners, and contributed to a unit that targeted social justice science issues. The partners negotiated multiple challenges that emerged as they designed and implemented the integration of science and social justice in their classrooms. This investigation has relevance and implications for future work in the field.

6.1 | RQ1: Teachers' perspectives on their experiences and needs when integrating justice into science

The interviews yielded insight into the motivations, goals, and challenges of teachers who are beginning to integrate social justice into their science teaching. The partner teachers believed that integrating social justice into their science curriculum would benefit their students. They anticipated that investigations of environmental racism would make science more relevant to students and draw on their students' lived experiences. They thought that including social justice in science could make injustice visible. They wanted to create opportunities for students to use knowledge of injustices to advocate for change.

6.1.1 | Teachers' reflections indicate value of co-design methodology

In prior work, individual teachers report spending years building and refining localized environmental racism curriculum materials (Marks-Block, 2011; Morales-Doyle, 2017). Following the KI-informed co-design process featuring the Curriculum Visualizer, each partner in this study reported that the experience advanced their understanding of pedagogical and local justice issues. Partners benefitted from their shared understanding and use of KI pedagogy. They learned from jointly locating and evaluating data, constructing visualizations of data, and reviewing news articles about air quality, asthma, and the historical practice of redlining in their local area. The community pooled their ideas and supported each other as they developed ways to teach this topic and support students to connect science and social justice across the KI processes. The partners helped each other to identify and build on the skills and techniques they have used in prior KI instruction. Further, the partnership greatly benefited from seeking out a project advisor who brought new perspectives along with expertise in social justice in science and helped improve the unit design. Each participant had the opportunity to benefit from the expertise and experiences of the others. The interviewed teachers reported deepening their knowledge of structural racism in their local community during the design process and believed that the codesign process could help other teachers to do the same.

The use of an open education authoring and customizing environment facilitated the co-design process. Partners could negotiate their ideas and jointly plan the design using the pedagogy-informed Visualizer. These resources supported the partners to localize the curriculum. Additionally, using the Visualizer enabled each partner to contribute to the refinement of the design by commenting on each other's suggestions. Partners took on varied roles including author, evaluator, and designer, supporting mutual learning. The partnership design process resulted in shareable and editable materials where the pedagogical intentions of each activity were visible. Transforming teachers' ideas about how to connect the science content to redlining in the first version of the curriculum was a generative starting point, as reported in the teacher interviews. Further, the shared pedagogical framework developed in prior collaborations, a co-design process aligned to that framework, and technologies that supported rapid design and localizing of the unit enabled the design of a unit that reflected and contributed to teachers' broadening of their pedagogy to incorporate a social justice lens. It also resulted in a unit that allowed teachers to identify the challenges and concerns they faced when implementing a unit that called for new teaching practices, which they want to refine when teaching the unit the next time. This opens a new pathway for research on partnership co-design in social justice science, extending prior work that demonstrated how teachers singularly built and iteratively refined social justice science units over 5+ years (Morales-Doyle, 2017).

The partner teachers valued the co-design process that enabled them to develop a historical understanding of a local justice issue. They felt they benefited from the community of peers and partners who contributed their expertise and perspectives and from their shared knowledge of KI pedagogy. After participating in the co-design process, teachers expressed interest in more opportunities to strengthen their understanding of social justice science issues in their local communities (Morales-Doyle, 2017) and social justice pedagogies, consistent with other investigations (Brown & Crippen, 2017). In response to teacher interest, the partnership developed new professional development activities to accompany the co-design process where partners reflect on how their own identities and histories intersect with those of the students they serve and with the issues raised in the curriculum. This was followed by activities where the partners reflected on how they approach the design and teaching of the units (Gerard et al., 2022). Additional research is needed to develop professional development programs that leverage co-design using localized OER, broaden teacher perspectives and clarify effective practices, as well as deepen understanding of social justice pedagogy in the science context.

6.1.2 | Teaching for social justice in distinct, local contexts

Prior research has elucidated the importance of science teachers developing a sense of social justice issues in their community and a political understanding of the content that they teach (Madkins & Nazar, 2022; Madkins &

McKinney de Royston, 2019; Morales-Doyle, 2017). This research gives insight into how two experienced science teachers, new to integrating social justice in their science teaching, grappled with the issues that arose as they introduced social justice science issues (Morales-Doyle, 2017) into their curriculum. Both teachers supported their students to make sense of and envision solutions for social inequities in their region; they both expressed thoughtful ways that they cared for their students' well-being. Teaching in distinct contexts with differing constraints, the teachers also contributed unique perspectives on the goals that the Air Quality and Asthma unit would help them accomplish. Alex aligned their teaching for social justice with their expected adherence to science standards by prioritizing the NGSS practice of arguing from evidence about solutions for high rates of asthma, an issue many of their students and their school community faced (Ladson-Billings, 1995; Madkins & Nazar, 2022; Morales-Doyle & Gutstein, 2019; Morales-Doyle, 2017). Sam believed that teaching the unit could support students to see themselves as belonging in the field of science and develop their capacity as future voters who can influence policies that impact their communities.

Developing knowledge of history, racism, and effective activism in science supported the teachers to enact their customized lessons. The teachers expressed different stances on whether to center race during their enactment of the Air Quality and Asthma unit. Alex, avoided the words race and racism, concerned that discussion of race would be inherently negative for the students. This teacher preferred to ground the class discussion around concepts such as ethnicity and socioeconomic status. Alex's decisions might have been influenced by their experience as an educator of color concerned with pressure and oversight from the administration. Their experiences highlight the contextual complexities a teacher must navigate when considering whether and how to integrate social justice into science teaching.

Another teacher in our study, Sam, explicitly centered the unit on race. Sam had spent the summer before the formation of our partnership reading books about race and thinking about connections between their curriculum and racial injustices. This provided Sam a different starting point for conceptualizing how racial and social justice pertain to science. Additionally, Sam had differing supports and constraints in their teaching contexts than Alex did. Sam had a supportive administration and peers to collaborate with while implementing the unit while Alex felt pressure from the administration to adhere strictly to standards. The examples from Sam and Alex's experiences illustrate the value of developing science educator knowledge of structural racism and how systems of power operate within science as critical preparation for teaching about science and social justice (Madkins & McKinney de Royston, 2019; Madkins & Nazar, 2022). They also demonstrate starting points for teachers grappling with different political climates and institutional constraints at their school sites.

6.2 | RQ2: Student ideas linking science and social justice

This study contributes new examples of the ways students are able to develop integrated disciplinary understanding through engaging in inquiry into local issues causing injustices in their communities (Dimick, 2012; Morales-Doyle, 2017). Through their engagement with the curriculum, students were able to deepen their understanding of the impacts of climate change and distinguish that not all communities are impacted by climate change in the same way. Some students were also able to further their understanding of the factors that contribute to these disparities, including discrimination based on race and socioeconomic status. Interestingly, we found that many students were already thinking about how geographic location could impact the ways someone experiences the consequences of climate change and pollution from combustion. They could argue that proximity to pollution sources or types of natural disasters common to certain regions was important. In addition, some students already had an awareness of social factors related to the disparity in impacts, primarily linked to ideas about socioeconomic status. Some were able to connect that understanding to ideas about racial injustice throughout the activities in the unit. They understood how racial discrimination could explain why some communities experience more harmful

effects from climate change and combustion pollution than others. This pattern suggests the promise of building on students' ideas to integrate ideas of racial justice into discussions of economic inequality.

Consistent with related research, student interviews revealed that integrating social justice with data visualizations from local communities promoted beliefs that science is relevant (Polman & Hope, 2014; Rubel et al., 2016). The visualization activities supported students to explore issues relevant to their community and broadened the factors students considered in interpreting the relationship between asthma and pollution. Combining justice-centered science pedagogy (Morales-Doyle, 2017) with the KI design principles (Linn & Eylon, 2011) proved to be a valuable approach to support students to integrate understanding of disciplinary content with insights from investigating local injustices as called for in the literature (Barton & Tan, 2010; Buxton, 2010; Calabrese Barton & Tan, 2020; Dimick, 2012; Morales-Doyle, 2017).

The student interviews revealed the need for future revisions of the units to include additional opportunities for students to make sense of evidence in the visualizations to distinguish and explain disparities in impacts. The interviews also revealed the value of exploring the magnitude and gravity of the climate crisis with more precise and generalizable models. More opportunities to reflect on the connections between science and social justice were also identified as important, particularly as students think about how to use their scientific knowledge to advocate and take action for a more just future for their communities.

6.3 | Looking across RQ1 and RQ2: Relationship between teacher framing and student written explanations

We found that whether the teacher chose to center race might have influenced whether and how students discussed the impact of race in their explanations about the impacts of climate change and who is most impacted. Sam expressed during the interview that it is important to name race directly in class discussions. A higher proportion of Sam's students included discussion of racist beliefs and historical racist housing policies in their explanations. In contrast, Alex indicated a preference not to mention race directly and instead focus on socioeconomic and ethnic differences. Their students did not mention race as frequently in their explanations. These findings illustrate how a teacher's framing might influence students' own framing of an issue. The language a teacher uses communicates to students both what are important factors for understanding the issues and the types of explanations that address the issues. If the teacher embraces discussion of race when exploring data that has been called out as racialized in the curriculum, it can signal to students that they can discuss race as well. These findings contribute to prior research that has identified how a teacher's pedagogy which neglected attention to race in guiding data analysis led to choices during teaching that resulted in a student's disengagement from the class discussion (Philip et al., 2016), as well as research that illustrates cases of how teachers who effectively enacted a justice-centered and culturally sustaining pedagogy in their science classrooms positioned students as science learners (Madkins & McKinney de Royston, 2019).

This finding highlights the importance of partnership support for implementation of a unit that prompts students to address social justice issues rooted in racism. Teachers benefit from opportunities to clarify their political stance and explore the implications of their decisions (Madkins & McKinney de Royston, 2019) which was facilitated through our curriculum co-design process. They also benefit from considering the impact of neglecting race (Philip et al., 2016). Devoting attention to the pedagogical moves that support the implementation of antiracism activities in preservice and inservice professional learning programs, including supporting students to explore emotionally charged issues can support teachers to reflect and refine their views (e.g., Morales-Doyle, et al., 2021). Teachers reported that starting from a curricular example in the Visualizer supported them by providing a model for integrating social justice into science. Further, engaging in co-design with the Visualizer elicited the negotiation of design decisions, surfacing pedagogical moves and instructional designs that support this integration. This is a promising approach for teachers who are new to integrating social justice into their science teaching and might hold roles that limit time available for curriculum design.

7 | CONCLUSIONS

The experience of our partnership as we implemented a social justice unit illustrating environmental racism in a constructivist science curriculum revealed challenges and opportunities for teachers new to integrating social justice into their science teaching. The opportunity to build on the partners' knowledge and insights empowered the other partners to deepen their understanding of local social justice science issues and to reflect on their experiences. Combining social-justice science pedagogy (Morales-Doyle, 2017) and KI (Linn & Eylon, 2011) yielded a unit that supported students to investigate racially disparate asthma rates in their local communities alongside standards-aligned science content. The unit can be customized by additional teachers. We found that the co-design process, using a pedagogically informed authoring and customizing environment, supported partner learning about local social justice science issues. We gained insight into the issues science teachers grapple with as they begin to integrate social justice into their science teaching.

This study suggests ways to empower teachers to shift the content and practices of their science instruction toward the integration of locally relevant issues by illustrating connections between science and social justice. Further effort is needed to integrate design pedagogies such as KI (Kali, 2006; Linn & Eylon, 2011) with social justice pedagogies (Bolgatz, 2005; Ladson-Billings, 1995; Morales-Doyle & Gutstein, 2019; Morales-Doyle et al., 2019). Synergies across pedagogies offer ways to support students to expand their epistemologies of science. They also reveal the importance of supporting teachers to refine their understanding of science instructional design and social justice pedagogy.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

ORCID


Allison Bradford http://orcid.org/0000-0002-4198-4435

REFERENCES

Agarwal, P., & Sengupta-Irving, T. (2019). Integrating power to advance the study of connective and productive disciplinary engagement in mathematics and science. *Cognition and Instruction*, *37*(3), 349–366.

Barton, A. C., & Tan, E. (2010). We Be Burnin'! Agency, identity, and science learning. *Journal of the Learning Sciences*, *19*(2), 187–229.

Bichler, S., Gerard, L., Bradford, A., & Linn, M. C. (2021). Designing a remote professional development course to support teacher customization in science. *Computers in Human Behavior*, *123*, 106814.

Bolgatz, J. (2005). *Talking race in the classroom*. Teachers College Press.

Bradford, A., Bichler, S., & Linn, M. C. (2021). Designing a workshop to support teacher customization of curricula. In E. de Vries, Y. Hod, & J. Ahn (Eds.), *Proceedings of the 15th International Conference of the Learning Sciences - ICLS 2021*. International Society of the Learning Sciences.

Brown, J. C., & Crippen, K. J. (2017). The knowledge and practices of high school science teachers in pursuit of cultural responsiveness. *Science Education*, *101*(1), 99–133.

Buxton, C. A. (2010). Social problem solving through science: An approach to critical, place-based, science teaching and learning. *Equity & Excellence in Education*, *43*(1), 120–135.

Calabrese Barton, A., & Tan, E. (2020). Beyond equity as inclusion: A framework of "rightful presence" for guiding justice-oriented studies in teaching and learning. *Educational Researcher*, *49*(6), 433–440.

Corburn, J. (2005). Street science: community knowledge and environmental health justice. Cambridge, MA, MIT Press.

Dimick, A. S. (2012). Student empowerment in an environmental science classroom: Toward a framework for social justice science education. *Science Education*, *96*(6), 990–1012.

Foster, J. (2020, May). Learning about environmental racism and local contaminants. *National Science Teaching Association Next Gen Navigator*. https://www.nsta.org/blog/investigating-environmental-racism-high-school-biology-classroom

Freire, P. (1970). The adult literacy process as cultural action for freedom. *Harvard Educational Review*, *40*(2), 205–225.

Gerard, L., Bradford, A., DeBarger, A., Wiley, K., & Linn, M. C. (2022). Cultivating teacher efficacy for social justice in science breadcrumb. *Science Scope*, *45*(5), 35–43.

Inhelder, B., & Piaget, J. (1958). *The growth of logical thinking from childhood to adolescence: An essay on the construction of formal operational structures* (22). Psychology Press.

Kali, Y. (2006). Collaborative knowledge building using the design principles database. *International Journal of Computer-Supported Collaborative Learning*, *1*(2), 187–201. https://doi.org/10.1007/s11412-006-8993-x

Kraig-Turner, G. (2016). Medical apartheid: Teaching the Tuskegee Syphilis study. *Rethinking Schools*, *31*(2). https://rethinkingschools.org/articles/medical-apartheid/

Ladson-Billings, G. (1995). Toward a theory of culturally relevant pedagogy. *American Educational Research Journal*, *32*(3), 465–491.

Ladson-Billings, G. (2009). *The dreamkeepers: Successful teachers of African American children*. John Wiley & Sons.

Linn, M. C., & Eylon, B. S. (2011). *Science learning and instruction: Taking advantage of technology to promote knowledge integration*. Routledge.

Linn, M. C., Eylon, B. S., & Davis, E. A. (2004). The knowledge integration perspective on learning. In M. C. Linn, E. A. Davis, & P. Bell (Eds.), Internet environments for science education (pp. 29–46). Lawrence Erlbaum Associates Publishers.

Linn, M. C., & Hsi, S. (2000). *Computers, teachers, peers: Science learning partners*. Routledge.

Liu, O. L., Lee, H.-S., & Linn, M. C. (2011). Measuring knowledge integration: Validation of four-year assessments. *Journal of Research in Science Teaching*, *48*(9), 1079–1107. https://doi.org/10.1002/tea.20441

Madkins, T. C., & McKinney de Royston, M. (2019). Illuminating political clarity in culturally relevant science instruction. *Science Education*, *103*(6), 1319–1346.

Madkins, T. C., & Nazar, C. R. (2022). Theoretical perspectives for developing antiracist teaching dispositions and practices in preservice teacher education. *Science Education*, *106*(5), 1118–1134.

Marks-Block, T. (2011). Science for the people: High school students investigate community air quality. *Rethinking Schools*, *25*(3). https://rethinkingschools.org/articles/science-for-the-people-high-school-students-investigate-community-air-quality/

Morales-Doyle, D. (2017). Justice centered science pedagogy: A catalyst for academic achievement and social transformation. *Science Education*, *101*(6), 1034–1060. https://doi.org/10.1002/sce.21305

Morales-Doyle, D., Childress Price, T., & Chappell, M. J. (2019). Chemicals are contaminants too: Teaching appreciation and critique of science in the era of Next Generation Science Standards (NGSS). *Science Education*, *103*(6), 1347–1366.

Morales-Doyle, D., & Gutstein, E. (2019). Racial capitalism and STEM education in Chicago public schools. *Race Ethnicity and Education*, *22*(4), 525–544.

Morales-Doyle, D., Varelas, M., Segura, D., & Bernal-Munera, M. (2021). Access, dissent, ethics, and politics: Pre-service teachers negotiating conceptions of the work of teaching science for equity. *Cognition and Instruction*, *39*(1), 35–64.

Philip, T. M. (2011). An "ideology in pieces" approach to studying change in teachers' sensemaking about race, racism, and racial justice. *Cognition and Instruction*, *29*(3), 297–329.

Philip, T. M., Olivares-Pasillas, M. C., & Rocha, J. (2016). Becoming racially literate about data and data-literate about race: Data visualizations in the classroom as a site of racial-ideological micro-contestations. *Cognition and Instruction*, *34*, 361–388.

Polman, J. L., & Hope, J. M. G. (2014). Science news stories as boundary objects affecting engagement with science. *Journal of Research in Science Teaching*, *51*(3), 315–341.

Rodriguez, A. J. (2015). What about a dimension of engagement, equity, and diversity practices? A critique of the next generation science standards: What about a dimension of engagement, equity, and diversity practices? *Journal of Research in Science Teaching*, *52*(7), 1031–1051.

Rubel, L. H., Lim, V. Y., Hall-Wieckert, M., & Sullivan, M. (2016). Teaching mathematics for spatial justice: An investigation of the lottery. *Cognition and Instruction*, *34*(1), 1–26.

Saldaña, J. (2013). *The coding manual for qualitative researchers*. Sage.

Sheth, M. J. (2019). Grappling with racism as foundational practice of science teaching. *Science Education*, *103*(1), 37–60.

Sleeter, C. E. (2017). Critical race theory and the whiteness of teacher education. *Urban Education*, *52*(2), 155–169.

Tate, E. D. (2009). *Asthma in the community: Designing instruction to help students explore scientific dilemmas that impact their lives*. University of California.

Vakil, S., & Higgs, J. (2019). It's about power. *Communications of the ACM*, *62*(3), 31–33.

How to cite this article: Bradford, A., Gerard, L., Tate, E., Li, R., & Linn, M. (2023). Incorporating investigations of environmental racism into middle school science. *Science Education*, *107*, 1628–1654. https://doi.org/10.1002/sce.21824