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"People Need to Speak Up": Preservice Secondary Science Teachers' Movement Toward a Justice-Centered Science Education

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ABSTRACT

Teacher education programs must prepare their preservice science teachers to center social justice and to meet the academic needs of culturally, racially, and linguistically diverse students, as justice-centered discourses are traditionally absent from science classrooms yet integral to the teaching and learning of rich and relevant phenomena. In this study, we investigated a cohort of preservice secondary science teachers enrolled in a yearlong, post-baccalaureate teacher education program that attended to social justice. We conducted four interviews with each participant across their program and qualitatively analyzed their discussions of social justice ideas and teaching practices using three tenets of a justice-centered science pedagogy framework: enacting an antiracist and equitable science education, grounding instruction in social and environmental justice phenomena, and framing students as transformative intellectuals. We found preservice teacher participants discussed enacting antiracist and equitable science teaching by using a critical lens to identify inequities in classrooms and schools, and by attending to high academic expectations. Preservice teachers described focusing on socioscientific phenomena and local contexts as starting points for teaching about social justice science issues. Participants also shared their work toward framing students as transformative intellectuals by developing teacher-student relationships, building from students' ideas, and discussing emerging ideas and efforts for student advocacy. Findings from this study underscore the need for more focused work on ways to prioritize the justice component of social justice science issues and the student advocacy component of students as transformative intellectuals so as to prepare preservice teachers to fully enact a socially just science education.

KEYWORDS

Justice-centered science; reform-based teaching; science teacher education; secondary science

Scholars note that the transformation of teacher education is critical to advancing equity and justice goals in K-12 school settings (Domínguez, 2019; Goodwin & Darity, 2019; Kretchmar & Zeichner, 2016; Zeichner, 2016). In the United States, students of increasingly diverse ethnicities, races, socioeconomic backgrounds, and languages attend public schools, yet teachers continue to be predominantly White, middle class, and monolingual native English speakers (Cochran-Smith & Villegas, 2016; Sleeter, 2017). To make further progress in preparing preservice teachers to center social justice and to meet the academic needs of culturally, racially, and linguistically diverse students, it remains crucial to investigate how

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preservice teachers learn to enact teaching that decenters whiteness; fosters criticality; values diverse languages, cultures, and epistemologies; and supports students in working to change social inequities (Kohli et al., 2022; Ladson-Billings, 2000).

The need for socially just preservice teachers of science is perhaps even more critical, as justice-centered discourses are often absent from science classrooms and science teacher education contexts (Rodriguez, 2015). Social justice in science teacher education is concerned with teaching and learning science as a civil right and social responsibility (Moore, 2007). It requires that preservice teachers work to construct a social justice science teacher identity (Boylan & Woolsey, 2015), including the belief that every student has the right to have access to and learn science, and the commitment to creating learning opportunities that center phenomena based on real social and environmental justice issues. Preservice teachers who make socially just science education the foundation of their classrooms build connections to students' lives, cultures, interests, and experiences (Paris & Alim, 2014); implement curriculum and instruction that is academically rigorous and culturally relevant to students (Ladson-Billings, 2000); examine the historically racist and inequitable aspects of science practices and products (Mutegi et al., 2022); and encourage students to use science as a critical tool in addressing equity and social justice issues (Buxton, 2010; Morales-Doyle, 2017). Because preservice science teachers may not have learned to connect the teaching and learning of science with social justice issues in their own elementary, secondary, and/or university experiences, it is imperative that science teacher education programs provide preparation in social justice frameworks and pedagogies (Chen & Mensah, 2018; Madkins & Nazar, 2022). Because research shows that teachers' visions of teaching matter for their instruction (Hammerness & Kennedy, 2019; Windschitl et al., 2021), it is important that teacher education programs understand preservice teachers' ideas about justice-centered science education so as to support their emerging practice in meaningful ways (Boylan & Woolsey, 2015; Jones & Donaldson, 2022; Moore, 2007).

In our study, we explored one cohort of preservice secondary science teachers enrolled in a yearlong, post-baccalaureate teacher education program with a renewed commitment to addressing antiracism and injustice in response to the murder of George Floyd in May 2020. We used Morales-Doyle's (2017) justice-centered science pedagogy framework to guide our qualitative analysis of preservice teacher interview data. Morales-Doyle's justice-centered science pedagogy frames students as producers of knowledge and engages them in academically rigorous learning to investigate and act on social and environmental justice issues. Our study's purpose was to contribute to the emerging, critically needed literature on how to prepare preservice teachers to teach science in equitable and socially just ways (see Morales-Doyle, 2017, p. 1057). We focused on preservice teachers' ideas because ideas provide the foundation upon which they make decisions about and enact socially just science teaching in their classrooms (Jones & Donaldson, 2022; Moore, 2007). The following research question guided our study: How did preservice secondary science teachers discuss their ideas about and their teaching practices related to justice-centered science pedagogy?

Conceptual framework

We used the construct of justice-centered science pedagogy (Morales-Doyle, 2017) to frame our research on preservice teacher learning of a socially just science education. More specifically, because courses in the teacher education program under study

attended to social justice in different ways, we analyzed our data using Morales-Doyle's justice-centered science pedagogy framework to better identify possibilities for how preservice science teacher education can become more socially just. Morales-Doyle's framework is rooted in two foundational constructs: Freire's (1970) conscientization and Ladson-Billings' (1995) culturally relevant pedagogy. It expands on the work of Freire and Ladson-Billings by using social justice science issues as anchoring phenomena. The framework includes three tenets: enacting an antiracist and equitable science education, exploring local justice-related science issues, and positioning students as transformative intellectuals. These tenets intersect and overlap with each other.

To elaborate, one tenet of justice-centered science pedagogy is the enactment of an antiracist and equitable science education (Morales-Doyle, 2017). Teachers are expected to hold equitable academic expectations by teaching rigorous science content and adequately scaffolding students' access to disciplinary ideas and participation in discourse and practices. Alignment with the NGSS disciplinary core ideas (DCIs), crosscutting concepts (CCCs), and science and engineering practices (SEPs) serves as the criterion for meeting equitable academic expectations (NGSS Lead States, 2013). Instruction aligned to the NGSS promotes equity by teaching students the science content and practices that are valued by schools and that are required for advancing in educational and career opportunities related to science. To avoid assimilating students into traditional Western science, however, this tenet also emphasizes helping students to develop a critical awareness: to understand the ways that the economic order, gender and sexism, race and racism, and resistance to linguistic diversity structure schools and society; and to learn to see themselves as capable of addressing inequities in their classrooms, in their communities, and in science itself.

A second tenet of justice-centered science pedagogy requires social justice science issues to be the central themes in instruction (Morales-Doyle, 2017). Social justice science issues provide a starting point for students to interrogate their local context—to investigate the intersection of pressing social issues with natural, scientific, or technological phenomena as well as to question and critically consider aspects of culture, race, language, and diverse epistemologies. By foregrounding students' own experiences in and knowledge of their community, by then using their ideas and investigations both to understand a local example of a socioscientific issue and to work toward social and/or environmental justice, social justice science issues are explored in ways that are ambitious, hopeful, and transformative.

As a third tenet of justice-centered science pedagogy, students are framed as transformative intellectuals—as producers of knowledge and culture who enact change in their communities (Morales-Doyle, 2017). Teachers must provide opportunities for students to not only define the social justice science issue to be explored, and to plan and conduct investigations related to it, but to engage in advocacy by making decisions about and acting on their findings as well (see Lee et al., 2022). In disseminating their findings to other students, their families, and their community, students learn both that they are capable of generating knowledge about the world and that they are able to address systemic inequities in their community in culturally relevant ways. We add that, in our study, we broadened this tenet to include the foundational practices of developing teacher-student relationships, establishing a safe classroom community, and building on students' ideas and experiences (see Brown-Jeffy & Cooper, 2011).

Review of relevant literature

We organized our review of preservice science teacher education studies using Morales-Doyle's (2017) three tenets. Studies related to Morales-Doyle's tenet of an antiracist and equitable science education make clear that preservice teachers' own ideas, their teacher education coursework, and their field placements can support or constrain their development as socially just and culturally relevant teachers (Chen & Mensah, 2018; Jones & Donaldson, 2022; Larkin et al., 2016; Mensah et al., 2018; Moon et al., 2021; Rivera & Titu, 2021; Rivera Maulucci, 2013; Windschitl et al., 2021). As one example, Rivera and Titu (2021) found that preservice secondary science teacher participants struggled to identify connections across diversity, race, and the teaching of science. The preservice teachers' own colorblind ideologies contributed to their resistance to implement antiracist and equitable pedagogy. As a second example, Jones and Donaldson (2022) examined preservice secondary science teachers' understanding of culturally relevant science teaching, an extension of Ladson-Billings's (1995) culturally relevant pedagogy. Jones and Donaldson (2022) found that most participants discussed tenets of academic success and cultural competence in their self-reports of instruction; however, few described the tenet of developing students' sociopolitical consciousness. These researchers underscored the need for teacher education programs to focus on cultivating preservice teachers' own sociopolitical consciousness and teaching them how to implement this tenet in their instruction. As a third example, Windschitl et al. (2021) investigated what preservice secondary science teachers learned from their field placements about equitable and reform-based teaching, defined as aligned with the NGSS and as foregrounding contextualization, opportunities for sensemaking, engagement in disciplinary work, and assessment practices to improve instruction. Windschitl et al. found that preservice teachers placed with cooperating teachers who shared this vision of instruction had markedly more opportunities to plan and teach in equitable and reform-based ways than those placed with more traditional teachers.

Studies we identified related to Morales-Doyle's (2017) tenet of social justice science issues described mixed success in helping preservice teachers integrate local contexts and social justice issues into their science instruction (Borgerding & Dagistan, 2018; Mark & Id-Deen, 2020; Tolbert et al., 2019). Tolbert et al. (2019), for example, used the Secondary Science Teaching with English Language and Literacy Acquisition (SSTELLA) instructional framework, a framework for situating lessons within relevant contexts and using student funds of knowledge, to determine the extent to which two preservice teachers contextualized their science instruction. Researchers found that preservice teachers made connections between science content and students' lives. However, when one preservice teacher taught about toxicity and water contamination, he missed opportunities to ask students to apply this to their own community. Both preservice teachers also failed to facilitate connections across science content, local politics, environmental justice, and community economic issues. As a second example, Mark and Id-Deen (2020) used the lens of culturally relevant pedagogy to examine preservice secondary science and mathematics teachers' instructional planning. Researchers found that a small subset of participants designed lessons to engage their students in learning about social injustices, such as urban heat islands linked to environmental racism, and created opportunities for students to take empowered action, connected to our third tenet below. Mark and Id-Deen recommended teacher educators help all preservice

teachers teach justice-centered science by beginning instruction with frameworks that disrupt historical power and privilege, rather than concluding lessons by making culturally significant connections.

Studies related to Morales-Doyle's (2017) tenet of youth as transformative intellectuals also reported mixed success in preservice teachers' efforts to engage their students in agency and advocacy (Mark & Id-Deen, 2020; McCollough & Ramirez, 2012; Mensah, 2022). McCollough and Ramirez (2012), for example, found K-8 preservice teachers successfully built connections across school, families, and communities through participation in community science events and family science nights. Creating culturally relevant science activities and building home-school connections deepened and diversified preservice teachers' content knowledge and knowledge of the communities in which they taught. However, the preservice teachers in their study did not go further to engage their students and families in working to understand and enact change in their communities. Mensah (2022), as a second example, substantiated the need for science teacher education to address preservice teachers' cultural competence and abilities to plan instruction that supports students in social action. Mensah investigated the ways that preservice elementary teachers integrated higher levels of Banks' (2013) multicultural pedagogy into their science planning, teaching, and assessing of student learning. In contrast to McCollough and Ramirez's (2012) participants, the preservice teachers in Mensah's (2022) study learned to engage their students in social action. Mensah emphasized the need for teacher education to support preservice teachers in learning to use the science standards, broaden their understanding of science as a means to integrate multiculturalism and address inequities, and incorporate students' knowledge and interests into their planning and instruction. Scholars outside of science teacher education underscore the importance of helping youth engage with science in a community context to support equitable learning outcomes, disrupt power dynamics, and position students as competent and agentic (Archer et al., 2020; Calabrese Barton & Tan, 2018; Dimick, 2012; Gray et al., 2020; Upadhyay et al., 2020).

Our study, then, contributes to the emerging research base on how teacher education programs can better support their preservice teachers in learning to teach a socially just science education. It offers new possibilities by using the tenets of justice-centered science pedagogy (Morales-Doyle, 2017) to identify mis/connections within and across preservice teachers' discussions of ideas and teaching practices related to an antiracist and equitable science education, social justice science issues, and students as transformative intellectuals.

Materials and methods

We used a case study research design (Yin, 2018) to understand the complex, context-embedded phenomenon of science teacher education at one university. A case study method allows researchers to engage in an in-depth examination of a "how" (or "why") question. A case is defined as a single unit derived from one's research question and bounded by time, content, and organization. We defined our case as the cohort of preservice secondary science teachers earning their credential during the 2020–2021 year. For the larger study, data collected included course materials, interviews with teacher educators and preservice teachers, course observations, and preservice teacher coursework. For this particular study, we focused on the preservice teacher interview data: We explored how

participants made meaning of their own ideas and actions (Brinkmann & Kvale, 2015) as they engaged with topics and activities related to a socially just science education in their teacher education program.

Science teacher education context

The context for this study was a small, 12-month, post-baccalaureate teacher education program at a public university in California. Preservice teacher participants were enrolled in a secondary single-subject teaching credential program, earning teaching credentials in physics, chemistry, and/or biology. Most were earning a concurrent master's degree in education. Preservice teachers completed courses at the university, including three science methods courses, a professional issues course, and a program-wide seminar on antiracism and social justice. Participants also completed three field placements at local junior high and high schools.

To elaborate, preservice teachers completed three secondary science methods courses to develop their pedagogical content knowledge related to reform-based and equitable science; to learn to design and implement learning experiences for diverse students, particularly multilingual learners; and to become reflective educators. Two of the methods courses used ambitious science teaching (Windschitl et al., 2018) as their organizing framework; the third, principles of effective multilingual learner instruction (Meier et al., 2020). For example, in their summer methods course, preservice teachers investigated the social justice science issue of dying shellfish due to ocean acidification in the Pacific Northwest and its effect on local indigenous tribes and the local economy (e.g., oyster farming). Preservice teachers used this social justice science phenomenon to examine climate change through different disciplinary lenses, to identify connections to the NGSS, and to gain experience with the ambitious science teaching framework.

In their yearlong professional issues course, preservice teachers learned about various aspects of becoming an effective and equitable science teacher, including ambitious science teaching methods, socially just and antiracist science content and instruction, and building positive relationships with students. The course website provided resources covering a wide range of topics, many of them aligned with one or more of the three tenets of justice-centered science pedagogy. The course itself was divided into 10 topics, including the topics of environmental justice, race and gender in STEM, the need to diversify STEM practitioners and products, antiracism, and Indigenous ways of knowing. The teacher educator also brought in guest speakers to share their expertise; topics that guest speakers discussed included restorative justice, alternative schooling, and building positive relationships with students.

An antiracism seminar was held monthly by the teacher education program to help preservice teachers understand how systemic racism and internalized racism impact both their teaching practices and the larger structures of school and society. Preservice teachers examined how racism is woven into the history of public education; how this systemic racism shapes their own teaching visions, curriculum, and pedagogy; and how implicit biases affect their ability to work in discretionary spaces with students. Preservice teachers also learned strategies to design and enact antiracist teaching in their own classrooms. See Table 1 for details of alignment between justice-centered science pedagogy and the frameworks and topics used in these courses.

Table 1. Alignment of the justice-centered science pedagogy framework to teacher education courses.

Justice-Centered Science Pedagogy Framework	Methods Course Ambitious Science Teaching Framework	Methods Course Principles of Multilingual Learner Instruction	Professional Issues Course Topics	TEP Antiracism Seminar Topics
Antiracist and equitable science education	Aims to support students of all racial, ethnic, and class backgrounds to understand science ideas, participate in scientific activities, and solve authentic problems aligned with the NGSS Plans for engagement with important science ideas Supports on-going changes in student thinking Presses students for evidence-based explanations	Cultivates learning environments where students' languages and ideas are centered Attends to disciplinary language demands and the creation of appropriate supports for students' understanding and use of disciplinary language Engages students in cognitively demanding work aligned with the NGSS	Demonstrates how the field of science has perpetuated racism through unethical and unjust experiments, hiring practices, and a lack of inclusion in academia and industry Highlights the contributions of scientists of minoritized races Demonstrates ways that art, music, and technology can be integrated into science learning and the presentation of scientific ideas Engages students in understanding how scientists can ensure that their research is conducted ethically and safely, and that their data are reliable Integrates science and social studies and facilitates collaboration with social studies teachers to support students in planning lessons based on socioscientific issues Utilizes an asset-based perspective to explore alternative schooling and teaching practices for students who were expelled or previously incarcerated	Provides space for preservice teachers to learn about and reflect on how systemic racism and internalized racism impact their teaching Explores the legacy of racism in the US educational system Examines how teachers are socialized around racism and how this shapes their teaching Encourages holding conversations around race and justice Identifies and disrupts implicit biases
Social justice science issues	Centers anchoring phenomena, which can be tied to social and/or environmental justice issues		Explores how students can design solutions to climate change issues Supports students in learning about indigenous ways of knowing and highlights learning activities that explore relationships with the environment Encourages place-based teaching and centering the local community when planning science units	

(*Continued*)

Table 1. (Continued).

Justice-Centered Science Pedagogy Framework	Methods Course Ambitious Science Teaching Framework	Methods Course Principles of Multilingual Learner Instruction	Professional Issues Course Topics	TEP Antiracism Seminar Topics
Youth as transformative intellectuals	Focuses on eliciting and using ideas from a wide range of students	Encourages a safe classroom community where all students' ideas are valued, elicited, and built on Builds on and uses students' funds of knowledge and resources, for example, by encouraging use of multiple languages and modalities, and centering family and community knowledge Provides students multiple opportunities for rich language and literacy exposure and practice	Examines environmental justice issues and grassroots organizations that work to improve their communities Supports the implementation of restorative justice practices in classrooms Encourages the building of positive relationships with students and facilitating a welcoming and safe learning environment	Utilizes "mirrors, windows, and doors" to provide opportunities for all students to see themselves in the curriculum and become empathetic to the experiences of others Supports preparing for, holding, and reflecting on difficult conversations with students

Participants and researchers

All nine preservice secondary science teachers enrolled in the teacher education program during the 2020–2021 year participated in this study. To help provide participants a voice in how they were represented, we asked them open-ended questions about their race/ethnicity, first language, and gender, and gave them the option to select their pseudonym. Participants included four White or Caucasian women, three White or European men, one Japanese man, and one Latinx man. Seven spoke English as their first language; one, French; and one, Japanese. Two were first-generation college students. (See Table 2.)

We acknowledge that our own ideas, histories, and positionalities as researchers shaped the culturally situated meanings we brought to the research process, our interactions with preservice teacher participants, and what we were able to see in our data (Madkins & Nazar, 2022; Mattheis et al., 2020; Windschitl et al., 2021). The first author identifies as a Mexican woman and her first language is English. While she served as an instructor in the teacher education program, she did not teach the preservice teachers in this study. She led the collection, analysis, and presentation of data. The second author is the daughter of Italian immigrants who speaks English as her first language. Because she taught the science methods course focused on effective instruction for multilingual learners, she participated only in the analysis and presentation of data. We hope that, by sharing extended excerpts from our interviews with preservice teachers, our claims are less dependent on our own identities and more reflective of our participants' ideas and experiences.

Data collected

To investigate preservice teachers' ideas about and reported enactment of justice-centered science pedagogy, we used a semi-structured interview protocol (McIntosh & Morse, 2015). The protocol included 22 questions, most with one to three follow-up questions; the protocol was used, with minor changes, for each of four administrations. (See Appendix for the spring protocol.) Questions were organized into seven broad categories, including their conceptions of effective science teaching and learning, their own development as an effective teacher, the NGSS practices and crosscutting concepts, and the teaching of multilingual learners.

Table 2. Preservice secondary science teacher participants' demographic information.

Preservice Teacher	Science Credential	Race/ Ethnicity	First Language	Gender	First Generation College Student
Rachel	Biology	White	English	Female	No
Mobius	Chemistry	European	French	Male	No
Stella	Chemistry	Caucasian	English	Female	No
Gil	Biology	White	English	Male	No
Sawyer	Chemistry	Latinx	English	Male	Yes
Kat	Biology	White	English	Female	No
Turtle Dad	Chemistry	White	English	Male	No
Liam	Physics	Japanese	Japanese	Male	Yes
Kim	Biology	Caucasian	English	Female	No

Preservice teachers were given the option to select their own pseudonyms in their final interview; those who declined to do so were given one by the researchers. All other information was self-reported by preservice teachers in an initial survey. Questions about race/ethnicity, first language, and gender were posed as open-ended questions.

Each preservice teacher participant was interviewed four times across the yearlong program. The first interview was conducted during their summer teacher education coursework but prior to their fieldwork experiences. The remaining three interviews were conducted while preservice teachers were in their teaching placements: at the end of fall, winter, and spring quarters. Participants were interviewed individually on Zoom by the first author or another member of the research team. Interviews lasted 60 to 90 minutes and were video recorded. Eight of our nine preservice teachers participated in all four interviews. Because Kim participated in only the first two interviews, she was excluded from our analysis.

Data analysis

To begin our qualitative analysis, recorded interviews were machine transcribed. Transcripts were then checked by a member of the research team and imported into the qualitative software program NVivo. Assignment of codes and identification of themes occurred over three cycles (see Table 3). In the first cycle, we used three a priori codes (Saldaña, 2016) constructed from the tenets of justice-centered science pedagogy (Morales-Doyle, 2017) to code preservice teachers' responses to each interview question. In the second cycle, we assigned subcodes to all responses coded in cycle 1. Most of these subcodes were created a priori, taken from careful examination of our expanded Morales-Doyle's framework; several emerged during the process of data analysis (i.e., ambitious science teaching and teacher as facilitator). In the third cycle, to answer our research question on preservice teachers' discussions of ideas and teaching practices related to justice-centered science pedagogy, we looked for patterns in and across subcodes to develop themes (see again Saldaña, 2016).

The trustworthiness of our qualitative findings (Brenner, 2006) was ensured in two ways. First, once the cycle 1 codebook was finalized, the first and second authors independently coded 20% of the interviews and checked their codes for agreement; an acceptable reliability of 88% was reached (O'Connor & Joffe, 2020). The first and second authors then coded the remaining interviews separately and met regularly to review and discuss each other's assigned codes. Second, we reviewed course materials to clarify information about activities and assignments shared by participants and invited a science teacher education colleague who taught methods and professional issues courses to provide feedback on a draft of our manuscript.

Findings

We present our findings by each tenet of justice-centered science pedagogy.

Enacting an antiracist and equitable science education

For the tenet of enacting an antiracist and equitable science education, we found that all eight preservice teacher participants discussed both critical awareness and equitable academic expectations in their interviews. For the former, participants underscored the importance of teachers and students understanding and working to address institutional and systemic inequities. For the latter, preservice teachers described how the NGSS could be used in synergistic ways with instructional

Table 3. Justice-centered science pedagogy codes, subcodes, and themes.

Cycle 1 Codes and Definitions	Cycle 2 Subcodes and Definitions	Cycle 3 Themes
Antiracist and equitable science education: A tenet of justice-centered science pedagogy focused on both equitable academic expectations and critical awareness.	Ambitious science teaching: Instructional approach that supports students of all backgrounds in engaging with important science ideas, participating in the activities of the discipline, and solving authentic problems. Conscientization: The process by which students come to view themselves as capable of eliminating oppression and social inequities. Critical awareness: Attention to the ways the economic order, gender and sexism, and race and racism structure schools and society. Culturally relevant pedagogy: Instructional approach that supports academic success, cultural competence, and critical consciousness. NGSS: Use of core ideas, practices, and/or crosscutting concepts in instruction. Racial awareness: Attention to environmental racism, scientific racism, and medical apartheid, among others. Scaffolds: Use of strategies to make content comprehensible to students (e.g., sentence starters, technology tools, group structures).	Participants hold equitable and rigorous academic expectations for all students. Participants discuss the need for critical awareness for themselves and for their students.
Social justice science issues: A tenet of justice-centered science pedagogy that calls for use of local contexts to both understand science and address systemic inequities.	Phenomenon tied to socioscientific issues: A natural, scientific, and/or technological phenomenon that is socially relevant and tied to social and/or environmental issues. Place-based: Use of the local community, culture, and/or environment to contextualize science learning. Attention to institutional, systemic, and structural inequities: Critical consideration of aspects of culture, race, language, and diverse epistemologies; connections to environmental racism; and/or work toward environmental justice related to the phenomenon under investigation.	Participants provide examples of phenomena tied to socioscientific issues. Participants connect phenomena to local contexts.

(*Continued*)

Table 3. (Continued).

Cycle 1 Codes and Definitions	Cycle 2 Subcodes and Definitions	Cycle 3 Themes
Youth as transformative intellectuals: A tenet of justice-centered science pedagogy that describes students as producers of knowledge and culture who enact change in their communities.	A safe and inclusive classroom environment: A classroom inclusive of the gender, race/ethnicity, culture, and language of all students. Cultural competence: Eliciting, valuing, and using diverse perspectives, ways of knowing, and contributions from students, their families, and their communities. Equitable discussions: Discussions that elicit ideas from a wide range of students and include diverse perspectives. Relationships and rapport with students: Teacher supports students in feeling safe, sharing ideas, and taking academic risks. Student advocacy: Students make informed decisions and take responsible actions to improve their lives and/or their community. Student ideas as important: Teacher and students value students' ideas by eliciting, listening to, and/or responding to each other. Student ideas or work publicly shared: Students present their work to families and/or communities in a culturally relevant way. Teacher as facilitator: Teacher facilitates students' participation, reasoning, and/or sensemaking.	Participants describe teacher-student relationships as the foundation for instruction. Participants see student ideas as important resources for teaching and learning. Participants share emerging conceptions of student advocacy.

scaffolds and ambitious science teaching practices to engage students in reasoning and sensemaking (Colley & Windschitl, 2016). We present two preservice teachers' discussions of these components of an antiracist and equitable science education below.

Sawyer, for example, shared his commitment to teaching chemistry to students "from impoverished communities or people of color" rather than "honors students in a very well-off neighborhood" in his summer interview. "I would much rather teach the students who [are] kind of detached from education," he continued, "because they've grown to do so just because of the way tracking works and everything." He stated his intent to integrate "inquiry-based learning," "antiracist" teaching, ways of "bringing culture into the classroom," and "gradeless teaching" that he had first learned about in an undergraduate science education course into his own instruction. He drew contrasts between how he was taught science as a K-12 student and how he intended to teach his own students, "It felt like I couldn't experience that [kind of education as a student], but I think it'd be awesome if I could help future students experience that [as a teacher]." In both his winter and spring interviews, Sawyer discussed what had become a focus of his antiracist teaching efforts: "grading for equity practices." He described how he tried to ensure that "the way students are assessed is equitable"—aligning assessments with the NGSS, requiring assessment retakes, and basing grades solely on assessments—so as to share "ownership of their learning" with students. Indeed, Sawyer investigated how equitable grading practices affected student motivation for his master's in education action research project.

Sawyer also discussed equitable academic expectations when sharing his teaching of science units aligned to the NGSS; his descriptions of some of these units connected to social justice science issues and to students as transformative intellectuals, the other two tenets of justice-centered science pedagogy. In his fall interview, Sawyer discussed engaging his high school chemistry students in the crosscutting concept of cause and effect, and the science and engineering practice of arguing from evidence when implementing a unit on climate change. To engage his students in arguing from evidence, Sawyer elaborated, he asked them to systematically evaluate a number of tweets about climate change using the following three questions as an instructional scaffold:

> [First,] is the person who tweeted this a reliable source, or trustworthy person, trustworthy source? [Second,] is the evidence they provide trustworthy, so like the website or the data? And then [third,] does the evidence actually support the claim?

Sawyer stated that he sought out resources to teach students how to evaluate whether or not information was from a reliable source and to identify misinformation. As a science teacher, he emphasized, he had a responsibility to support students in critically evaluating information about topics such as climate change or COVID vaccines that they found online: "I really, really think that, as science teachers, a huge responsibility lies on our shoulders to prepare our kids to really just not accept things at face value that people claim, especially on social media."

As did Sawyer, Rachel expressed a commitment to engaging in antiracist and culturally relevant teaching as a beginning biology teacher in her summer interview. In her winter interview, she discussed what she had learned about "anti-racism and justice-centered pedagogy" specifically from the teacher education program's antiracism seminar. She

suggested ways the program could further support preservice teachers in learning to enact purposeful antiracist and social justice work:

> [We're] recording all these [classroom] videos for the edTPA [assessment]. Have others watch these videos and look for instances . . . . Are your unconscious biases influencing your decision here? Look at your grades. Are your grades revealing [a] pattern? . . . Or the feedback you give or the types of support you give. [Is] this offered [only to] certain students? Does that reveal any biases or prejudice that you might have?

To address teacher biases once they had been identified, Rachel continued, it would be helpful to learn how to "check yourself and how to stop that from continuing going forward." It would also be helpful to learn how to hold the antiracist conversations that were introduced in the seminar:

> What to do if your CT [cooperating teacher] does something that you think isn't equitable in the classroom. What to do if an administrator does something. What to do if a student says something in a classroom that you think may be coming from a place of racism.

Rachel thought she might have learned more about how to engage in diversity, equity, and justice work had the seminar topics been better "integrated with our classes" and had preservice teachers been "asked to critique our own teaching or reflect on our own teaching."

Also as did Sawyer, Rachel discussed holding equitable academic expectations for her students by implementing science units aligned to the NGSS; some of the units Rachel shared connected to the tenets of social justice science issues and students as transformative intellectuals. In her spring interview, Rachel discussed teaching a unit on the decline of the monarch butterfly population to her seventh-grade students. She explained how she integrated ambitious science teaching practices, such as using an anchoring phenomenon and iterative models, with science and engineering practices, such as analyzing and interpreting data, and designing a solution, to teach this unit:

> It's [the unit is] using this anchoring phenomenon of [the decline of] monarch butterflies and making a prediction about what's [happening to] the population, making a graph, analyzing the graph, coming up with models, learning more, and learning more, and revising the model, making your solution, and communicating that.

Rachel added that she did not regularly engage her students in the practice of "obtaining, evaluating, and communicating information, because I haven't had students communicate information to outside stakeholders before." One way to include this practice in future iterations of the monarch butterfly unit, she noted, would be for students to present their work to the local "botanical garden. That'd be cool if they presented their solutions for the butterfly decline."

Centering social justice science issues

We found preservice teachers' discussions of the tenet of social justice science issues focused on two components: socioscientific phenomena and place-based instruction. More specifically, we found that six of our eight preservice teacher participants, all but Stella and Liam, described connecting phenomena they could or did use to organize their instruction to

socioscientific issues and/or to place. To provide concrete examples, we present two preservice teachers' discussions of these components of social justice science issues below.

In his fall interview, for example, Mobius drew connections between the social justice science issue of Pacific Ocean acidification investigated in his methods course and that of California wildfires discussed in a science teacher conference session. He thought that students would find California wildfires as an anchoring phenomenon for a chemistry unit both locally relevant and emotionally salient:

> The benefit of using a phenomenon like that [a phenomenon tied to a socioscientific issue] is that you can gear it towards something that would be more culturally relevant to a group of students that you have. An example that I learned from a . . . [science teacher conference was] fire tornadoes, which is a very California thing to describe. Yeah, to do maybe a climate change unit or a thermodynamics unit [on fire tornadoes would be effective] . . . . I think that most Californians are tired of fires. And so I think that that kind of gears it in a way that it makes people engage in the material more.

We add that while Mobius described fire tornadoes as a socioscientific issue connected to students' place and experiences, he did not discuss the ways wildfires, specifically, or climate change, more generally, connected to environmental racism or other types of institutional, systemic, or structural inequities, a third component of the social justice science issues tenet (Morales-Doyle, 2017). We also add that Mobius did not teach this unit during his placement.

As a second example, in her fall interview, Rachel discussed teaching a social justice science issue to her high school biology students centered on designing solutions to local ecological problems. Working in groups, she explained, students first selected one of four local issues to pursue: monarch butterfly decline, mountain lion habitat fragmentation, DDT pollution in the ocean, or sea star disease. (We clarify for readers that Rachel discussed a different monarch butterfly unit taught to seventh graders in the section above.) Students then engaged in an NGSS-aligned engineering design process to propose a solution:

> [The lessons series] was about local issues and it guided the students through different steps, like background research, and they had to identify criteria and constraints based on their background research. [They then had to] draw a model of their solution, do a peer review, revise their solution based off the peer review, and then communicate the solution to others. So, I think it hit . . . a handful of the different SEPs.

Rachel stated that the project engaged her students in reasoning, revisions based on feedback and new evidence, and collaboration. However, like Mobius, Rachel did not discuss asking her students to extend their design work to address institutional, systemic, or structural injustices in their solutions to these local ecological issues.

Framing students as transformative intellectuals

We found all preservice teacher participants discussed the tenet of students as transformative individuals. Participants foregrounded two components in their interviews: an emphasis on teacher-student relationships as the foundation for instruction, and a recognition of student ideas as important resources for teaching and learning. Most participants, like Sawyer, Rachel, Mobius, Gil, Stella, and Liam, also touched on a third component, offering emerging ideas of ways to support students in making decisions about and taking action

against injustices. As with the previous findings sections, below, we use two preservice teachers' discussions to provide details about these components.

As one example, in her spring interview, Stella explained how strong teacher-student relationships helped build a safe community in her high school chemistry class where students willingly shared their ideas:

> I think they have to be comfortable with me and with each other and that will allow them to share. I also feel like you have to make it very apparent that, when you are asking for ideas, there is not necessarily a right or wrong [answer] . . . . You are asking them to share their thinking and put themselves out there. And it's less about looking for a yes or no, and more like, "What's your idea? How can we build on it?"

Connected to the last line in the excerpt above, Stella described her students' ideas as important in shaping her instruction. In addition to building on students' ideas during discussions, she noted that she asked her students to determine each unit's "guiding question. I pick a phenomenon, and then by doing [the instructional language routine of] co-craft questions, we figure out what the kids want to learn about that phenomenon."

As a second example, Liam also discussed how he was able to form positive teacher-student relationships and facilitate a space for students to feel comfortable sharing their ideas. In his spring interview, he noted that there was a student who was typically very quiet, but in his high school physics class, the student talked more because she "had a safe space to be herself." Some students need more support in order to share their ideas, he clarified, so he "tried to give everyone [an] equal chance to participate and speak up." In his winter interview, Liam described the importance of using students' ideas to shape his instruction, "I try not to ignore any ideas that are thrown out from a [student's] genuine thinking." He continued, "[I] have students build on other students' ideas, . . . kind of pass it to another student to add on to what he or she just said. Or [to ask], 'What do you think from your experience or perspective?'"

Further, Liam stated that he encouraged his students to "speak up" not only about science content, but about injustices they saw or experienced as well. This connects to a third component of this tenet: emerging ideas of and efforts toward student advocacy. During his fall interview, Liam shared that a student called him an anti-Asian "racial kind of slur" during class. After consulting with his cooperating teacher, Lian continued, the next day, he facilitated a whole class discussion about the history of racism and injustice in the United States. He noted that when the same student later made an anti-Asian racial slur, other students "advocat[ed] against that behavior." Liam emphasized the importance of teaching students that "people need to speak up" against racist acts. He added that students first needed to feel comfortable to do so, "We need a safe space to do that." We clarify that while Liam described encouraging his students to speak up against racism, he did not connect student action to the teaching and learning of science.

Discussion and implications

We acknowledge that learning to teach science in socially just ways is complex work (Madkins & Nazar, 2022). In our study, we found that the ideas and teaching practices preservice teachers discussed reflected Morales-Doyle's (2017) three tenets of justice-centered science pedagogy to varying degrees. In their discussions of an antiracist and

equitable science education, preservice teachers attended to both critical awareness and equitable academic expectations. Connected to the tenet of social justice science issues, participants noted the importance of engaging students in socioscientific phenomena that were local and relevant, but did not extend their discussions to include investigating institutional, systemic, or structural inequities. With respect to framing students as transformative intellectuals, preservice teacher participants described establishing teacher-student relationships as foundational to encouraging students to share their ideas and using students' ideas to shape their instruction. Participants' discussions of relationships and ideas, at times, included emerging ideas and efforts for how students could act to improve their lives and communities. Below, we suggest ways our findings can inform the growing research base on a socially just science teacher education. We note that, because the tenets overlap, we draw from across findings sections in our discussion of each tenet.

Attending to the "how" and "why" in equitable and antiracist teaching

The preservice teachers in our study attended to equitable academic expectations in their discussions of ideas and teaching practices related to student engagement in rigorous, reform-based science learning. This finding is consistent with research that describes teacher education coursework and field experiences as integral to helping preservice teachers learn to utilize reform-based practices (Moon et al., 2021; Windschitl et al., 2021). It aligns with Hammerness and Kennedy's (2019) recommendation to provide beginning teachers with a repertoire of practices grounded in a vision of good teaching: In our study, preservice teachers were given both coherent frameworks (i.e., ambitious science teaching, and effective instruction for multilingual learners) and concrete strategies (e.g., use of anchoring phenomena, iterative models, and instructional language routines) to drive their reform-based instruction.

Preservice teachers' discussions of ideas and teaching practices also attended to critical awareness, an equally important component of an antiracist and equitable science education. Helping preservice teachers develop and enact critical awareness is a necessary first step toward a socially just science teacher education (Jones & Donaldson, 2022; Rivera & Titu, 2021). Our findings surfaced a number of ways teacher education programs could strengthen participants' critical awareness. Rachel's suggestion to use the edTPA assessment as an opportunity to deepen her learning about implicit biases and how to enact antiracist practices is consistent with Kavanagh and Danielson (2020), who proposed that teacher educators provide opportunities for preservice teachers to watch videos of their own teaching with an orientation to social justice. Rachel's request to learn how to hold conversations with students about racist acts and Liam's discussion of a lesson about racism and racial slurs resonate with Alexakos et al.'s (2016) recommendations for ways to navigate difficult conversations so that they are generative for student learning. Moreover, Rachel's recommendation that justice-oriented teaching be better integrated into teacher education courses aligns with Gorski's (2012) claim that teaching about race and social justice in a single course is not sufficient and Milner's (2006), that preservice teachers need repeated opportunities to learn about racism and social justice. As such, teacher education programs must coordinate the teaching of concrete strategies within a coherent social justice framework to help preservice teachers both deepen their own critical awareness and learn how to engage their students in developing their critical awareness (Jones & Donaldson, 2022;

Mensah, 2022). Indeed, although the teacher education program under study has taken additional steps to make social justice teaching a more central component of preservice teacher learning, teacher educators have yet to adopt a common, clearly articulated social justice framework.

Foregrounding justice in the teaching of social justice science issues

Preservice teachers attended to social justice science issues by focusing on socioscientific phenomena and place. Sawyer's discussion of a unit on climate change, Rachel's description of units on the decline of the monarch butterfly population and on designing solutions to local ecological issues, and Mobius' suggestion about a unit on California wildfire tornados serve as cases in point. Participants' lack of attention to a third component of this tenet—institutional, systemic, and structural inequities—was not unexpected given that they experienced only one model unit organized around a social justice science issue during their yearlong program.

Morales-Doyle and Frausto (2021) acknowledged that planning instruction around social justice science issues is complex: Teachers require time and energy to identify and understand the systemic and structural issues that exist in their students' community. The findings by Tolbert et al. (2019) and Mark and Id-Deen (2020) lend support to this claim. Given the recognized challenges of teaching about social justice science issues, teacher education programs must do more to help their preservice teachers move from teaching socioscientific issues tied to local contexts, to developing units that foreground and attempt to address inequities foundational to these issues. Beginning the planning of instructional units "with culturally conscious frameworks that aim to disrupt historical power dynamics, rather than conclud[ing unit development] by making culturally significant connections" seems a necessary additional step in creating a science teacher education for social justice (Mark & Id-Deen, 2020, p. 742).

Shifting focus from student ideas to student advocacy

Further, we found our participants' discussions of students as transformative intellectuals centered on using teacher-student relationships to create safe classrooms and on building from students' ideas to shape instruction. As noted by Stella and Liam, teacher-student relationships were crucial to encouraging all students to participate in discussions. Stella's valuing of the sharing of science ideas over the need to provide right answers and Liam's encouragement to students to build on each other's ideas were also important in engaging all students in science learning. These crucial connections across teacher-student relationships, valuing students' ideas, and attending to equity goals resonates with the recommendations of Carlone et al. (2011). These researchers argued that generative, dialogic classrooms were key to fostering an equitable science education and called for teachers to question normative science practices and to examine how their classroom "privileges one right answer at the expense of acknowledging the logic and reasoning" of diverse students (p. 480; see also Brown-Jeffy & Cooper, 2011). Helping preservice science teachers value, regularly attend to, and build from students' ideas in their classrooms is essential to framing all students as transformative intellectuals.

Preservice teachers in our study discussed facilitating opportunities for students to use their ideas to enact change in their lives or communities—a third component of students as transformative intellectuals—in less clear and powerful ways. This finding was not unexpected as preservice teachers themselves were not asked to engage in collective decision-making or action as part of their teacher education program, for example, to enact a solution to the social justice science issue of ocean acidification in their methods course or to address some aspect of systemic biases in schools in their antiracism seminar. Clearly, if preservice teachers are to engage their students in action, they must be provided opportunities in their program to adopt an activist stance themselves (Cebrian-Robles et al., 2021; Jones & Donaldson, 2022).

Encouraging teacher educators to more closely attend to and work to extend what preservice teachers are already doing in their classrooms also appears important in promoting student advocacy within and outside the classroom. Sawyer's discussion of adopting non-normative ways of assessing his students and Stella's sharing of her decision to have her students determine each unit's driving question resonate with Calabrese Barton and Tan's (2010) discussion of equitable science classrooms where students share authority and negotiate participation with their teacher. Liam's description of a lesson on antiracism, Sawyer's discussion of engaging students in evaluating climate change tweets, and Rachel's suggestion to have students present to the local botanic garden should be recognized as emerging ideas and efforts to engage students in advocacy beyond the classroom that can be built upon to more fully enact the tenet of students as transformative intellectuals. Mensah's (2022) approach to scaffolding preservice teachers' development of social justice lessons using Banks' (2013) framework and a set of sequenced activities appears another promising step in helping preservice teachers engage their students in decision-making and action to address injustices.

Conclusion

While our study contributes to the growing body of research that envisions social justice and equity as integral to effective science teacher education, it has several limitations. First, neither the teacher education program under study nor our interview protocol was explicitly organized around Morales-Doyle's (2017) framework. Explicit attention to the tenets of justice-centered science pedagogy might have yielded different insights. Second, we were unable to observe preservice teachers' classroom instruction because of district restrictions. Classroom observations would have provided support for and additional examples of ideas and teaching practices related to a socially just science teacher education. Third, our study would have been enhanced by the inclusion of more preservice teachers from diverse racial, ethnic, and linguistic backgrounds. This last limitation serves as a reminder that most science teacher education studies remain centered on the experiences of White participants (Mensah & Jackson, 2018).

Morales-Doyle and Frausto (2021) expressed concern that socially just science education frameworks may become "formulaic" over time (p. 63), where teachers simply follow a series of recommended steps to teach an approach in name rather than in substance. To truly position students as transformative intellectuals who act to address social justice science issues, the situated nature of and complexities in implementing a socially just

science education must be better acknowledged and understood. Our preservice teacher participants encouraged student engagement with and understanding of the NGSS, while identifying ways to connect students' science learning to socioscientific issues in their local context, as academic success occurs more readily when students' racial, cultural, and linguistic assets are valued (Tolbert et al., 2019). Participants nurtured the development of a relational infrastructure, as building trusting relationships with students helps to highlight the knowledge and experiences students bring to their classroom and community (Sleeter, 2015). Additional examples of how preservice teachers think about and do this work can further inform the efforts of science teacher educators and their preservice teachers to enact a socially just science education.

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Appendix

Spring Quarter Semi-Structured Interview Protocol

Fieldwork Placement Information

1. In which course(s) were you placed this spring (e.g., what discipline, grade, CP/Honors/AP, etc.)? I assume these courses were all hybrid, yes?
2. What is one success and one challenge you have had in your student teaching this spring?

Conceptions of Effective Science Teaching and Learning

3. Looking back over your TEP year, what did you learn about effective science instruction from your teacher education courses and field placements? What more would you like to learn?
4. Looking back over your TEP year, what have you learned about how students learn from your teacher education courses and field placements so far? What more would you like to learn?

Teaching Multilingual Learners

5. What do you see as the strengths of multilingual learners in science classrooms? (a) What challenges do you think multilingual learners in these classrooms encounter? (b) What are the characteristics of an effective teacher of multilingual learners?
6. Tell me about how you have interacted with multilingual learners in your placement. (a) How does your cooperating teacher work with multilingual learners? (b) How are you engaging multilingual learners in your instruction? (c) What teaching practices are you using in your day-to-day instruction to work with multilingual learners? (d) How have you modified instruction to work with your multilingual learners? For example, do you provide digital materials in Spanish? Are you purposefully grouping multilingual learners in breakout rooms? (e) How do you see remote or hybrid instruction affecting the learning of multilingual learners?
7. How are you implementing what you learned from your spring methods course and other TEP coursework in your student teaching placement related to engaging multilingual learners in remote or hybrid instruction?
8. How did ED 321 and other Spring 2021 coursework shape your understanding of ways you can engage multilingual learners? How did the COVID-19 learning environment affect your knowledge regarding multilingual learners?
9. When considering working in a hybrid instruction environment, what adjustments do you imagine having to make to challenge or support multilingual learners? (a) On a scale of 1 through 5, with 5 being the most prepared, how prepared do you feel to engage in effective instruction with multilingual learners in a hybrid instruction environment? Why? (b) What do you see as the major differences between supporting multilingual learners in hybrid vs remote contexts?

Teaching and Learning Through Hybrid Instruction

10. Overall, how do you feel about *teaching your students* through hybrid instruction? (a) Can you describe a typical day of teaching your in-person students, as well as the students on Zoom? (b) What has been going well? (c) What has been challenging?
11. Please think back to when you were only doing remote instruction. If you had difficulty with engaging students over remote instruction, what did you do to try to overcome that?

Development as an Effective Teacher

12. What does your content supervisor do to build relationships and make you feel comfortable sharing ideas with your cohort? Can you give a specific example?
13. What do you think makes students feel willing to share about their lives, ideas, and experiences in class? (a) What do you think makes students feel comfortable sharing their ideas when it comes to science? (b) What specific things do you do to build relationships with your students and create an environment in which they feel comfortable sharing their ideas in class? (c) Where did you learn this from (TEP courses, working with students, cooperating teacher, etc.)? (d) How have your interactions and relationships with students changed from being only online to being in-person /hybrid?
14. How has your understanding of what makes an effective teacher changed since starting the program (if at all)?
15. [Show PPT slide. Encourage PSTs to circle or underline on the cards.] Various teacher responsibilities are listed on this slide [facilitating student discussion, building relationships with students, fostering home-school partnerships, managing student behavior, implementing culturally relevant instruction, preparing lesson plans, maintaining student engagement, scaffolding work, assessing student learning]. (a) When you think about your work in the classroom, which areas do you feel successful in? Why? (b) Are any of these areas challenging for you? Why? (c) What might help you to grow in those areas?
16. Imagine that you are having a conversation with your field work supervisor—they observed one of your lessons, and it did not go as well as you had hoped. How would you like them to support you in order to help you grow in that area? (a) What helps you to feel encouraged? (b) Are there any ways of coaching or providing support that have been particularly helpful for you? (c) Is there anything that might make you not as receptive to their feedback?

(*Continued*)

(Continued).

NGSS Science and Engineering Practices and Crosscutting Concepts

17. What have you learned about the eight science and engineering practices and the seven crosscutting concepts from the NGSS in your current courses?
18. How have the NGSS practices and crosscutting concepts been implemented in your placement(s) by your cooperating teacher(s)?
19. How have you incorporated these NGSS practices and crosscutting concepts in your own teaching?
20. [Show PPT slide. Encourage PST to circle or underline on the cards.] These are cards with the eight science and engineering practices from the NGSS. (a) Which two do you most often implement in your student teaching placements? How do you implement them? (b) Out of all eight, which one do you think is most important to teach students? Why? (c) Which one or two practices do you think you need more help to understand or implement? Why?
21. [Show PPT slide. Encourage PST to circle or underline on the cards.] These are cards with the seven crosscutting concepts from the NGSS. (a) Which two do you most often implement in your student teaching placements? How do you implement them? (b) Out of all seven, which one do you think is most important to teach students? Why? (c) Which one or two crosscutting concepts do you think you need more help to understand or implement? Why?

Wrap-Up

22. Do you have anything else you would like to add or do you have any questions for me?