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Justice-Centered STEM Education with Multilingual Learners: Conceptual Framework and Initial Inquiry into Pre-Service Teachers' Sense-Making

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ABSTRACT

When pressing societal challenges (e.g., COVID-19, access to clean water) are sidelined in science classrooms, science education fails to leverage the knowledge and experiences of minoritized students in school, thus reproducing injustices in society. Our conceptual framework for *justice-centered STEM education* engages all students in multiple STEM subjects, including data science and computer science, to explain and design solutions to pressing societal challenges and their disproportionate impact on minoritized groups. In the first part of this article, we extend our conceptual framework by articulating the affordances of justice-centered STEM education for one minoritized student group that has been traditionally denied meaningful STEM learning experiences: multilingual learners (MLs). Justice-centered STEM education with MLs leverages the assets that MLs bring to STEM learning, including their transnational knowledge and experiences as well as their rich repertoire of meaning-making resources, thus refuting deficit narratives of these students. To illustrate the affordances of justice-centered STEM education with MLs, we draw on examples from our instructional unit that engages students in the pressing societal challenge of the COVID-19 pandemic. In the second part of the article, we report on an initial inquiry into how 14 undergraduate pre-service teachers made sense of our conceptual framework after participating in lessons from our COVID-19 instructional unit. Findings indicated that pre-service teachers perceived both opportunities and obstacles of justice-centered STEM education with MLs. We close by discussing what it might take to prepare the next generation of teachers to disrupt systemic injustices in and out of school.

KEYWORDS
Computer science; data science; justice in STEM; multilingual learners; pre-service teacher preparation

Pressing societal challenges disproportionately impact minoritized groups, including Black, Latinx, and Indigenous groups in the U.S. context (e.g., Oladele et al., 2022). For example, in Miami (US) where the present research was carried out, rising sea levels have driven up housing costs in flood-protected Latinx communities and, in doing so, displaced existing populations (Santiago, 2020). Traditionally, pressing societal challenges, such as climate change, access to clean water, and the COVID-19 pandemic, have been underrepresented in K–12 science curriculum and instruction (Lee & Grapin, 2022). However, when pressing

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societal challenges are sidelined in science classrooms, science education fails to affirm and leverage the knowledge and experiences of minoritized students in school, thus reproducing injustices in society. Furthermore, as pressing societal challenges are complex, STEM subjects need to be integrated to address these challenges (National Research Council, 2014a). We advocate for *justice-centered STEM education* (Lee & Campbell, 2020; Lee & Grapin, 2022), which leverages multiple STEM subjects to engage all students in explaining how pressing societal challenges disproportionately impact minoritized groups and then designing justice-centered solutions.

Justice-centered STEM education could be powerful for all K–12 students but especially minoritized student groups, who have not traditionally seen their lives or communities reflected in science classrooms. One such group of minoritized students is a fast-growing population of multilingual learners (MLs) in the U.S. K–12 context. Currently, more than one in 10 students are classified as “English learners” by their schools (National Center for Education Statistics, 2021), and approximately one in five students report speaking a language other than English at home (sometimes called “language minority students”). We refer to these students, collectively, as MLs to center the assets they bring rather than the English they are still developing (see González-Howard & Suárez, 2021; Grapin, 2021; Takeuchi et al., 2022). Despite increased attention to these students’ experiences in STEM education research (National Academies of Sciences, Engineering and Medicine, 2018), MLs continue to be denied meaningful STEM learning experiences in schools. For example, MLs are frequently pulled from “mainstream” STEM instruction to remediate their perceived deficits in English, thus fragmenting their learning experiences and ultimately restricting their access to advanced STEM learning (National Academies of Sciences, Engineering and Medicine, 2018). Justice-centered STEM education represents one promising framework for countering this persistent marginalization by engaging MLs in STEM subjects in ways that center their knowledge, experiences, and language as assets for STEM learning.

Justice-centered STEM education with MLs will require shifts not only in the learning that takes place in K–12 classrooms but also the preparation of pre-service teachers (PSTs) to facilitate MLs’ STEM learning (National Academies of Sciences, Engineering and Medicine, 2022). However, preparing to teach STEM with an emphasis on justice can present difficulties for PSTs as they grapple with ideological commitments, institutional constraints, and broader sociopolitical contexts (Morales-Doyle et al., 2021; Philip et al., 2019). These difficulties are compounded by politically contentious debates currently transpiring in the U.S. K–12 context around the purpose of education and the role of teachers (Petrzela, 2021). What’s more, science PSTs generally report feeling underprepared to teach MLs (Banilower et al., 2018), particularly when it comes to leveraging MLs’ cultural and linguistic resources in science instruction (Rutt et al., 2021). This lack of preparation may be due, in part, to the fact that teacher preparation programs tend to address the teaching of STEM subjects and the teaching of MLs separately (De Jong & Naranjo, 2019). As a result, PSTs, like the MLs they will teach, have fragmented learning experiences that may prevent them from making sense of justice-centered approaches to STEM education and the potential of these approaches for harnessing the assets of an increasingly linguistically diverse student population.

The purpose of this article is twofold. The first purpose is to propose a conceptual framework for justice-centered STEM education with MLs. Building on our existing framework for justice-centered STEM education with minoritized students broadly (Lee & Campbell, 2020; Lee & Grapin, 2022), we have extended the framework to foreground the knowledge, experiences, and language of MLs specifically. To illustrate the affordances of justice-centered STEM education for MLs, we draw on examples from our instructional unit that engages MLs and their peers in the pressing societal challenge of the COVID-19 pandemic. The second purpose is to report on an initial inquiry into how PSTs made sense of our conceptual framework after participating in lessons from our COVID-19 instructional unit. Specifically, we describe how 14 undergraduate PSTs perceived the opportunities and obstacles of justice-centered STEM education with MLs for their future teaching. We close by discussing future directions for justice-centered STEM education with MLs and what it might take to prepare the next generation of teachers to disrupt systemic injustices in and out of school.

Conceptual framework for justice-centered STEM education with MLs

We define justice as "full and equitable participation of people from all social identity groups in a society that is mutually shaped to meet their needs" (Bell, 2016, p. 3). Specifically, we view educational justice for minoritized student groups in school as one aspect of advancing social justice for minoritized groups in society (National Academies of Sciences, Engineering and Medicine, 2022). In proposing our conceptual framework, we join others in STEM education advocating for justice-centered approaches across contexts, disciplines, and levels of the education system (Bang et al., 2012; Calabrese-Barton & Tan, 2020; Lachney et al., 2021; Madkins et al., 2020; McGee, 2020; Mensah, 2019; Morales-Doyle, 2017; Pozos et al., 2022; Tolbert et al., 2018; Tzou et al., 2021; Vakil, 2018).

Our conceptual framework for justice-centered STEM education is grounded in three interrelated principles (Lee & Campbell, 2020; Lee & Grapin, 2022). First, justice-centered STEM education engages students in pressing societal challenges (e.g., COVID-19, climate change, access to clean water) that disproportionately impact minoritized groups in society. This is a fundamental shift from anchoring science learning in "sanitized" phenomena (Lee & Grapin, 2022) that are disconnected from pressing societal challenges and remain silent about injustices facing minoritized groups. Second, given the complexity of pressing societal challenges, justice-centered STEM education leverages the convergence of STEM subjects, such as data science and computer science, to explain these challenges. This is a fundamental shift from addressing STEM subjects separately in school or integrating them in a contrived manner (National Research Council, 2014b), which falls short of reflecting the interdisciplinary work of STEM professionals to address such challenges in the real world (National Research Council, 2014a). Third, justice-centered STEM education engages students in designing justice-centered solutions that center the knowledge and experiences of minoritized groups. This is a fundamental shift from designing solutions that privilege the knowledge of STEM disciplines while overlooking minoritized groups. Together, these three principles form the foundation of our framework, which is intended to guide current and future efforts at developing instructional materials and teacher learning experiences that converge in centering justice for minoritized groups in STEM education and society at large.

We argue that justice-centered STEM education has the potential to transform science education for minoritized students by engaging them in pressing societal challenges

Table 1. Affordances of justice-centered STEM education for all students and MLs specifically.

STEM subject	Affordances for all students	Affordances for MLs
Justice-centered data science	Students use their everyday knowledge and experiences to make sense of patterns in data.	MLs leverage their transnational knowledge and experiences to interpret data across local and global contexts.
Justice-centered computer science	Students engage in computational modeling to make sense of injustice as an emergent phenomenon in societal systems.	MLs leverage multiple and varied meaning-making resources (e.g., graphs, code) to communicate explanations and solutions.

relevant to their lives, families, and communities in ways that center their knowledge and experiences. However, given the heterogeneity of students commonly referred to as "minoritized," an important step in further developing the framework is to articulate the potential affordances of justice-centered STEM education for specific minoritized student groups, such as MLs, with each group (as well as learners within each group) bringing unique strengths and characteristics.

Building on our ongoing program of research on MLs in science education (e.g., Grapin et al., 2022; Haas et al., 2020; O. Lee et al., 2019), we focus on justice-centered STEM education with MLs for three key reasons. First, MLs are linguistically minoritized while often being members of racial or ethnic minority groups (National Center for Education Statistics, 2021). As a result, MLs experience multiple intersecting injustices in schools and society (see Flores & Rosa, 2015 on raciolinguistic ideologies). Second, MLs have traditionally been excluded from meaningful STEM learning due to the common practice of relegating these students to remedial instruction that emphasizes "fixing" their perceived deficits with English (National Academies of Sciences, Engineering and Medicine, 2018). Third, despite this persistent remedial framing of MLs, an extensive body of research indicates that these students bring cultural and linguistic resources to science classrooms that can be harnessed as assets to promote their meaningful engagement in STEM subjects (National Academies of Sciences, Engineering and Medicine, 2018).

In the sections that follow, we highlight the unique affordances of justice-centered STEM education for MLs. We focus on the affordances of leveraging two key STEM subjects that have gained traction in K–12 education—data science and computer science—to engage MLs in explaining and designing solutions to pressing societal challenges. For each STEM subject, we highlight affordances for all students, followed by affordances for MLs specifically (see Table 1 for a summary). Then, we illustrate these affordances using examples from our COVID-19 instructional unit. The unit, available open source on the National Science Teaching Association website, engages middle school MLs in using data science (nsta.org/playlist/tracking-covid-19-united-states) and computer science (nsta.org/playlist/understanding-covid-19-disparities-using-computational-modeling) to explain and design solutions to the disproportionate impact of COVID-19 on racial and ethnic minority groups.

Justice-centered data science with MLs

With data permeating nearly all aspects of our lives, data science education has emerged as a rapidly expanding research area (Finzer, 2013; Jiang et al., 2022). This research has been concerned not only with learners' engagement in key data practices (e.g., collecting, analyzing, interpreting) but also the historical, social, and political dimensions of data production and use (Kahn, 2020). For example, Wilkerson and Polman (2020) argue for positioning learners as "agentive data practitioners who recognize the historical and political dimensions of data as social texts" (p. 4). V. Lee et al. (2021) synthesized research programs on K–12 data science education to propose a humanistic stance "that deliberately centers the human dimensions of student engagement with data" through personal, cultural, and sociopolitical layers (p. 665). Together, these emerging lines of work highlight the unique affordances of data science for students to explain pressing societal challenges by integrating their everyday knowledge and experiences with disciplinary data practices. As learners engage with data related to these challenges, they examine whose interests are served by the data that get collected (or not collected) and respond agentively to "big data" messages with "small data" counternarratives (see, Calabrese Barton et al., 2021 for an example in the context of the COVID-19 pandemic).

For MLs specifically, justice-centered data science provides unique affordances to leverage their knowledge and experiences for STEM learning. Since Moll et al. (1992) first proposed the construct of *funds of knowledge*, an extensive body of research has shown that MLs "bring a wealth of resources to . . . STEM, including knowledge and interest in STEM-related content that is born out of their experiences in their homes and communities" (National Academies of Sciences, Engineering and Medicine, 2018, p. 1). In our framework, we highlight one key aspect of these funds of knowledge with particular relevance to explaining and solving pressing societal challenges: *transnational* knowledge and experiences (Hornberger & Link, 2012; McGinnis et al., 2007). Although the majority of MLs were born in the US (National Center for Education Statistics, 2021), many continue to maintain ties to two or more countries (or nation states), whether through physical travel, virtual communication, or cultural practices (Skerrett, 2012). In other words, MLs and their families often "live locally but with global connections" (De la Piedra & Guerra, 2012, p. 629). For example, research has shown how Latinx youth leverage their transnational knowledge and experiences to engage in STEM practices, such as design thinking in engineering (Wilson-Lopez & Acosta-Feliz, 2021; Wilson-Lopez et al., 2016). Such transnational knowledge and experiences make MLs uniquely positioned to interpret data related to pressing societal challenges, which are inseparably and simultaneously local and global (Gupta et al., 2007). By (re)framing MLs' knowledge and experiences that "might otherwise be . . . framed merely as *immigrant*" as assets for STEM learning (Cervantes-Soon & Kasun, 2018, p. 1), justice-centered data science flips the script on deficit narratives of these students.

In the first part of the COVID-19 unit, students make sense of COVID-19 data using large datasets from publicly available sources, such as Johns Hopkins University Coronavirus Resource Center (http://coronavirus.jhu.edu/map.html) and Our World in Data by Oxford University (https://ourworldindata.org/coronoavirus). Students look for patterns in the spread of COVID-19 locally, nationally, and globally. For example, they compare COVID-19 data across countries as well as regions within the US. As they identify patterns in the data, they consider possible explanations for these patterns. Next, students compare COVID-19 data by racial and ethnic group (see Figure 1). As they analyze these data, they consider how decisions about data collection, analysis, and representation impact interpretations, especially in light of inadequacies in data collection on race and ethnicity that can underrepresent disparities in outcomes (e.g., Oladele et al., 2022). Overall, students

Rate ratios compared to White, Non-Hispanic persons	American Indian or Alaska Native, Non-Hispanic persons	Asian, Non-Hispanic persons	Black or African American, Non-Hispanic persons	Hispanic or Latino persons
Cases[1]	1.6x	0.7x	1.1x	1.5x
Hospitalization[2]	3.1x	0.8x	2.4x	2.3x
Death[3]	2.1x	0.8x	1.7x	1.8x

Race and ethnicity are risk markers for other underlying conditions that affect health, including socioeconomic status, access to health care, and exposure to the virus related to occupation, e.g., frontline, essential, and critical infrastructure workers.

Figure 1. Risk of COVID-19 infection, hospitalization, and death by race and ethnicity. *Note*. From "Risk for COVID-19 Infection, Hospitalization, and Death by Race/Ethnicity," by Centers for Disease Control and Prevention, 2022, https://www.cdc.gov/coronavirus/2019-ncov/covid-data/investigations-discovery/hospitalization-death-by-race-ethnicity.html

identify a key pattern that racial and ethnic minority groups have been disproportionately impacted by COVID-19. Students conjecture possible causes for the patterns, which they will explore in greater depth in the second part of the unit.

This first part of the unit illustrates the affordances of justice-centered data science for all students and MLs in particular. For all students, analyzing data about a pressing societal challenge that directly impacts their lives positions students as "agentive data practitioners" (Wilkerson & Polman, 2020, p. 4) who bring rich knowledge and experiences to interpret patterns in data (e.g., knowledge of different government responses to the pandemic) and interrogate the consequences of data use (e.g., consequences of missing data on racial and ethnic groups, including underestimating disparities and designing inadequate solutions).

For MLs specifically, analyzing data about a pressing societal challenge that transcends local and global contexts leverages their transnational knowledge and experiences. For example, MLs' experiences with international travel restrictions become assets for explaining why COVID-19 outcomes differ between countries, while their knowledge of cultural practices (e.g., multigenerational living in Latinx families) becomes a valuable asset for designing solutions that account for the practices of local communities (Grapin et al., in press).

Justice-centered computer science with MLs

Our framework focuses on computational modeling as one application of computer science that synergizes computational concepts and tools with the practice of modeling (Lehrer & Schauble, 2015; National Research Council, 2012). Specifically, we argue that *agent-based* computational modeling (Sengupta et al., 2013) represents a promising avenue for learners to explain and design solutions to pressing societal challenges. This is because agent-based computational models enable learners to program interactions of individual agents in a system and then observe emergent whole-system behavior that could not always have been predicted from the individual agent interactions alone (Brady et al., 2015; Klopfer, 2003; Papert, 1980; Resnick, 1994; Wilensky & Reisman, 2006). Thus, agent-based computational models make visible the hidden mechanisms in societal systems that give rise to injustices facing minoritized groups. As learners make sense of injustices as an emergent phenomenon, they come to recognize how the behavior of minoritized groups is constrained by systems, thus refuting widespread deficit perspectives that locate deficiency in individuals or groups (e.g., lack of effort, culture of poverty; see Valdés, 1997). At the same time, learners can use their computational models to design solutions that directly address systemic injustices. A key affordance of agent-based computational modeling lies in the potential of computational agents to serve as *mediational objects* (Papert, 1980; Winnicott, 1953) onto which learners can project their own experiences as well as reason about the experiences of others with whom they would not typically identify (Hostetler et al., 2018).

For MLs specifically, justice-centered computer science provides unique affordances to construct and communicate STEM meaning. In parallel with how MLs draw from their transnational knowledge and experiences that transcend local and global boundaries (see previous section), MLs also make meaning in ways that transcend rigidly constructed boundaries between meaning-making resources (National Academies of Sciences, Engineering and Medicine, 2018; WIDA Consortium, 2020). This meaning-making transcends modalities of communication (e.g., "linguistic" vs. "nonlinguistic"; e.g., Canagarajah, 2018), registers of language (e.g., "academic" vs. "non-academic"; e.g., Bunch & Martin, 2021), and named languages (e.g., "English" vs. "Spanish"; e.g., Otheguy et al., 2019). Specifically, emerging research on computer science with MLs has shed light on how these students construct and communicate STEM meaning by leveraging the affordances of visual blocks-based programming environments (Weintrop & Wilensky, 2015). For example, MLs coordinate meaning across multimodal representations (e.g., graphs, computer programs, dynamic visualizations; Pierson et al., 2020, 2021); draw on a range of registers, including the programming register underlying their models (e.g., commands such as "collide with"; Grapin et al., 2022; Haas et al., 2020); and move fluidly across named languages as they interact with human and technological participants (Vogel, 2021; Vogel et al., 2020). Leveraging a wider range of meaning-making resources than has been traditionally sanctioned creates an "inversion in semiotic power" (Kress, 2003, p. 9) that affords MLs novel avenues for engaging diverse audiences, conveying nuanced cultural meanings, expressing their identities, and developing agency for resisting dominant and often harmful discourses about their communities (Pacheco & Smith, 2015; Smythe & Neufeld, 2010; Vasudevan, 2006). By breaking down socially constructed boundaries that have restricted what "counts" as legitimate meaning-making in STEM, justice-centered computer science could empower MLs to draw from their full linguistic and semiotic repertoire as they explain and design solutions to pressing societal challenges.

In the second part of the COVID-19 unit, students use a computational model to explain patterns related to the disproportionate impact of COVID-19 on racial and ethnic minority groups. Students observe two different shape agents in the model, spheres and pyramids, which represent two different groups of people (see top of Figure 2). Whereas spheres appear as single agents and always stay close to their starting point, pyramids appear in clusters, with one or more of the pyramids going out to random locations and returning to their starting point. After making and testing predictions about how the two different shape agents (spheres and pyramids) will be impacted by the spread of the virus, students identify a key pattern that pyramids tend to be infected at a higher rate than spheres (see the gap between purple and blue lines in the graph on the left side of Figure 2). To explain why pyramids are infected at a higher rate, students interpret the code underlying the

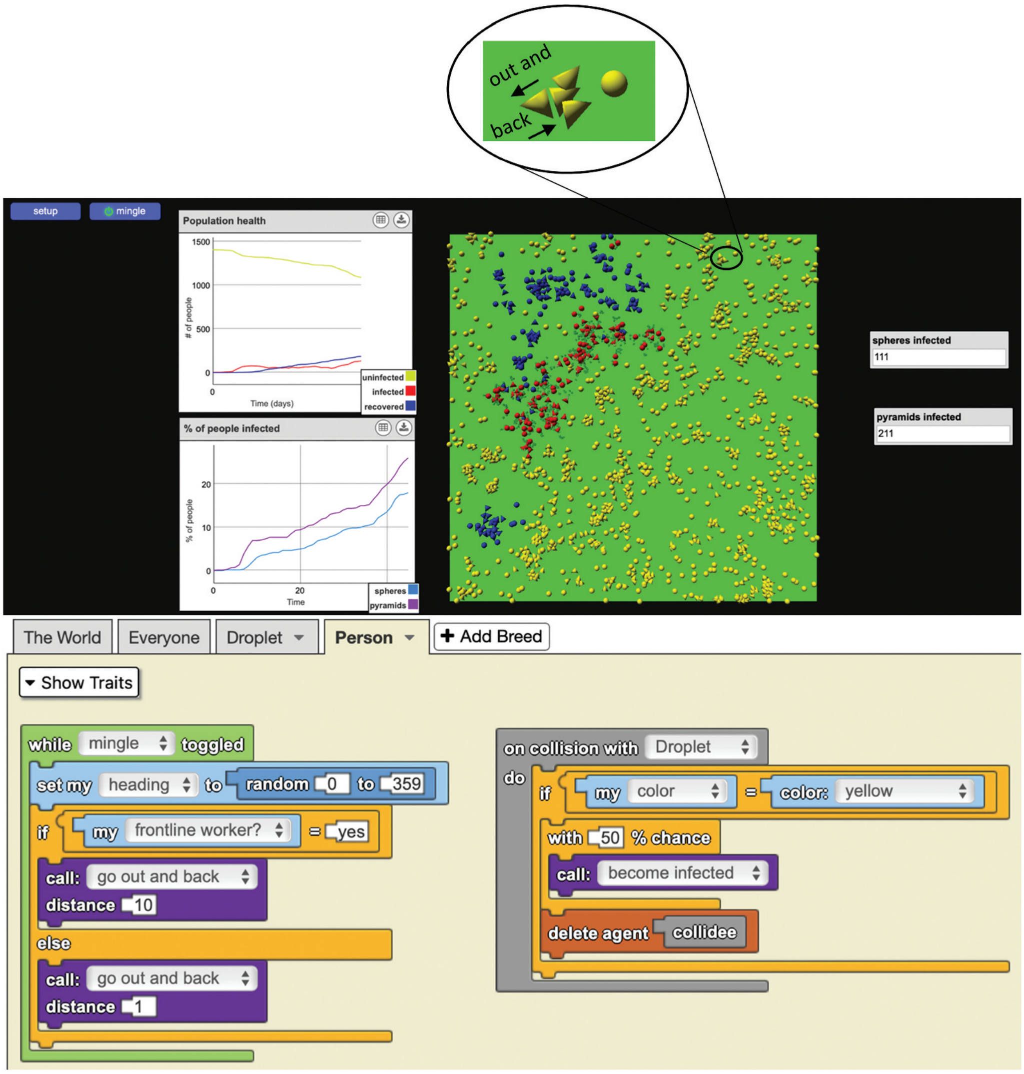

Figure 2. Computational model to explain how different groups of people are impacted by the spread of a virus.

computational model (see bottom of Figure 2) and figure out that, while spheres in the model represent households with people who can stay at home and whose living arrangements allow them to maintain distance in their households, pyramids represent households with frontline workers who cannot stay at home and whose living arrangements may prevent them from maintaining distance in their households. Students combine what they figure out from their computational models with data from other sources (e.g., report on demographic characteristics of frontline workers, research study on household living arrangements) to argue that two conditions contributed to the disproportionate impact of COVID-19 on racial and ethnic minority groups: frontline work and household living arrangements (Reitsma et al., 2021). Finally, students use their computational models to design systemic solutions to the problem of disproportionate impact, such as ensuring safer public transit for frontline workers or ensuring access to affordable housing for their families.

This second part of the unit illustrates the affordances of justice-centered computer science for all students and MLs in particular. For all students, computational modeling makes visible conditions that contribute to the disproportionate impact of COVID-19 on racial and ethnic minority groups (i.e., frontline work, household living arrangements). It also enables students to design systemic solutions that directly address these conditions. Moreover, computational agents (e.g., pyramid agents) serve as mediational objects onto which learners can project their lived experiences (e.g., knowing frontline workers who may be concerned about bringing COVID-19 into their households but are constrained by systems).

For MLs specifically, as they engage in interactions with their computational models and their peers around those models, they move fluidly across varied meaning-making resources. For example, they use resources from multiple modalities (e.g., graph, gesture), registers (e.g., "go out and back" from the programming register), and named languages (e.g., "las esferas se quedan [the spheres stay] in place") to communicate their explanations and solutions. For example, in a presentation prepared for their town council, a group of MLs and their peers deployed a strategic combination of graphs, code blocks, and written language to argue for increasing protections and pay for frontline workers in their local community (Grapin et al., in press).

Initial inquiry into PSTs' sense-making of justice-centered STEM education with MLs

An important step in bringing our framework to implementation is to understand how teachers make sense of the framework and the instructional materials that instantiate it. In parallel with the latest science education reform that emphasizes *student sense-making* (Schwarz et al., 2016), we join efforts at investigating *teacher sense-making* of STEM education and their roles in it (e.g., Allen & Penuel, 2015; Miller et al., 2022; Sezen-Barrie et al., 2020). In this section, we report on an initial inquiry to answer the following research question: How do PSTs make sense of justice-centered STEM education with MLs? The purpose of this inquiry was to gain preliminary insight into PSTs' sense-making that could inform future efforts to design teacher learning focused on justice-centered STEM education with MLs.

Participants and context

The context for the study was an undergraduate teacher preparation course at a midsize university in the southeastern US. The course, called *Interdisciplinary Methods in the Content Areas*, was developed and taught by the first author. In contrast with other methods courses that address content areas separately (e.g., science methods, social studies methods, fine arts methods) and without an explicit equity focus (De Jong & Naranjo, 2019), this course was innovative in its focus on the interdisciplinary integration of content areas in ways that leverage the assets of MLs. A key premise of the course, as described in the course syllabus, was *symmetry* in teacher learning, which Mehta and Fine (2019) describe as "giving adults opportunities to learn in ways that parallel how students learn" (p. 484). Consistent with this premise of symmetry, the first author engaged PSTs in two lessons from the COVID-19 instructional unit that instantiates our framework for justice-centered STEM education with MLs.

Of the 16 PSTs enrolled in the course, 14 consented to participate in the study. Table 2 displays the self-reported characteristics of the PSTs. Of the 14 study participants, 13 identified as female and one as male. This distribution is somewhat expected given that 76% of K–12 teachers and 89% of elementary teachers identify as female (National Center for Education Statistics, 2021). Three PSTs identified as Black or African American, five as Hispanic or Latinx, and six as White. Five PSTs identified as Spanish speakers. Whereas the broader PST population in the US is predominantly White and monolingual-identifying (Solano-Campos et al., 2020), this variability in terms of race, ethnicity, and language background enabled us to explore the sense-making of PSTs with a more diverse set of backgrounds and experiences. Ten PSTs were interested in teaching in the elementary grades (i.e., K–5) and four in both the elementary and secondary grades (i.e., both K–5 and 6–12). All of the PSTs were pursuing an endorsement in English for Speakers of Other Languages (ESOL), which would certify their preparation for teaching MLs in public schools.

The location of the teacher preparation program made it a particularly compelling context for investigating PSTs' sense-making. In recent years, the state in which the university is located has been at the center of the latest school culture wars (Petrzela, 2021). These culture wars came to a head when, in December 2020, the state passed legislation banning the teaching of critical race theory in public schools. At the same time, the metropolitan area in which the university is located (and where PSTs complete their field experiences) is home to a majority Hispanic population, and nearly one in four students in local public schools is classified as an "English learner." Moreover, this metropolitan area has been colloquially referred to as ground zero for pressing societal challenges, such as climate change, that disproportionately impact minoritized communities (see Santiago, 2020 on climate gentrification in Miami). The confluence of these political, social,

Table 2. Participants' self-reported characteristics.

Pseudonym	Gender	Race/Ethnicity	Language(s)	Target grade(s)
Anita	Female	White	English	Elementary
Ariana	Female	Hispanic	English Spanish	Elementary Secondary
Carly	Female	White	English	Elementary
Claire	Female	White	English	Elementary
Dennis	Male	Black	English	Elementary Secondary
Elena	Female	Hispanic	English Spanish	Elementary
Erin	Female	White	English	Elementary Secondary
Imani	Female	Black	English	Elementary Secondary
Jody	Female	White	English	Elementary
Keysha	Female	Black	English	Elementary
Luna	Female	Hispanic	English Spanish	Elementary
María	Female	Hispanic	English Spanish	Elementary
Molly	Female	White	English	Elementary
Sofía	Female	Hispanic	English Spanish	Elementary

demographic, and educational forces made this site a particularly compelling one for examining how PSTs made sense of our framework.

Data collection and analysis

In the fifth and sixth week of the 14-week course, PSTs engaged in lessons from our COVID-19 instructional unit over two 1-hour sessions. In the first session, PSTs identified patterns in COVID-19 data by race and ethnicity (see Figure 1), proposed possible explanations for the patterns, and engaged in computational modeling to help explain the patterns (see Figure 2). In the second session, PSTs used the COVID-19 data and computational model, in combination with other data sources (e.g., demographic report, research study), to argue for explanations of how COVID-19 has disproportionately impacted racial and ethnic minority groups. Although, due to time constraints, PSTs were not able to design justice-centered solutions, they briefly reviewed the instructional materials for this final part of the unit.

Data sources consisted of written reflections and focus groups. After each lesson, PSTs completed an online reflection form in which they responded to a series of questions about their experiences engaging in the lessons. These questions targeted various components of our framework for justice-centered STEM education with MLs (e.g., “What are the benefits and challenges of bringing issues of justice into the science classroom?”; “What are the benefits and challenges of addressing multiple STEM subjects together?”; “How could this lesson capitalize on the strengths of multilingual learners?”). The first author also conducted focus groups to further elicit PSTs’ sense-making. Eight PSTs agreed to participate in the focus groups: five PSTs after the first lesson (Ariana, Anita, Erin, Imani, Keysha) and three after the second lesson (Dennis, Molly, Sofía). The focus groups (30–45 minutes each) enabled PSTs to elaborate on their responses to the questions from the reflection form as well as engage in collective sense-making around their emerging understandings and concerns.

The analysis was carried out in three stages (Table 3). In the open coding stage, the written reflections and focus group transcripts were coded inductively, with the only a priori codes being components of our framework (e.g., “Affordances of computer science”). In the axial coding stage, codes generated in the previous stage were organized into broader categories. For example, the codes “Resistance from outside forces” and “Stigmatization of students” were organized into the broader category of “Obstacles to addressing justice issues in science.” Using the constant comparative method (Strauss & Corbin, 1998), this stage also involved looking for similarities and differences within and across PSTs’ sense-making. This constant comparison was important given that PSTs approached their sense-making with different personal histories and lived experiences (e.g., Athanases et al., 2015) and often expressed ambivalent or even contradictory views (e.g., Darvin & Norton, 2018) as they grappled with new ways of thinking about STEM education with MLs and their roles as teachers. In the selective coding stage, the categories were further refined into overarching themes that addressed the research question.

Findings

We report on how PSTs made sense of the opportunities (Theme 1) and obstacles (Theme 2) of justice-centered STEM education with MLs.

Table 3. Stages of data analysis.

Open coding	Axial coding	Selective coding
Action and advocacy	***Opportunities of addressing justice issues in science***	Theme 1: Perceived opportunities of justice-centered STEM education with MLs
Affordances of computer science	Connections to real world	
Affordances of data science	Awareness of injustices	
Awareness of injustices	Action and advocacy	
Benefits of collaboration for MLs	***Opportunities of interdisciplinary teaching***	
Connections between standards and justice issues	Interdisciplinary as "whole game"	
Connections to real world	Affordances of computer science	
Developmental appropriateness	Affordances of data science	
Essentializing the cultural practices of MLs	***Opportunities with MLs***	
Interdisciplinary as "whole game"	Teaching language in context with MLs	
Lived experiences of MLs	Lived experiences of MLs	
Multimodality with MLs	Benefits of collaboration for MLs	
Practical constraints of interdisciplinary teaching	Multimodality with MLs	
Resistance from outside forces	***Obstacles to addressing justice issues in science***	Theme 2: Perceived obstacles to justice-centered STEM education with MLs
Stigmatization of students	Resistance from outside forces	
Teaching language in context with MLs	Stigmatization of students	
Tokenistic multiculturalism with MLs	Developmental appropriateness	
	Obstacles to interdisciplinary teaching	
	Practical constraints of interdisciplinary teaching	
	Connections between standards and justice issues	
	Obstacles with MLs	
	Essentializing cultural practices of MLs	
	Tokenistic multiculturalism with MLs	

Theme 1: Perceived opportunities of justice-centered STEM education with MLs

PSTs perceived opportunities related to various components of our framework. These included (a) opportunities of addressing justice issues in science, (b) opportunities of interdisciplinary teaching, and (c) opportunities with MLs specifically.

Opportunities of addressing justice issues in science. The most salient opportunity identified by PSTs was using pressing societal challenges to connect science to the real world. Unsurprisingly, PSTs made sense of this aspect of justice-centered STEM education by making comparisons between their experiences engaging in the COVID-19 lessons and their previous science learning experiences. Elena, for example, characterized the difference as follows: "Usually when you think of science experiments, we think of H2O and molecules, but I felt like this lesson was science but shown differently to students . . . connected to real life." Similarly, PSTs described how their previous science learning experiences addressed general science topics, such as diseases (Erin) and heredity (Anita), but typically in isolation of their real-world significance—what Keysha referred to as the "whimsical nature of random facts of science." Erin, who lamented that science learning was always "overwhelming and never made much sense," imagined how the COVID-19 lessons might have played out in her own schooling experiences: "[In school], we would've talked about disease progression in general instead of a specific instance we've all lived through, [which] helps make [science learning] more attainable." Likewise, Anita recounted a high school science lesson about heredity that was anchored in a "fake made-up question, 'Who is the father?,' whereas [COVID-19] is real life [so] students can conceptualize more clearly a phenomenon already prevalent in their own lives."

Beyond the benefits of connecting science to the real world, PSTs noted the benefits of addressing justice issues in science learning. Specifically, PSTs highlighted how centering justice could raise students' awareness of how pressing societal challenges disproportionately impact minoritized groups in society. Ariana gave a compelling example of how this awareness could help refute deficit views of racial and ethnic minority groups:

> Social issues can't be solved unless you're aware of them. People, even adults, might look at the [CDC data on deaths] and be like, "Well, this just means that, like, non-White people are genetically inferior or something." But these things don't just exist within a vacuum. There are real-world and, like, social aspects that affect the science. The first step to facing these issues is recognizing they're there.

PSTs emphasized that raising students' awareness of justice issues could lead to other affective outcomes, such as "creating students who are caring and kind to each other" (Claire) and "giving them a sense of empathy and compassion towards people in general" (Erin). Sofía argued that, for students from minoritized groups specifically, "when you tie in those real-world issues, it's a reflection of their own lives so they are able to see that they have a voice and someone (the teacher) is listening and taking them more seriously" (Sofía). Even though the COVID-19 lessons that PSTs engaged in did not emphasize designing justice-centered solutions, several PSTs mentioned how students' awareness of justice issues could lead them to advocate for themselves and their communities. For example, Erin conjectured that students could use their newfound awareness to "practice things like self-advocacy and … make choices about these inequities." María suggested that, "when students aren't 'sheltered' about the reality that is happening around them," they can "come up with their own solutions to combat inequities." Imani imagined that "if [students] know about inequities and have that awareness, they can protest it and even go into the field to correct it in a way."

Opportunities of interdisciplinary learning. PSTs also recognized the value of interdisciplinary learning that integrated multiple subjects, including science, data science, computer science, and engineering. In particular, PSTs emphasized that integrating STEM subjects to explain and solve a problem gave meaning to their learning, as it "simulated how the experts learn … in the real world" (Claire) and how, "in a workplace, you are never going to be just … using one skill at a time" (Erin). PSTs described how an interdisciplinary approach could help students see "the whole image" (Molly), get "a whole picture" (Ariana), and engage in "a full circle approach" (Sofía), which stood in contrast with PSTs' previous schooling experiences characterized by strict separation of subjects. Moreover, PSTs emphasized the unique affordances of different subjects for explaining pressing societal challenges. For example, with respect to data science, PSTs noted that interpreting real-world data could help students make sense of the "data they already see in their Instagram or highlight reels" (Keysha) and bring their own knowledge to interpreting how "people's lives and status play a role in the data we look at" (Luna). With respect to computer science, PSTs recognized how computational modeling could enable students to "visualize … that phenomenon" (Anita) and "manipulate different factors [while] exploring things that take a really long time" (Imani).

Opportunities with MLs specifically. In addition to identifying opportunities for all students, PSTs recognized unique affordances of justice-centered STEM education for

MLs specifically. PSTs emphasized that MLs could draw on their rich and varied lived experiences to make sense of pressing societal challenges. Consistent with Papert's (1980) notion of computational agents as mediational objects, Ariana suggested that MLs could "consider their own families and how their lives may be similar or different to [agents in] their models" while "connecting their own life experiences with some of the data [about frontline workers]." Sofía added that MLs' experiences with the cultural practice of multigenerational living in Latinx families could "provide valuable insight into how cultural differences play a part [in societal challenges]." Imani added that MLs could bring knowledge of "COVID traveling restrictions that may have affected their families and loved ones," thus leveraging their transnational knowledge and experiences (Cervantes-Soon & Kasun, 2018). Erin emphasized that MLs' knowledge and experiences could enrich the sense-making for all students in the classroom community by "providing evidence to support claims and giving the class more insight into the systemic issues" while also "showing how this problem reaches people they know."

Finally, PSTs recognized how justice-centered STEM education could harness MLs' rich meaning-making resources. Specifically, PSTs described how computer science and data science afforded "multiple opportunities [for MLs] to express their knowledge in ways that aren't reading or conversation based" (Molly). They also described how engagement with models, charts, graphs, and tables from multiple sources could support MLs to "notice patterns that they can later make connections about without necessarily needing all the vocabulary" (Dennis), thus giving MLs the "upper hand'" (Keysha) when they normally wouldn't have it. PSTs further noted opportunities to use multiple modalities in the context of meaningful collaboration, with students sharing different interpretations of their data and models (Jody) and asking questions of their peers (Claire) to "help each other get on the same page" (Keysha). These opportunities for goal-directed collaboration made the learning "more of an experience rather than a [language] lesson" (Molly) and could help MLs gain deeper understanding of both "the topic as well as the language that goes along with what the student is studying" (Carly). In this way, justice-centered STEM education could contribute to refuting deficit narratives that "just because you don't understand something in English doesn't mean you're incompetent" (Erin).

Theme 2: Perceived obstacles of justice-centered STEM education with MLs

PSTs also anticipated obstacles related to bringing justice-centered STEM education with MLs into their future classrooms. These included (a) obstacles to addressing justice issues in science, (b) obstacles to interdisciplinary teaching, and (c) obstacles with MLs specifically.

Obstacles to addressing justice issues in science. The most common obstacle that PSTs anticipated was resistance to addressing justice issues in the science classroom. Specifically, PSTs were concerned about the negative reactions of a range of stakeholders, especially parents and members of the broader community. Drawing on her own schooling experiences, Keysha explained how the lessons she had experienced, though compelling, would not be possible in the southern U.S. state where she grew up, since "talking about racial issues was not a thing, like, parents would be very upset." Keysha went on to describe how this obstacle was amplified in the current political climate in which "new laws in different states" restrict what can be taught—a concern that was particularly salient in the state where PSTs were preparing to teach. Likewise, Erin described how, in her “narrow minded farm community” that was “not a very diverse place,” people “wouldn’t necessarily see the point [of addressing justice issues].” In light of these obstacles, PSTs expressed uncertainty about the “boundaries you should have with your kids” (Sofía) and how to navigate the “hard balance” (Molly) of bringing justice issues into the classroom. Navigating these complexities elicited a range of emotions for PSTs. Molly felt “scared . . . because I don’t want kids to go home and say [to their parents], ‘Miss Molly leans this way or another.’” Anita expressed frustration: “Showing your students real world . . . evidence shouldn’t be something that causes uproar, so that’s frustrating.” Summing up the concerns expressed by several of her PST peers, Keysha lamented: “I just don’t know how feasible it is the way our world is right now.”

PSTs expressed concerns not only about outside forces that could influence their teaching, but what obstacles were likely to arise in their own classrooms. Specifically, PSTs were concerned that justice-centered lessons could create an uncomfortable environment or even stigmatize certain groups of students. Jody, for example, expressed a concern that students could “feel singled out” in lessons that call out their racial or ethnic group. Sofía gave a compelling example of this concern from her own experiences in social studies class: “I was genuinely the darkest girl in my class [so] when they would talk about Bay of Pigs, it was, like, all eyes on me [as a Cuban girl], so that’s why I feel like you have to kind of be careful [in lessons that highlight certain racial or ethnic groups].” This concern became particularly salient in the second focus group in which Sofía, Molly, and Dennis considered the obstacles of bringing justice-centered STEM education into early elementary classrooms. Molly worried about creating an uncomfortable classroom environment, since “things would get skewed” and her students would “grasp [issues] in the wrong light at a young age.” Dennis agreed that this would be an obstacle, especially when addressing issues such as “COVID mortality that could involve a loved one to somebody.” Though this concern was not fully resolved during the focus group, PSTs generally agreed that “it all depends on how it’s presented” (Dennis). Dennis proposed the possibility of teaching science in a spiraling manner such that K–12 students “build on the same problems [across the grades] . . . with more and more in depth” and in developmentally appropriate ways.

Obstacles to interdisciplinary teaching. PSTs identified obstacles that were likely to arise in teaching multiple subjects together. The most common obstacle anticipated by PSTs was time, both the planning time to develop interdisciplinary lessons and the instructional time to facilitate interdisciplinary learning. Other obstacles included limited opportunities for collaboration with teachers across subject areas (Jody); the privileged status of certain school subjects, such as math, that would require dedicated instructional time (Molly); and high-stakes testing mandates that narrowed the curriculum (Sofía). Two PSTs (Molly and Claire) specifically highlighted the obstacle of finding connections between justice issues and content standards across science and other subjects. For example, Claire expressed a concern with “making sure the topic of equity/justice in science is relevant to [students’] lives *and* also connects to . . . standards.” However, while contending with these structural constraints (e.g., instructional time, standards), Claire expressed the need to assert her agency as a teacher and “un-train [herself] from the years of schooling with separate subjects . . . since the truth is all the subjects are intertwined in the real world.”

Obstacles with MLs specifically. While enthusiastic about seeing MLs from an asset-oriented view, PSTs faced difficulty envisioning authentic ways of leveraging MLs' cultural and linguistic resources in the context of justice-centered STEM education. This became a topic of interest during the second focus group in which PSTs considered ways they might bring justice issues into their early elementary classrooms. Dennis recounted how, in his kindergarten field placement, "they have things [on the walls] acknowledging their race and culture," but "it's kindergarten so it's not deep or anything." Molly suggested a somewhat surface-level approach to building on MLs' knowledge of their home countries and languages: "[You could ask:] 'Marlene, you speak Polish, right? What does this mean in Polish?' Just to make them feel included [and convey that] it's good to come from different places and learn some cool facts about their country." Sofía proposed an activity in which young students "bring in something [related to the science topic] that represents their culture," such as "a can of beans since I'm Cuban." She acknowledged that, since "culture does tie into racial and justice issues," this activity would avoid "forcing it down their throats," thus reflecting her and other PSTs' earlier concerns about resistance and stigmatization. Overall, PSTs tended to adopt a tokenistic approach that effectively sanitized pressing societal challenges of their political dimensions.

It is important to point out that, despite the obstacles, PSTs qualified many of their concerns by reiterating the potential of justice-centered STEM education with MLs. For example, PSTs were excited about the prospect of anchoring STEM learning in pressing societal challenges relevant to their local context, for example, hurricanes in South Florida that have displaced historically marginalized communities. In response to concerns about resistance to justice-centered STEM education from parents and community members, Ariana pointed out that "it's a privilege thing to be able to turn a blind eye to justice issues in science" and that "these kids [from racial and ethnic minority groups] are living these inequities" and "can't afford to just, like, not pay attention." In response to concerns about whether students were ready to address justice issues beginning at a young age, Imani put it simply: "Let's not sugarcoat it. Ignorance is bliss .... Maybe it's adults who aren't ready to have kids that are more woke I guess." Keysha added that "students need actual context for a lot of the information they're seeing" and "I think that's more important than scaring a few kids maybe."

Future directions for justice-centered STEM education with MLs

In this article, we extended our conceptual framework for justice-centered STEM education to foreground the unique assets of MLs. Then, we reported on an initial inquiry into how PSTs made sense of the opportunities and obstacles presented by the framework and associated instructional materials.

This initial inquiry offered key insights that can inform future efforts to engage PSTs in justice-centered STEM education with MLs. One key insight is that the opportunities and obstacles perceived by PSTs were deeply informed by their life and schooling experiences (e.g., Erin's experience with school science disconnected from the real world; Sofía's concern about stigmatization arising from her experiences as a Cuban girl). This insight reinforces the importance of designing teacher learning that is symmetrical to student learning (Mehta & Fine, 2019) by eliciting, affirming, and building on the rich resources and personal histories that teachers bring. Another set of insights relates to the obstacles anticipated by PSTs, which could inform the revision and refinement of our framework. Specifically, key issues that require further consideration are how to promote justice-centered STEM education (a) in politically contentious education contexts, (b) at the early elementary grades, and (c) in ways that leverage MLs' assets while avoiding tokenistic approaches that essentialize these students and their communities.

While this initial inquiry offered insights into the opportunities and obstacles anticipated by PSTs in one teacher preparation program, it did not investigate implementation of the framework and instructional materials by teachers in different contexts. Thus, to further explore the potential of our framework, we are investigating teachers' sense-making and implementation across multiple dimensions of diversity. First, we are working with teachers at different stages of the teacher learning continuum (Villegas et al., 2018), including PSTs (as reported in this study) as well as in-service teachers (Grapin et al., in press). Second, within the in-service teacher group, we are studying the implementation of our COVID-19 instructional unit with teachers who specialize in different disciplinary areas (e.g., science, computer science, STEM). Third, we are implementing the unit across classrooms of MLs with different characteristics (e.g., home language, family country of origin, English proficiency) and across two major metropolitan areas (Miami and New York City), with each area facing different, though overlapping, societal challenges pressing to their communities. By collaborating with teachers at different stages of their careers, with different disciplinary backgrounds, and in different demographic and geographic contexts, we hope to better understand how our framework can be taken up, refined, and ultimately expanded to teachers and students across the K–12 education system.

As we continue this work, we are encouraged by comments such as the following, which was shared by one PST, Elena, at the end of the second COVID-19 lesson:

> I used to think everyone should stay home and COVID would be done, but after this lesson and hearing from others, it has really opened my eyes up to . . . what exactly is a "systemic" problem. I did not know the meaning of this word prior to the lesson.

Elena's candid comment, which we suspect would resonate with many of her PST peers, underscores how justice-centered STEM education shifts attention from perceived deficits of individuals (e.g., people are not trying hard enough to avoid COVID-19) to the policies and practices of societal systems that have privileged some groups while marginalizing others (e.g., lack of access to affordable housing in the housing system).

We argue that this shift is crucial not only for K–12 students to make sense of injustices facing minoritized groups in society, but also for PSTs to make sense of injustices facing minoritized student groups in the education system. As a reflection of the larger society, the education system has been responsible for privileging some student groups while marginalizing others (e.g., MLs' lack of access to meaningful STEM learning). As PSTs prepare to enter this system and confront the injustices it (re)produces, justice-centered STEM education could support them in making sense of how injustices result not from deficiencies of MLs but from failure of policies and practices to adequately center these students' strengths and needs. By engaging MLs in STEM subjects in ways that center their transnational knowledge and experiences as well as their rich repertoire of meaning-making resources as assets for STEM learning, justice-centered STEM education empowers PSTs to take on agentive roles in transforming the education system toward more just ends. As PSTs refute deficit narratives of minoritized groups in schools and society, they will be better equipped to disrupt systemic injustices within and beyond the school walls.

Disclosure statement

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