Preservice Teachers' Attention to Children's Expansive Sensemaking in Elementary Science

Jessica Bautista & Elizabeth A. Davis

University of Michigan

jessiba@umich.edu

betsyd@umich.edu

Abstract

Preservice elementary science teachers' beliefs and practices influence the kinds of adaptations they make to curricula and the extent to which they are able to enact science lessons in justice-oriented ways. Through this qualitative study, we explored the beliefs and practices of five focal preservice teachers through an analysis of their lesson plans, recorded enactments, and interviews about their science teaching throughout their student teaching experience. We also introduce a framework for *expansive sensemaking* that integrates beliefs and practices related to four key themes: (1) believing in children's brilliance, (2) building a collaborative classroom culture, (3) expanding what counts as science, and (4) positioning children as epistemic agents. While teachers varied in their beliefs about and approaches to each of these themes, they demonstrated strengths that illustrate what may be possible for early career teachers, like working to integrate many ways of knowing and being into science lessons, connecting to embodied knowledge, or supporting children to be scientific decision-makers. We discuss implications for teacher preparation programs and for theory development related to justice-oriented teaching in general and expansive sensemaking in particular.

1 Introduction

Preservice teachers have a range of beliefs, experiences, and resources to draw upon as they begin their work with children. Though teachers' own school-based science experiences have likely been influenced by dominant ways of knowing and being (e.g., white, male, Euro-centric, and post-Enlightenment ideologies), preservice teachers are capable of challenging these norms and expanding what counts as science for young children.

Scientific knowledge and practices taught within a K-12 education context often reflect a dominant framing that positions science as a politically-neutral "culture of no culture" (Bang & Medin, 2010; Haraway, 2018; NASEM, 2022). Within this framing, 'success' is frequently limited to 'right' answers that align with dominant ways of knowing, prioritizing English and academic vocabulary, memorization over meaningful engagement in sensemaking, and human-centric approaches over more relational and reciprocal epistemologies (Bang et al., 2012; NRC, 2012). Science, however, reflects the values, experiences, and cultures of its participants (Gunckel, 2019; Harding, 1986; Liboiron, 2021; Rosebery et al., 2010; Warren et al., 2020). Educators navigating this dominant framing while working to provide more equitable learning experiences for historically marginalized youth face unique challenges, even when they have a deep awareness of structural and systemic injustices (Louie, 2018).

To address these existing inequities and injustices in science education, elementary educators should continue working towards expanding ideas about *who does science* and *what counts as science* (NASEM, 2022). Expanding who does science means ensuring that children, particularly children of color, girls, and those who speak languages other than English, are situated as capable and competent, and respected as knowledgeable contributors to classroom scientific discourse (Carlone et al., 2021). Children must also have opportunities to actively

engage in science practices with epistemic agency (Calabrese Barton & Tan, 2010; González-Howard & McNeill, 2020). Expanding what counts as science means valuing non-dominant ways of knowing, working to incorporate multiple onto-epistemologies into science teaching, and being attuned and responsive to moments when children demonstrate scientific thinking that challenges dominant science norms (Bang et al., 2012; Warren et al., 2020). In valuing and integrating multiple ways of knowing, educators position children as individuals with complex, rich, and meaningful lives. Teachers seeking to engage in this work need to consider the unique "experiences, knowledge, interests, and identities of children and their environments" (NASEM, 2022, p. 106) as part of expanding *who does science* (Bang et al., 2017; Penuel et al., 2023). In this study, we bring this orientation toward science education as we explore five preservice elementary science teachers' approaches to attending to children's expansive sensemaking in science learning.

2 Background

Ensuring that all children have access to high-quality resources, curriculum, and teaching is a baseline for creating equitable learning opportunities (NASEM, 2022). Beyond considering *what* children learn, educators need to consider *how* children engage with phenomena. Children need opportunities for meaningful and relevant engagement in science practices that support sensemaking. These opportunities for disciplinary learning and sensemaking should support a sense of belonging and identity within science, which requires that teachers work to disrupt dominant ways of knowing and expand what counts as science (Bang et al., 2012; Calabrese Barton & Tan, 2020; Carlone & Johnson, 2007; Luehmann et al., 2024). One component of this work centers on how teachers support children's sensemaking. Sensemaking is an iterative process where knowledge is co-constructed in order to figure out "how and why the world

works" (C. V. Schwarz et al., 2021, p. 113). This encompasses processes like participating in collaborative discourse, making connections between everyday knowledge and scientific perspectives, engaging in meaningful experiences with natural phenomena, and checking for coherence with one's other resources (Haverly et al., 2020; Odden & Russ, 2019). Sensemaking happens in context, leveraging children's linguistic, cultural, and community resources, experiences, and knowledge (Bang et al., 2017; NASEM, 2022).

Expansive sensemaking, as introduced here, builds upon these ideas of sensemaking to incorporate multiple ways of knowing and interpreting new knowledge that challenge dominant norms and assumptions (Carlone et al., 2021; Nasir et al., 2022). Teaching science with a justice and equity orientation requires supporting children to bring their full selves into classroom spaces and engage with science, each other, teachers, and their community in ways that are "dignity-conferring" (Espinoza & Vossoughi, 2014, p. 285). To better understand how preservice teachers might support expansive sensemaking, we posed the following research questions:

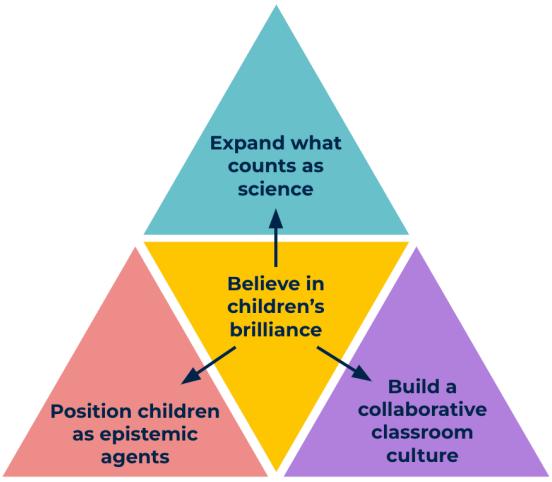
1. What are preservice teachers' beliefs about promoting children's expansive sensemaking in science?
2. What moves do preservice teachers plan for and enact that promote children's expansive sensemaking in science?

3 Conceptual Framework and Literature Review

Our conceptual framework for expansive sensemaking emphasizes four interconnected themes: *believing in children's brilliance*, *building a collaborative classroom culture*, *expanding what counts as science*, and *positioning children as epistemic agents*, as shown in Figure 1 (Bautista & Davis, in press). These themes interact with and inform each other.

Figure 1

Conceptual Framework for Expansive Sensemaking



3.1 Believing in children's brilliance

In this study, we sought to understand the extent to which preservice teachers demonstrated beliefs in children's brilliance and how they did so. Within our framework, centering children's assets and recognizing their strengths is foundational to other aspects of promoting expansive sensemaking (Moll & Greenberg, 1990; NASEM, 2022; Rosebery et al., 2010). For example, facilitating collaborative discourse, recognizing varied forms of competence, and supporting children to engage in scientific decision-making are all supported by asset-oriented beliefs about children. Affirming children's brilliance here means recognizing the fullness of who they are and positioning their lived experiences, cultures, and identities as important resources for their learning. Carlone and colleagues (2021) describe a teacher who saw it as central to their role to "recognize, nurture, and celebrate students' assets—their varied ways of thinking, being, and creating" (p. 180). This may also involve demonstrating an interest in "developing the whole person" (Haverly et al., 2020, p. 68), or viewing children as inherently knowledgeable, with valuable epistemological and linguistic resources that contribute to broader discourse and learning (Suárez, 2020). Recognizing children's brilliance often extends to how teachers perceive and work to include children's families and communities (Bricker et al., 2014).

Perhaps more fundamentally, teachers who believe in children's brilliance see each child as capable and competent and actively support their success within and beyond the classroom (Ladson-Billings, 1995).

3.2 Building a collaborative classroom culture

Learning happens within the context of relationships and discourse (Moll & Greenberg, 1990; Rogoff, 2003; Vygotsky, 1978). We take a sociocultural approach and recognize that different communities emphasize different practices around discourse and collaboration (Kang & Zinger, 2019; Suárez, 2020; Wright, 2019). Examining how teachers build collaborative classroom cultures is thus integral to understanding sensemaking as co-constructed. Sensemaking is a social process where public discourse is crucial to negotiating understandings of science concepts (Rosebery et al., 2010). A beautiful example of what this might look like comes from Carlone and colleagues' (2021) engagement with Mrs. W, a first-grade teacher who saw community as a central driving force behind her work with children:

> I draw on other teachers and the specialists and their parents. It's bigger than just me and the child. It really takes a full community to work together to create a safe space for this kind of learning… [I]n the end I try to keep a really positive and loving atmosphere, one where we really celebrate each other and we celebrate our successes, but also our failures. (p. 181)

This example reveals both Mrs. W's mindset as well as some of the 'behind the scenes' work necessary to create spaces where expansive sensemaking is possible. In this study, we examined teachers' beliefs about collaboration, as well as specific strategies teachers used to build classroom community (e.g., co-creating norms with children or working to build positive relationships).

3.3 Expanding what counts as science

Expanding what counts as science, another key component of our framework and a central goal of justice-focused science education, requires that teachers attend to and support a range of onto-epistemologies, or ways of knowing and being (Bang et al., 2017; NASEM, 2022; Warren et al., 2020). Teachers who expand what counts as science work to recognize and respond to the richness of children's experiences and ideas in ways that demonstrate a deep respect for children's cultural, family, and community knowledge. Science teachers may support connections between scientific phenomena and children's lived experiences (Carlone et al., 2021; Kang & Zinger, 2019). They may also work to recognize competence in ways that push against dominant norms of what it means to be 'good' at science (e.g., validating children's thought processes or recognizing creative approaches to a problem) (Louie, 2017). Teachers may approach this by reflecting on whose knowledge is considered valuable and working to recognize and integrate different perspectives (Gunckel et al., 2024). Teachers might also embrace perspectives that challenge dominant onto-epistemologies and seek to support sensemaking through multimodal thinking, (e.g., making, storytelling, or movement) (Barajas-López & Bang, 2018; Solomon et al., 2022). Children have rich and varied ways of communicating that do not always reflect the discourse styles privileged within schools. Students may use humor and word play to build on and critique other's ideas (Wright, 2019), or use translanguaging, like mixing home and school-based languages or using non-verbal gestures, to communicate scientific understandings (Suárez, 2020; Suárez & Otero, 2023).

Central to expanding what counts as science is desettling whiteness and dominant Euro-centric scientific onto-epistemologies—emphasizing children's knowledge and experiences not for purposes of assimilation but to uplift the inherent value in children's diverse funds of knowledge (Moll & Greenberg, 1990; Sanchez, 2023). Without this desettling, onto-epistemologies that do not fit within dominant frameworks will continue to be viewed from a deficit-orientation, actively dismantled, and ultimately excluded from science spaces. Expanding what counts as science to provide more equitable science learning experiences means using children's cultural and linguistic resources not just as scaffolding tools but as integral components of the learning space (Ladson-Billings, 1995; Lee et al., 2003).

3.4 Positioning children as epistemic agents

In this study, we explore how preservice teachers position children as epistemic agents and work to recognize children's inherent agency. If children are to have a rightful presence in science, they must meaningfully engage in authentic scientific decision-making that positions them as both *knowers* and *doers* of science (Calabrese Barton & Tan, 2020; Damşa et al., 2010; Miller et al., 2018; NASEM, 2022). By critically examining who has the authority to engage in science practices, including making decisions about what questions to ask, what data to collect, and how to organize that data, teachers can work to destabilize pervasive stereotypes of the solitary white male scientist in a sterile laboratory. Elementary teachers may support epistemic agency by shifting power from teacher to student, supporting children to co-construct knowledge together, and working to 'hear' the science in children's ideas (Ko & Krist, 2019; Rosebery et al., 2016; Stroupe, 2022; Vossoughi & Gutiérrez, 2017). Teachers may also work to recognize and uplift children's inherent agency, which is often unrecognized or diminished in classroom spaces. This work is often challenging, especially for preservice teachers, and is supported by asset-

oriented beliefs and respect for children as knowledgeable others (Bautista & Davis, 2024; Calabrese Barton & Tan, 2010; González-Howard & McNeill, 2020).

We see epistemic agency as a key component of expansive sensemaking, and one that is too frequently denied to children with marginalized identities. Modifying lessons and activities based on children's ideas, particularly those that diverge from canonical narratives, can support children to see themselves as competent co-constructors of meaning (Krist et al., 2023; C. V. Schwarz et al., 2021; Suárez, 2020). Some amount of pedagogical uncertainty is inherent in being able to make these kinds of adaptations, requiring a level of flexibility and knowledge that is often challenging even for expert teachers (Ko & Krist, 2019). We were interested in better understanding ways preservice teachers conceptualize and work to position children as epistemic agents as a way of highlighting both what may be possible and what early moments on a teacher's trajectory may look like.

3.5 Teacher beliefs and practices for expansive sensemaking

Teaching, as with science, is not neutral or objective (Cochran-Smith, 2010; Esmonde & Booker, 2017). A social justice approach to teacher education requires confronting ideas of neutrality and addressing systems of power. Teacher beliefs serve as interpretive frames for implementing and reflecting on their practices. Solely focusing on teacher beliefs, however, is insufficient for understanding what teachers may be able to do (Ball & Forzani, 2009). Teachers, for example, who believe that all children should have a rightful presence within science may be more likely to plan for and enact lessons where children make epistemic decisions during investigations, like developing their own questions. Similarly, teachers who are familiar with ways of thinking and doing that extend beyond dominant science norms may be more likely to notice and respond to moments when children name cultural or familial practices in ways that

uplift children's knowledge and experiences. Likewise, supporting teachers to plan and enact lessons where children have scientific decision-making power or engage in multiple ways of thinking may provide teachers with opportunities to reflect on and shift their beliefs. Teachers' beliefs and practices are interconnected, where "science teachers' beliefs greatly influence their teaching practices that are in turn influencing their beliefs" (Jones & Park, 2023, p. 1103).

Work to develop 'well-started beginners' within elementary science education then requires that teachers have "knowledge, beliefs, and practices" that support them to engage in "rigorous, consequential, just, and equitable science teaching" (Davis & Haverly, 2022, p. 83). By teaching practices, we mean the "work of teaching"—what teachers are doing and how these practices seem to relate to their beliefs about science, teaching, and justice (Ball & Forzani, 2009). Within our conceptual framework, we see *believing in children's brilliance* as connected to teachers' beliefs, with each of the other components drawing on teachers' beliefs, knowledge, and practices. Here, we focus on beliefs and practices together, and attend to them as interconnected, overlapping, and developing in conjunction with one another. In doing so, we hope to illuminate areas where meaningful practices and beliefs might be cultivated in teacher preparation programs and into induction. In this study, our aim is to explore preservice teachers' beliefs and practices as one way of attending to their learning as they begin the transition into their first year of teaching.

4 Methods

4.1 Study context

Participants included 25 preservice elementary teachers in an intensive four-semester integrated master's and teacher certification program at a large public university in the US. During their science methods course, which took place in the second semester of the

program, preservice teachers analyzed and adapted an existing science lesson and taught that lesson in their placement classrooms. Participants were in a year-long student teaching placement within a well-resourced district where roughly 50% of students identified as white, 14% as Black, 14% as Asian or Asian/Pacific Islander, 11% as Hispanic or Latino, 11% as two or more races, and less than 1% as American Indian or Alaskan Native[1]. Around 26% of students in the district were considered economically disadvantaged, and just under 10% were identified as "English Learners." Teachers primarily used open-source, web-based curriculum materials aligned to the NGSS and state science standards. They also used several tools within the science methods course, including a Practical Justice and Anti-Racism Framework, or Justice Framework, to critique and adapt curriculum materials and reflect on their teaching (Davis, 2022b). These tools and frameworks were intended to support the integration of science practices and 'justice moves,' which generally align with our conceptual framework. The Justice Framework, based on approaches to equity and justice identified in NASEM (2022) which build off of work by Philip and Azevedo (2017), includes sections on historical background, teaching moves, critical reflection questions, and resources to support preservice teachers in navigating some of the complexity around teaching elementary science from a justice orientation. This framework, for example, encourages teachers to connect to children's cultural knowledge or reflect on how children engage in scientific decision-making. Teachers annotated their lesson plans to show how they would incorporate similar justice moves.

4.2 Focal participants

We identified five focal preservice teachers, as shown in Table 1, who reflected the four themes of expansive sensemaking based on a preliminary review of their science methods lesson

[1] The categories here use the naming conventions of the state agency responsible for collecting this data.

plans. Because all preservice teachers who worked to expand what counts as science and position children as epistemic agents also had a strong asset orientation and emphasized collaborative classroom culture, teachers were selected who were most likely to "illuminate and define the boundaries and relevance" of expanding what counts as science and supporting epistemic agency (Bryant & Charmaz, 2007, p. 611). We considered gender and racial diversity, though most teachers in this cohort were white women, which is largely reflective of the population of elementary teachers in the US. Of the focal teachers, two identified as white women (Amber and Ruth), one as a Japanese man (Junto), one as a Chinese American woman (Monica), and one as a white man (Xavier). We also considered grade level diversity when selecting participants, allowing us to look across first through fifth grade classroom contexts.

Table 1
Overview of participants, contexts, and science methods lesson topics

Participants	Grade level	Lesson topic	Self-ascribed identities
Amber	Grade 5	Sea level rise	White woman
Junto	Grade 1	Day and night	Japanese man
Monica	Grade 4	Force and motion	Chinese American woman
Ruth	Grade 2	Classifying matter	White woman
Xavier	Grade 5	Sea level rise	White man

Amber completed her undergraduate degree at the university where this study took place. She noted in her interview that she considered her own identities and experiences in the context of her role as a teacher, including her limited prior experience with science. She planned to teach in public schools before eventually transitioning to a community-based education environment. Amber's student teaching experience, including the semester of science methods, took place in a 5th grade classroom at the same elementary school as Xavier. Amber and Xavier collaborated on their lesson plans but taught separate classes. She also earned an endorsement to support multilingual learners in the summer after she completed student teaching. When engaging with children, she asked questions with enthusiasm and curiosity that suggested a genuine interest in

children's thoughts on a topic. She also frequently sought out feedback on her lesson plans and enactments.

Junto had significant experience in research as an undergraduate student in Canada after growing up in Japan. We learned in the course of our data collection that he did not have plans to continue teaching full-time, but he did hope to continue working with children in the future as a pediatrician. Junto's student teaching took place in a first-grade classroom and he often described children in ways that extolled their capabilities and suggested a shared sense of authority over classroom operations. Throughout science methods, Junto frequently expressed an interest in incorporating non-dominant ways of knowing into his science teaching, with a particular focus on integrating Indigenous perspectives.

Monica described wanting to work at a school "with demonstrated need" in the same town where she completed this teacher preparation program. In the summer following her certification, she also earned an endorsement to support multilingual learners. She completed her student teaching in a fourth-grade classroom where science instruction took place within Project Lead the Way (PLTW), an engineering-focused curricular program adopted by the district to supplement their science curriculum. While all focal teachers planned and taught a science lesson during their science methods course, Monica was the only one who did not plan and lead a science unit in her final semester. Her interview provided considerable insight into how she thought about and planned for expansive sensemaking across her student teaching experiences.

Ruth entered the teacher preparation program with a background in special education and described herself as "a lower elementary person." Ruth had prior experience working as a long-term substitute at another elementary school in the same district as her student teaching placement. Ruth conducted her student teaching in a second-grade classroom where science was

often integrated into the International Baccalaureate (IB) curriculum. She described her student teaching experience as "kind of chaotic," noting tensions with her mentor teacher. Despite this, she felt she "learned a lot from that placement." At the time of her interview, she had plans to move out of state and teach in an elementary school on or near the military base where her husband was stationed. She also earned an endorsement in supporting multilingual learners after completing the program.

Xavier was born and raised in the community where he was teaching and expressed a strong interest in staying in the area after finishing the preparation program. He felt that many people, including teachers, made assumptions about children in the town being "middle class, professors' kids," which he saw as an inaccurate depiction of the community. Prior to entering the teacher preparation program, he had experience as an AmeriCorps member and assistant teacher. Xavier was also placed in a fifth-grade classroom at the same school as Amber and they co-planned their lessons together. In his course reflection journal, a secondary data source, he described feeling a lack confidence in his ability to teach science, and unfamiliarity with the standards, content, and practices.

4.3 Data Sources

We collected lesson plans from all 25 preservice teachers and additional data for the five focal teachers, including video-recorded enactments and one semi-structured interview. We used the lesson plans to identify our focal teachers and to gain a deeper understanding of teachers' beliefs and intended practices for promoting expansive sensemaking. For their course assignment, preservice teachers were required to analyze and adapt an existing science lesson, teach the lesson in their placement classrooms, analyze examples of student work, and reflect on the experience. Preservice teachers were directed to select an investigation-based science lesson and use the Engage, Experience, and Explain + Argue (EEE+A) lesson model (Davis & Marino,

2020), as well as engage children in an investigation question or problem, an experience with a natural phenomenon, and an opportunity to develop explanations and/or arguments supported by evidence. Teachers also analyzed their lesson for the approaches to equity and justice put forth by a recent report on elementary science education and emphasized in the aforementioned Justice Framework (see NASEM, 2022; Philip & Azevedo, 2017).

We used recordings of focal teachers' enactments to look for teacher actions that supported opportunities for children's sensemaking. Enactments ranged from 25 minutes to two hours. Each enactment included multiple connections to NGSS science practices, opportunities for children to work with peers, experience with a natural phenomenon, and engagement in sensemaking.

We conducted interviews with these same five preservice teachers at the end of their student teaching, one semester after their science methods course. The interviews, ranging from 40 minutes to an hour, provided a different perspective on preservice teachers' beliefs about sensemaking and how these beliefs related to their elementary science teaching. The semi-structured interview protocol included questions about their science teaching experiences, how they noticed and responded to children's ideas, and how they built relationships with children.

In addition to the primary data sources mentioned above, we used course journals and lesson enactment reflections as secondary data sources. We reviewed reflections for the five focal teachers to gauge whether they provided new insight into preservice teachers' beliefs that were distinct from their interviews. We also reviewed digital class journals that spanned the entirety of the science methods course for each focal teacher to triangulate across data sources and look for confirming or disconfirming evidence related to their beliefs (Erickson, 1986).

4.4 Data coding and analysis

We used an emergent coding process which began with examining lesson plans from all 25 preservice teachers in the science methods course (Saldaña, 2016). We iteratively analyzed the data and engaged in memo-writing to revise and restructure our coding scheme as we coded each data source (Bryant & Charmaz, 2012). *Believe in children's brilliance*, for example, required an asset-orientation that positioned children's lived experiences, cultures, and identities as important resources for their learning (Moll & Greenberg, 1990). After an initial round of coding, we revised this theme to include two subcodes: (1) *held asset-oriented beliefs* and (2) *demonstrated a desire to empower children*. We continued this process as we looked across all data sources, eventually finalizing our coding scheme. Collectively, we used these codes when we observed teachers center children's funds of knowledge, position children as knowledgeable, connect children's assets to their learning, and support children to identify as scientists.

We developed most codes around preservice teachers' practices, often creating subcodes to zoom in on specific moves. In refining the theme of *expanding what counts as science*, for example, we established four main codes: (1) *connected everyday and scientific perspectives*, (2) *recognized a range of competence*, (3) *incorporated non-dominant ways of knowing*, and (4) *supported multimodal thinking*. Within *supported multimodal thinking*, we identified moments where teachers incorporated books and visuals as well as moments where they connected to children's embodied knowledge or physical experiences of phenomena. While most preservice teachers (19 out of 25) planned to use visuals, often intended to support emergent multilingual learners, some teachers (8 out of 25) planned for kinesthetic representations of phenomena, and one teacher (Amber) supported children to use translanguaging, all of which were coded under *supported multimodal thinking*. We resolved differences in interpretations of the data through

discussion among team members using an intercoder credibility process (O'Connor & Joffe, 2020). This process was iterative and included many rounds of coding. In one aspect of the process, we compiled all the references to a particular code and, based on the literature and the data themselves, regularly looked for and discussed references that either exemplified the code or seemed to fall just outside of what we hoped to capture with a particular code. Our full coding scheme is shown in Table 2.

Table 2
Theme, codes, and descriptions

Believe in children's brilliance	
Held asset-oriented beliefs	Preservice teachers centered children's funds of knowledge, believed children have valuable things to share, and identified children's strengths.
Demonstrated desire to empower children	Preservice teachers positioned children as knowledgeable, worked to connect children's assets to their learning, build children's confidence, and supported children to identify as scientists.
Build a collaborative classroom culture	
Built positive relationships	Preservice teachers worked to build and sustain positive relationships with children (e.g., connecting to children's interests or sharing personal stories).
Supported equitable participation	Preservice teachers planned for and/or enacted strategies to support equitable participation (e.g., co-constructing norms for collaborative work).
Expand what counts as science	
Connected scientific & everyday perspectives	Preservice teachers connected everyday and disciplinary perspectives, noticed when children brought up familiar everyday experiences, and/or support children to make connections to scientific concepts. Teachers planned for connections between everyday and scientific knowledge and/or took advantage of impromptu opportunities.
Recognized a range of competence	Preservice teachers recognized a range of competence, (e.g., naming different ways of being 'smart,' praising children for 'good thinking,' and/or validating children's thought processes and problem solving skills over having the 'right' answer.)
Incorporated non-dominant ways of knowing	Preservice teachers incorporated non-dominant ways of knowing, including reflecting on and integrating different perspectives (e.g., Indigenous, Black / Afro-Indigenous, feminist, or queer sensemaking).
Supported multimodal thinking	Preservice teachers incorporated opportunities to engage with books, visuals, embodied knowledge, and support for translanguaging where children could communicate using a range of linguistic resources (e.g., using multiple languages, gestures, and/or physical objects to explain ideas).
Position children as epistemic agents	
Publicly displayed and (re)centered children's ideas	Preservice teachers displayed children's ideas on a white board or projector, revoiced ideas shared by specific children, and/or referred back to ideas children shared earlier in the lesson to (re)center their thinking.
Oriented children to each other's ideas	Preservice teachers supported children to repeat or revoice ideas from their peers, and/or used questions to support children to elaborate on their own thinking or extend others' ideas.
Engaged children in science practices	Preservice teachers supported children to decide what data to collect, how to organize or record data, how to design models, and/or how to develop their own investigation questions.

In analyzing teachers' lesson plans, enactments, and interviews, we focused on seeing their strengths. We ultimately decided to connect teachers' beliefs with their practices, not to make claims about causal relationships (e.g., that a particular belief caused a teacher to use a particular move), but instead to acknowledge that beliefs and ways of being are entangled and reciprocal (Warren et al., 2020). Rather than arbitrarily separating beliefs from practices, we present them as integrated to clarify our arguments and illustrate the complexity of these teachers' work. In moving from codes to findings, we looked for areas of overlap both within and across themes, paying particular attention to moments where teachers' beliefs and practices seemed clearly connected. We also developed and iteratively refined conceptual maps using themes, codes, and indicators related to teachers' beliefs and practices to visualize these relationships (Bryant & Charmaz, 2012; Corbin & Strauss, 2008). Within each section of our findings, we include specific beliefs and practices that reflect a culmination of our coding and analysis process.

5 Findings

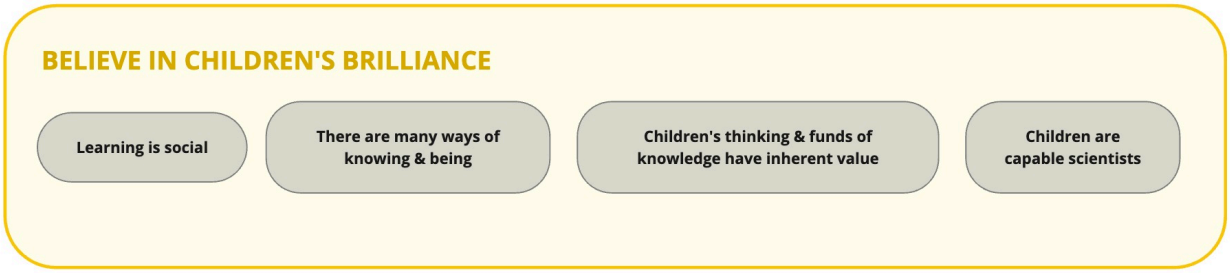
Focal teachers held a range of beliefs about science, children, and learning that pushed against dominant epistemologies. They planned for and enacted practices connected to these beliefs that worked to build a collaborative classroom culture, expand what counts as science, and position children as epistemic agents. These preservice teachers' practices and beliefs are not the only ways to support expansive sensemaking but can serve as examples of what may be possible, providing insight into how early career teachers might conceptualize and embark on this work.

5.1 Believing in children's brilliance

Within the theme of believing in children's brilliance, we identified four specific beliefs held by preservice teachers: (1) learning is social; (2) there are many ways of knowing and being; (3) children's thinking and funds of knowledge have inherent value; and (4) children are capable scientists, as shown in Figure 2. We then connected these beliefs to at least one practice within the other three themes.

Figure 2

Preservice teacher beliefs associated with believing in children's brilliance



Preservice teachers demonstrated beliefs in children's brilliance across data sources. Monica, for example, made a note in her lesson plan to "show that everyone's data (work, presence) is valuable and important." She also emphasized particular children's ideas as important by naming them in whole class discussions during her enactment and later reflected during her interview on the importance of "knowing their assets, drawing on it as much as possible, and having them know what their assets are." These brief examples demonstrate how Monica was thinking about children's funds of knowledge and their positioning as capable scientists. Junto described in his lesson plan that "students should feel empowered for having the knowledge that they bring which may be associated with religion, culture, or ethnic roots." He extended this belief during his interview, saying "I try to value different ways of knowing, like their ideas." He also described how children would engage in dramatic play, pretending to be scientists or science teachers, and how he supported children in his first-grade class to be

responsible for their own materials and procedures. These examples highlight his attention to learning as a social endeavor, his intention to value many ways of knowing, and his openness to seeing different onto-epistemologies as part of what it means to *be* a scientist or *do* science. Teachers' beliefs cut across themes and informed a range of practices. As a result, we elaborate on each of these beliefs in the context of expansive sensemaking practices in the sections that follow. Table 3 outlines each of the four beliefs associated with *believing in children's brilliance*, along with additional examples.

Table 3
Preservice teacher beliefs and examples connected to 'believe in children's brilliance'

Learning is social	"One person in your group is the data collector. I have already told the data collectors who they are. On this sheet, the data collector will draw the items in the trays how you sort them and write the categories you sorted them into on this line up here. The other team mates will be the data makers and will need to work together to move the objects into their trays." (Ruth, lesson plan)
There are many ways of knowing and being	"The physical representation of the sun and the earth was very effective. When students start moving, this engages the students involved in the model itself and their classmates. When doing science, when appropriate, I would like to use students as models to allow students to see phenomena." (Junto, lesson plan)
Children's thinking and funds of knowledge have inherent value	"Really drawing on your students' knowledge and experience and like showing students that what they know and what they have experienced and the things that they're bringing in, like are super valuable to our classroom learning and just like centering that, broadly, you know and everything." (Amber, interview)
Children are capable scientists	"I see so you're taking turns doing the roles, awesome. Also, I notice you're both holding it down, that is very smart! It's smarter than what I did. And I noticed [child's name] that just now you were being very precise." (Monica, enactment)

5.2 Building a collaborative classroom culture

Each focal teacher worked to build a collaborative classroom culture, often exemplified by how they connected with children and supported them to engage and connect with each other. As represented in Figure 3, we developed two assertions related to this theme:

(1.A) Teachers believed that children's thinking and funds of knowledge have inherent value and learning is social. These beliefs informed their practice of building positive relationships with children.

(1.B) Teachers believed there are many ways of knowing and being. This belief informed their practice of supporting equitable participation.

Table 4 provides a few examples of teaching practices associated with this theme's assertions.

Figure 3

Preservice teacher beliefs and practices associated with 'build a collaborative class culture'

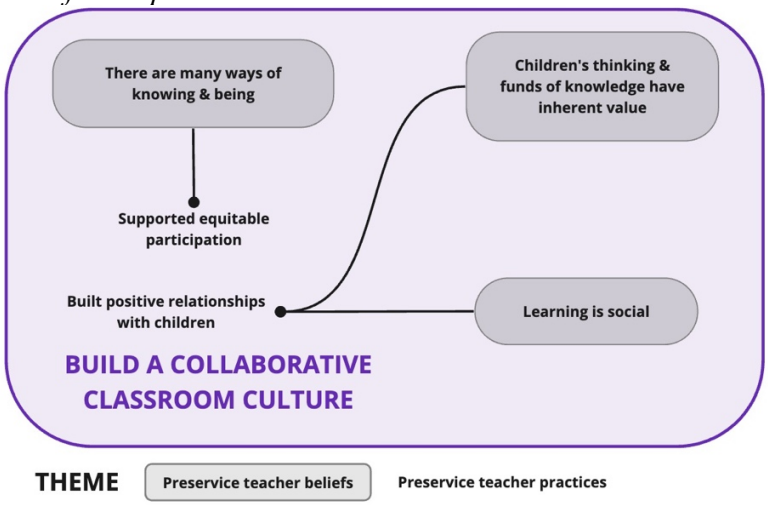


Table 4

Preservice teacher beliefs, practices, and examples associated with 'build a collaborative class culture'

1.A - Teachers believed that children's thinking and funds of knowledge have inherent value and learning is social. These beliefs informed their practice of...	
building positive relationships with children	"I would tell a lot of stories and [one] student really liked listening to my stories. And, like during recess he was like, 'Do you have another

	story? Do you have another story about this?' That's how, like, I would connect with this student." (Junto, interview)
1.B - Teachers believed there are many ways of knowing and being. This belief informed their practice of ...	
supporting equitable participation	"Think a little bit about how we like to work and be treated by our peers when we're doing groupwork and things people can do or say that make you frustrated." (Xavier, enactment)

Assertion 1.A: Teachers believed that children's thinking and funds of knowledge have inherent value and learning is social. These beliefs informed their practice of building positive relationships with children.

Amber, Monica, and Junto explicitly emphasized positive relationships with children as an aspect of building a collaborative classroom culture. Amber described her own efforts to listen closely to children during her interview:

> I really try to listen to what kids are saying before responding. Just kind of as a baseline goal, I need to hear what you're saying before I try to make sense of what you're saying… If I walk away from a conversation with the kid about a content area thing, and I have no idea what they were saying, I know that that's something on me that I need to re-address that and go back with that kid. That's like, it's something I try to be really conscious of in my own practice. Just how I'm understanding kids and what space I'm giving them to make sense of things and parse through things, and what materials and resources I'm presenting them with in order to be able to do that.

This intentional effort to ensure she understood children's thinking speaks to the importance she placed on their ideas and the care she took to get to know and understand children. In her interview, she described building a relationship with one Portuguese-speaking student where

Amber leveraged her own knowledge of Spanish to communicate and connect. She emphasized positioning herself as learning with and from the student, saying, for example, "there were opportunities for her to teach me different Portuguese words, and books, and things like that." Amber's belief that children have unique and valuable assets seemed to be an entry point in how she established relationships.

Monica also valued making personal connections. In her interview, she described writing personalized goodbye letters to children at the end of her student teaching. While this wasn't specifically connected to science, it highlighted her attention to relationships and her interest in knowing and relating to children as human beings and not just as 'students.' Junto focused on building trust. He described an experience with one child he felt he had a hard time connecting with, saying, "You just have to, like, be there. She'll throw water at you, but you just gotta be there like 10 minutes later, you know? It's a very slow process of building trust." Junto, supported in part by guidance from his mentor teacher, worked to build relationships with children by meeting them where they were, both personally and academically. His description of this interaction and others he had with children was one where he worked to demonstrate patience and tried to be a consistent and calm presence.

Assertion 1.B: Teachers believed there are many ways of knowing and being. This belief informed their practice of supporting equitable participation.

All focal teachers worked to support equitable participation. The clearest instances of this involved teachers supporting children to co-create norms for collaboration and implementing a variety of participation structures. The ways teachers conceptualized their use of these strategies was connected to how they worked to integrate children's unique ways of knowing and being into their science learning.

Amber reflected on how children's dispositions might influence their engagement. In her lesson plan she included different options for how children would share their group's data. She specifically asked for feedback from her science methods instructor (the second author) to help her "make sure that all students have the opportunity to build this [presentation] skill (especially if they want to do this in their group but may not necessarily be the loudest or quickest to volunteer)." She seemed to attend to the many ways children might engage in science, considering different forms of support based on children's needs and interests. Like Amber, Ruth described using questions to create a "more equitable platform for students to get ideas and bounce off each other, so that when it did come time to share, everyone had the opportunity to have something to share if they wanted to." In this way, there seemed to be a relationship between Ruth's commitment to supporting children's collaboration and other moves she made to promote expansive sensemaking, like orienting children to each other's ideas.

Xavier, along with Amber and Ruth, also considered how participation structures could support children in sharing ideas, reflecting on how these different structures impacted children's comfort and thus their engagement. He explained in his interview that he didn't love cold-calling strategies, like using "a jar full of popsicle sticks with student's names," saying "sometimes kids just aren't comfortable talking in [discussions], and trying to force them to just makes them more uncomfortable, makes them more worried about being called on than actually listening." During his enactment, though, Xavier used strategies similar to cold-calling to involve different children in handling and organizing investigation materials (for example, having the person in each group who has the next birthday return materials).

Monica and Xavier also supported equitable participation by modeling small group conversations during their enactments and later reflected on ways they would establish norms in

future years. Xavier's lesson plan included having children "brainstorm on what behavior students appreciate when they are working in groups and what behavior makes then angry or annoyed." He was also the only focal teacher that supported children to co-create norms for collaborative groupwork during his recorded enactment, spending about 10 minutes on this at the beginning of the lesson. In his interview, he expounded on his rationale for emphasizing children's ability to work together:

> Almost any context you're going to go into—and career you go into—you're going to have to know how to work as a team. And even if you are assessed as individuals, for performance assessments, things like that, your true measure of success is, well, what do you as a collective achieve? […] Even if you prefer to work best on your own, learn how to work well with others, because you're going to need to.

Here he identified learning as a collective social endeavor and seemed to view supporting children to reflect on their own ways of engaging with others as a key part of his role as a teacher. This example also connects to a tension around what it means to collaborate, what skills are necessary for effective collaboration, and how teachers' perceptions of participation might reify dominant modes of knowing and being, rather than expanding the ways children can engage. Xavier acknowledged in his interview that even with their class conversation on "how to be a good teammate," some children still experienced "some frustration." Related to this, Xavier described two children with "more introverted personalities" who he identified as successful when they worked independently and could illustrate or draw their thinking, but noted that "they didn't really contribute that much in the discussions—they participated a little bit in the model making, but they're not really taking a lead." Xavier's emphasis on vocal participation and

leadership as markers of success in this moment highlights how embedded dominant norms may be in teachers' own ways of knowing, despite efforts to engage in practices that broaden these definitions.

5.3 Expanding what counts as science

We developed two assertions related to teachers' beliefs and practices around expanding what counts as science, as illustrated in Figure 4:

(2.A) Teachers believed there are many ways of knowing and being and that children's thinking and funds of knowledge have inherent value. These beliefs informed their practices of recognizing a range of competence, supporting multimodal thinking, and incorporating non-dominant ways of knowing.

(2.B) Teachers believed that children are capable scientists and that children's thinking and funds of knowledge have inherent value. These beliefs informed their practice of connecting the scientific to the everyday.

Table 5 provides some examples of specific teaching practices associated with this theme's assertions.

Figure 4

Preservice teacher beliefs and practices associated with 'expand what counts as science'

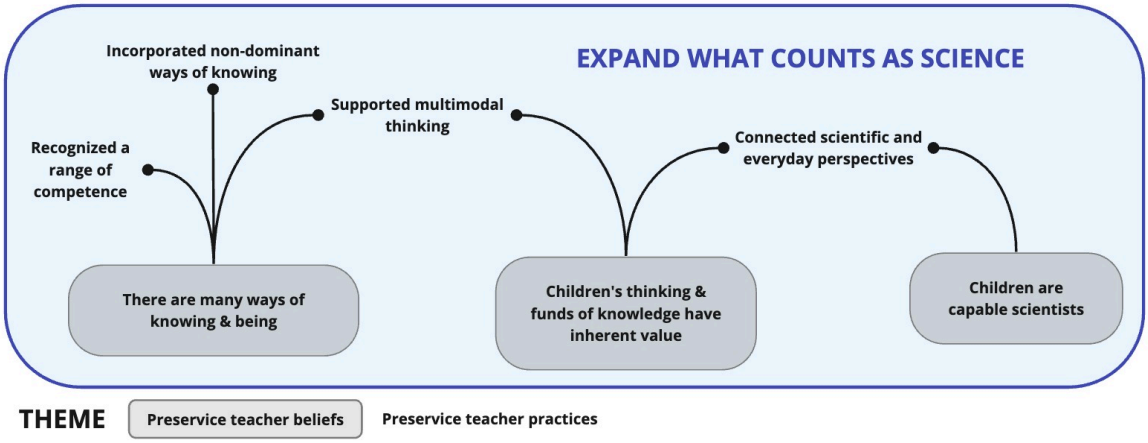


Table 5
Preservice teacher beliefs, practices, and examples associated with 'expand what counts as science'

2.A Teachers believed there are many ways of knowing and being and that children's thinking and funds of knowledge have inherent value. These beliefs informed their practices of...	
recognizing a range of competence	"I had to change my approach that I've had with this student all year to, you know, support her appropriately in this task. And a lot of it was just like, a confidence thing and kind of getting her out of her own head, and trying to just be like, 'There isn't a right answer here. You're looking for relevant information, but there's a lot of different ways to do that.' So it's a very, I think, expanding lesson for her. Kind of broadening those views and horizons around what school is." (Ruth, interview)
supporting multimodal thinking	"They're saying all the right things but not able to explain why they're saying them—that's an indication to me as a teacher, like, 'Oh, what tool do they need in front of them to think through what they're thinking?'" (Amber, interview)
incorporating non-dominant ways of knowing	"They are different ways of explaining things that happen around us. This is very important for students to appreciate different types of knowledge and not fall into the dominant narrative that schools often teach to students, rooted in how science and technology are valued so much in this country and in the West." (Junto, lesson plan)
2.B Teachers believed that children are capable scientists and that children's thinking and funds of knowledge have inherent value. These beliefs informed their practice of...	
connecting the scientific to the everyday	"They were observing and drawing trees, and going on nature walks, which is really great. And at one point they were curious about something and they were doing something to a tree. And other teachers were like, 'Don't do that.'… Instead of just saying, 'Stop shaking it,' I'd be like, 'Okay, well, one stop shaking it because it's not working! Not because it's annoying, but it's because it's not working. So what would you do? What are some tools that you could use here to get that thing from the tree?'" (Monica, interview)

Assertion 2.A: Teachers believed there are many ways of knowing and being and that children's thinking and funds of knowledge have inherent value. These beliefs informed their practices of recognizing a range of competence, supporting multimodal thinking, and incorporating non-dominant ways of knowing.

In her interview, Monica described how she thought about uncertainty, saying "It's important to not know and to admit you not know because that's exciting, because then you can learn more things." She expressed a desire to support children to be comfortable with uncertainty, seeing it as part of the scientific process. This was connected to her work cultivating a "safe space" for children to acknowledge when they are unsure or don't know something. For Monica, and for Ruth, there were many ways of approaching a question or problem, and being able to admit uncertainty was a step on the path to uncovering alternative approaches. During their recorded enactments, Monica and Xavier both named for children when they observed "good teamwork" and "listening" skills, positioning these as crucial to their success. Ruth also worked to name specific strengths she noticed, trying to go beyond what she saw as "empty positive reinforcement." During her interview, Ruth recalled an experience with one child, saying, "I would take interest in how he was thinking or how he was working with particular manipulatives, and be like, 'I find it so interesting that you're using this tool in this way. Can you tell me more about that?'" These teachers' efforts to name specific skills as indicators of success in science illustrated one of several ways they worked to recognize different ways of knowing and being, and thus to expand what counts as science.

The ways teachers worked to incorporate multimodal thinking typically centered around how they conceptualized supporting emergent multilingual learners. Teachers often described this as adding "pictures/visuals" or giving a choice to "draw or write their data." Three focal

teachers—Monica, Junto, and Amber—went beyond this image/word binary to further expand what counts as science. These three teachers incorporated embodied knowledge or physical representations to support children's sensemaking. Monica drafted a prompt with questions she planned to ask children, writing, "Remember a time you were on the swings. How did you make yourself go faster? How did you know in your body what to do, what it felt like?" She also brought this up during her enactment, encouraging children to recall the physical sensation of swinging as they began their lesson on potential and kinetic forces. Junto shared a similar way of thinking during his interview in connection to his own identity:

> I'm Japanese and in Japan—Japan's like a pretty scientific country. But at the same time, there are parts of Japan where we acknowledge that there are some things that you just cannot explain with numbers. For example, I play baseball and in baseball we talk about like—there's velocity of pitching—but at the same time, there's like, we call it 'hop' in Japan. It's how fast the ball actually feels.

Junto's description here highlights his belief in and personal connection to valuing multiple ways of knowing and being. Amber described an experience supporting one group that included a Portuguese-speaking child who had recently immigrated from Brazil. She supported this group to use a range of physical objects to co-construct meaning and communicate their ideas, emphasizing that the emergent multilingual child took the lead in this sensemaking moment. This highlighted Amber's own attention to and practices for supporting multimodal thinking as a means of translanguaging.

Junto and Xavier also worked to incorporate non-dominant ways of knowing as part of expanding what counts as science. Junto was explicit about his efforts in his lesson plan, writing that he would try to ensure that "the message that I am sending is that there are different ways of

explaining phenomena." During his interview, he elaborated on how he worked to incorporate and value non-dominant ways of knowing, while also noting his own uncertainty in doing so:

> I brought in poems. I brought in picture books about worms, and what it's like to live like a worm. Things like that. Different ways of knowing. That was a goal that I had, but when I reflect on that, it's like now—can I explain what an Indigenous way of knowing is? I can't. I can't really, like put it into words, you know? Or like, how can you know from poems? I can't really put that into words.

Of all the preservice teachers in this science methods course, Junto was clearest in his intentions to incorporate non-dominant ways of knowing across all data sources. The above quote also demonstrates how much he still grappled with this aspect of his practice. Xavier, who was also eager to incorporate non-dominant ways of knowing, did not express a similar conflict at the time of his interview. He described an interdisciplinary writing unit that he led during his student teaching experience:

> We talked about folk tales, and how folk tales were an alternative way humans have of explaining the world around them before they had the understanding or the technology to understand and to create scientific explanations for what was happening in the world around them. And just looking at the differences between the two, about how folk tales explain the world around them using narrative, whereas science does it using observations and data.

Here Xavier focused on bringing in diverse cultural stories as a key component increasing representation and broadening what counts as science, but seemed to still position this within a dominant epistemological framework. Xavier explained how he approached including these stories:

> I also had to frame it as like, people who made up these myths, don't think of them as being stupid, or not being as smart as us. They didn't have the technology that we have, or the knowledge that we have, to explain the world through scientific phenomenon and processes, so they made up stories. If they'd had the technology we had, they probably would have.

In what seemed to be an effort to assert the strengths of other cultures, Xavier may have unintentionally reified dominant narratives that position other ways of knowing and being as existing only in the past while positioning modern technology as necessary for scientific knowledge making. Both Xavier and Junto incorporated cultural stories related to the science topics they were teaching, taking risks and challenging themselves in doing so. Junto wrestled with whether or not he was successful in incorporating non-dominant ways of knowing and was particularly reflective about this aspect of his teaching during his interview. He did not seem convinced that the inclusion of non-Western stories and perspectives was sufficient in challenging dominant narratives. Xavier, on the other hand, did not express similar tensions or concerns at the time of his interview.

Assertion 2.B: Teachers believed that children are capable scientists and that children's thinking and funds of knowledge have inherent value. These beliefs informed their practice of connecting the scientific to the everyday.

Many of the ways that focal teachers worked to connect everyday knowledge to scientific knowledge overlapped with how they incorporated multimodal thinking. Junto described in his interview wanting to regularly connect everyday experiences, like the feeling of running after recess, to children's ideas about science. Monica integrated children's embodied knowledge of swinging on the playground. In her lesson plan, she emphasized that these were "real life

connections" where she wanted to "show students science is everywhere." During her interview, Monica elaborated on her interest in "making explicit those personal connections" and "showing them where [science] fits in." She also recounted an experience where she seemed to work in the other direction—observing children's exploration of a tree and using that to support children to see their play through a scientific lens. In this instance, she took advantage of an impromptu moment and seemed to 'see' the science in what children were doing, rather than take a punitive stance to their exploration of the world.

Xavier also worked to situate children as capable scientists, describing his efforts to make sure that all children were able to access scientific ideas and discussions. He described this in his interview as working to ask questions and present phenomena where "you didn't have to have a lot of prior knowledge to actively engage in that debate." An example he gave was asking children what they noticed as the seasons changed, saying, "Everyone who walks outside can participate in that discussion to some degree." Xavier's use of everyday experiences seemed to support his goal of making sure every child could engage with scientific concepts. This example also serves to illustrate a tension, however, around working to ensure equal footing with respect to the content while not avoiding certain topics out of concern that some children may not have extensive experience with them.

5.4 Positioning children with epistemic agency

We developed three assertions related to teachers' beliefs and practices for supporting children's epistemic agency, as illustrated in Figure 5, and as we discuss in Bautista and Davis (2024):

(3.A) Teachers believed that children's thinking and funds of knowledge have inherent value. This belief informed their practice of publicly displaying and (re)centering children's ideas.

(3.B) Teachers believed that learning is social. This informed their practice of orienting children to each other's ideas.

(3.C) Teachers believed that children are capable scientists. This informed their practice of engaging children in science practices.

Table 6 provides a few examples of teaching practices associated with this theme's assertions.

Figure 5

Preservice teacher beliefs and practices associated with 'position children as epistemic agents'

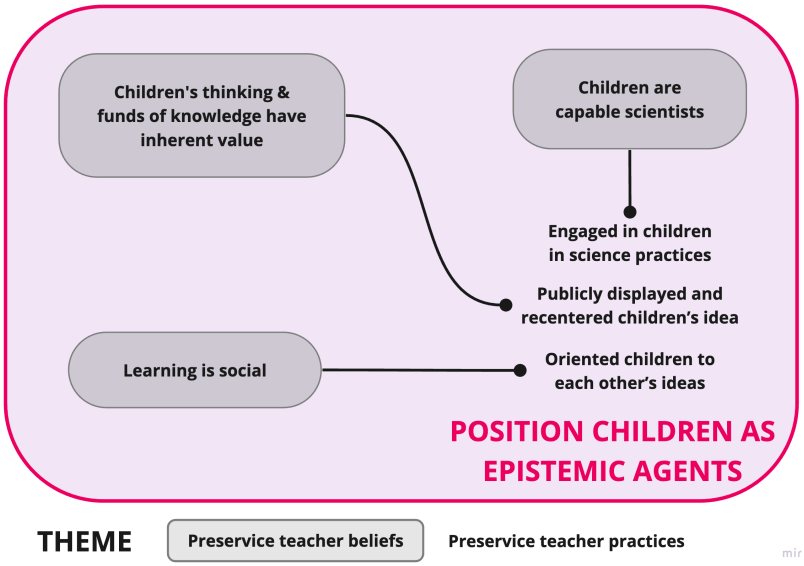


Table 6

Preservice teacher beliefs, practices, and examples associated with 'position children as epistemic agents'

3.A Teachers believed that children's thinking and funds of knowledge have inherent value. This belief informed their practice of...	
publicly displaying and (re)centering children's ideas	"Have each group graph their results on the back and front whiteboards. Once a group is done, they can walk around and see what data other groups got." (Xavier, lesson plan)
3.B Teachers believed that learning is social. This informed their practice of...	

orienting children to each other's ideas	"I saw some other groups who saw that too. Did everybody hear what [this child] just said? [Child's name] can you say that again for everybody?" (Amber, enactment)

3.C Teachers believed that children are capable scientists. This informed their practice of...

engaging children in science practices	"There are a few things we COULD measure and collect here (science doesn't have just ONE right answer, ONE right procedure) - instead asking, what is relevant and helpful here?" (Monica, lesson plan)

Assertion 3.A: Teachers believed that children's thinking and funds of knowledge have inherent value. This belief informed their practice of publicly displaying and (re)centering children's ideas.

While publicly displaying and (re)centering children's ideas were expectations of the elementary teacher preparation program, each focal teacher implemented these strategies in ways that positioned children as epistemic agents. Junto, for example, planned to "Show what the student is talking about to the class using the manipulatives to ensure that all students can also visually see what is being talked about." His emphasis on supporting first graders to see and understand each other's thinking related to his belief that children's thinking is inherently valuable, while highlighting how he worked to create opportunities for children to make sure they were understood.

Amber often (re)centered children's ideas. At one point during her enactment, a child came up with a different method for organizing and sharing data. Amber later presented this idea to the entire class as an improvement upon the lesson itself, saying, "I saw a couple different ways of calculating [the data], and I was talking to [this child] about it and we figured out that if we're going to graph our data that this way might make the most sense." Amber noticed and responded to this child's thinking in a way that demonstrated her belief in the value of children's

thinking, elevated this child's epistemic agency, and opened the door for others in the class to influence the ways they collectively engaged in scientific practices.

While the focal teachers did exceptional work to support children's epistemic agency, this was not without its challenges. Amber, for example, was careful in her plan and enactment to elicit children's ideas when guiding their model construction. One child shared an idea that Amber illustrated for the class, but Amber eventually replaced this with her own illustrations that more closely reflected the curriculum materials, saying, "I'll draw my idea and see what you guys think. It's similar to [a child's] but we're going to have to fill the tub with water to represent the sea." In her plan, Amber's decision to elicit ideas about model design provided support for children's epistemic agency, but during her enactment she seemed to be navigating her own uncertainty about the lesson progression, which may have influenced her decision to return to the original designs from the curriculum materials.

Assertion 3.B: Teachers believed that learning is social. This informed their practice of orienting children to each other's ideas.

Focal teachers took care to understand children's thinking, even when their ideas did not seem connected to the lesson at hand. This emphasis on understanding was apparent in how they worked to orient children to each other's thinking. During Junto's enactment, he asked, "Who can explain what [this child] just said?" This elevated one child's thinking while pushing others to interpret and reframe their idea, emphasizing his belief that learning is social. Amber described using similar strategies, asking questions like, "Oh, did you notice the same thing that this person is noticing?" Her questions also seemed to come from a place of genuine interest and curiosity about children's thinking.

While focal teachers often described an intention to orient children to each other's ideas during their interviews, some, like Amber, expressed a concern about children getting "stuck on the wrong idea." She reflected on this as something she seemed to still be developing, saying,

> I want to give kids space for kids to explore their ideas, and their thoughts, and be able to parse that out. But I also don't want them spreading misinformation to the class, and like having to work backwards to try to correct that. And I think that was something that was always in the back of my mind, especially as someone who does not have a very strong science background. This was—like I had to do research to teach this. And so it's like, I don't necessarily feel super confident in my ability to convince you that what you're saying is wrong.

Even as Amber navigated this dilemma, she used a range of practices that supported children's epistemic agency. Amber consistently centered children's funds of knowledge, experiences, and unique ways of thinking, positioning children's ideas as fundamental to their collective learning. She also often positioned herself as a co-learner by taking up children's ideas and, at times, making impromptu decisions to shift away from her lesson plans. In doing this work, she demonstrated her commitment to children learning collectively and collaboratively. Xavier, on the other hand, described wanting children to "think through ideas" in small groups, but added: "I normally try not to have any serious sensemaking happen in these small groups. I want that to be something where I can, kind of, that's whole group where there can be whole group instruction." Xavier seemed to prioritize being able to facilitate and lead sensemaking discussions himself, rather than allowing children to engage in this kind of thinking in their small groups where he might not have been able to monitor and support their discussion as easily.

While he seemed to view learning as a collective and social endeavor, he also expressed a belief that part of his role as a teacher was to carefully facilitate children's sensemaking.

Assertion 3.C: Teachers believed that children are capable scientists. This informed their practice of engaging children in science practices.

Focal teachers often indicated a belief in their lesson plans that children are capable scientists, with some extending this to how they supported children's engagement with science practices during their enactments. Monica, for example, told children to hold the bob of their pendulums at 'half height' and 'full height' to investigate potential and kinetic energy. During her enactment she realized that children had different interpretations of 'half' and 'full' height. Rather than leaning on her own understanding or the definition in the curriculum materials, she allowed children to continue collecting data based on their own interpretations. As the class discussed their results, Monica carefully drew children's attention to this discrepancy, noting the wide range of data recorded between groups and asking, "what are some things you may have done differently from group to group?" One child mentioned the height of the bob, which Monica uplifted to support children's collective sensemaking around science practices. Her series of in-the-moment decisions during this enactment prioritized children's epistemic agency, demonstrating how she positioned children as *doers* of science.

While most focal teachers' support for children's agency was epistemic in nature, Xavier's enactment focused on having children make creative decisions rather than scientific ones. While he gave children time to collaboratively develop model designs, he provided sufficient limitations that kept designs within the bounds of the curriculum materials, focusing their modifications on aesthetic decisions like whether or not they included clay figures. Xavier

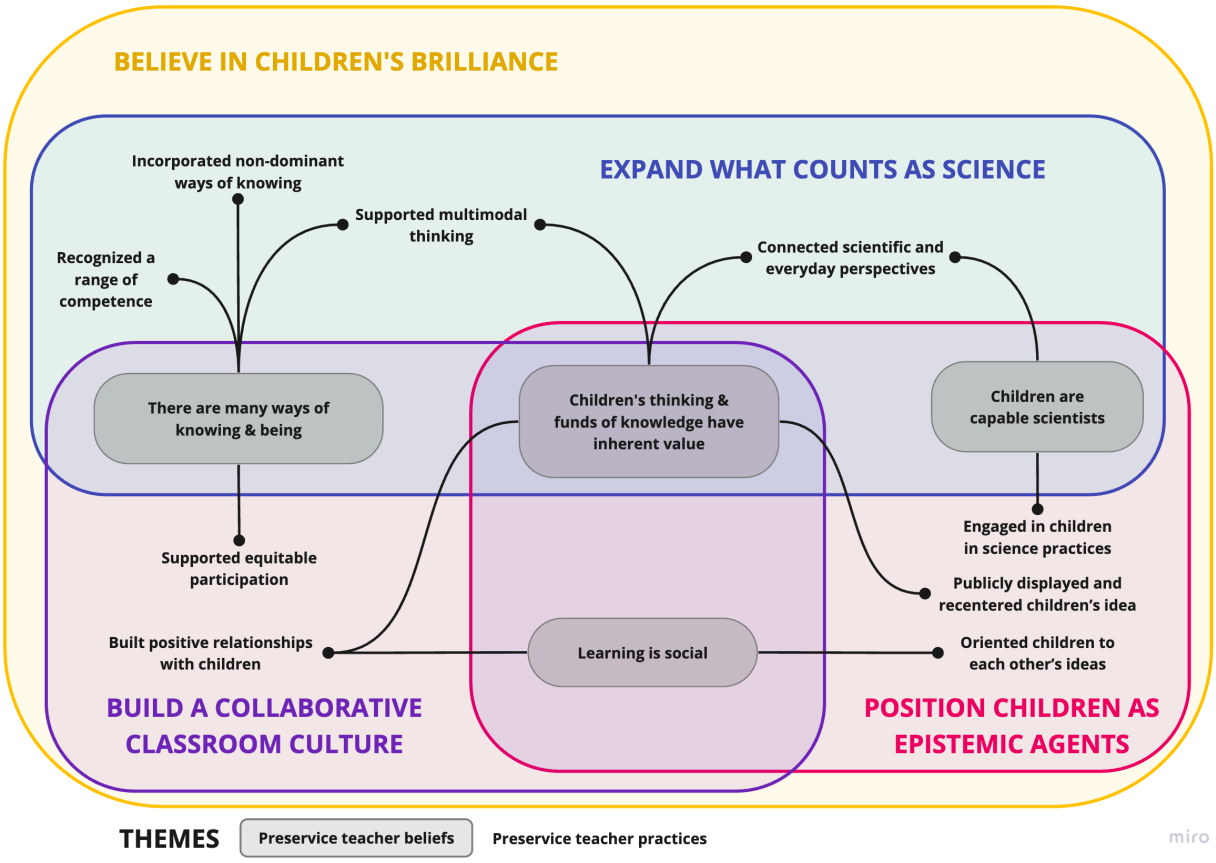
may not have differentiated between this kind of creative agency and epistemic agency, especially as his seemed to be working to integrate student choice throughout his lesson plan.

6 Discussion and implications

Preservice teachers who demonstrated beliefs in children's brilliance often described children as having valuable knowledge and experiences to share, emphasized the importance of children's funds of knowledge, and/or worked to identify and name children's strengths. As they emphasized children's assets, teachers often expressed beliefs around there being many valid and valuable ways to address to a single problem or learning experience. Every focal teacher engaged children in collaborative discourse with the specific intention of supporting their sensemaking (Rosebery et al., 2010; C. V. Schwarz et al., 2021). These teachers also made specific adaptations to curricular materials to support expansive sensemaking, like connecting to Indigenous ways of knowing and encouraging children to make decisions about model designs. Overall, the teachers in this study reflected a sociocultural orientation to thinking about teaching and learning. Each of the beliefs these teachers expressed was connected to a range of practices and multiple themes, as shown in Figure 6, which overlays Figures 2-5 to show the intricacy of these relationships.

Figure 6

Connections among preservice teachers' beliefs, practices, and conceptual framework themes



By showing how these themes, beliefs, and practices overlap and connect, we offer a theory of expansive sensemaking that works to weave together different yet related aspects of elementary science teaching. In an effort to explore implications for teacher learning, highlight how this learning can be supported in teacher education, and understand potential trajectories of these teachers, we focus our discussion on connections and tensions related to beliefs and practices for expansive sensemaking, particularly around the themes of *building a collaborative classroom culture*, *expanding what counts as science*, and *positioning children as epistemic agents*.

Each focal teacher engaged in practices that worked to *build a collaborative classroom culture*, *expand what counts as science*, and *position children as epistemic agents*, often in ways

that were interconnected and seemed held together by certain beliefs. Teachers' belief that there are many ways of knowing and being, for example, was connected to both how they supported multimodal thinking and equitable participation. Preservice teachers like Amber and Xavier considered how different children in their classes would benefit from being able to participate in a variety of ways. While Xavier did extensive work to support children in co-creating norms for equitable collaboration and discussion, he still seemed to be looking for certain ways of knowing and being as markers of success, like verbal participation and leadership, privileging dominant modes of participation and demonstrations of competence. This is an area where teachers may need to be supported to attend to the ways that the implementation of participation structures could be used to either reify or challenge dominant norms of scientific discourse. Working to build children's collaboration skills may require teachers to critically reflect on what they perceive to be 'effective' participation and why this might be (Mensah, 2022; Rosebery et al., 2016).

Each child in a teacher's classroom is unique and has their own situated knowledge and experiences, all of which provide rich connection to scientific thinking (Calabrese Barton & Tan, 2020; Gunckel, 2019; Haraway, 1988). Focal teachers believed that children's thinking and funds of knowledge have inherent value, but at times looked for examples that they felt anyone and everyone might relate to, rather than focusing on examples that the specific children in their class would connect with. There may be an important distinction, as in the case of Xavier, between focusing on topics where *everyone* is assumed to have prior knowledge and working to elicit and center children's diverse knowledge and experiences, especially those that do not necessarily align with dominant, school-centered science. This tension has implications for how teachers work to build a collaborative classroom culture, expand what counts as science, and position

children as epistemic agents. By considering and attending to the experiences and perspectives of the specific children in their classes, teachers may be able to learn more about the children and their communities, build stronger relationships, be better positioned to connect children's everyday experiences to scientific concepts, and support children to make connections among each other.

When we looked specifically at how teachers took up the work of expanding what counts as science, we found they emphasized different practices each with unique foci. Monica and Ruth both reflected on their intention to recognize a range of competence, for example, whereas Xavier commented on children's 'good thinking' and listening skills throughout his enactment (Carlone et al., 2021). Monica, Junto, and Amber each worked to support children to engage in multimodal thinking and included physical representations and embodiment as a component of children's sensemaking. Amber was particularly adept at this and was clear about her interest in ensuring children could pull from a range of linguistic resources, including providing them with physical tools and models to aid in their explanations. While Amber was the only teacher to support children in translanguaging, all focal teachers did some work to promote multimodal thinking. This seems to suggest the potential to uplift and emphasize translanguaging within teacher education programs by supporting teachers to think both expansively and critically about their inclusion of multiple modalities (Suárez, 2020; Suárez & Otero, 2023).

Junto seemed to more directly connect his thinking about multiple modalities with how he worked to incorporate non-dominant ways of knowing, possibly drawing on his own experiences, like those related to playing baseball in Japan. While Junto and Xavier were explicit in working to incorporate Indigenous ways of knowing, they both at times still situated dominant Euro-centric science as the primary or more accurate way of explaining the world. Dominant

norms and ideologies can be deeply embedded in teachers' own frameworks and onto-epistemologies, influencing their pedagogy and what they notice about children's ideas and engagement (Bang et al., 2012; Jones & Park, 2023; Vossoughi & Gutiérrez, 2017). This may be another area where preservice teachers could benefit from opportunities to critically reflect on their own ways of knowing and assumptions about alternatives in order to support their work to incorporate non-dominant ways of knowing without unintentionally 'othering' them or continuing to set them apart from what science is and can be (Alim et al., 2020; Gutiérrez, 2013). Many teachers may avoid incorporating non-dominant ways of knowing for fear of misrepresenting ideas or perceiving these epistemologies as too far from their own definitions of science. Personal connections and experiences with non-dominant ways of knowing may also influence teachers' commitments to incorporating and supporting multiple onto-epistemologies in the context of their classrooms, as we observed in the case of Junto, who worked across his Japanese upbringing and his schooling in the US and Canada. Preservice teachers might benefit from curriculum materials that authentically reflect non-dominant perspectives (e.g. Learning in Places Collaborative, 2021) or justice-oriented frameworks that can support them in making critical adaptations (e.g. Davis, 2022a; Luehmann et al., 2024). When access to such materials is limited, they may need guidance on where curricular adaptations might be most effective and meaningful for children.

Each of the preservice teachers in this study also worked to position children as epistemic agents (Bautista & Davis, 2024), including explicitly considering how to support children to engaging in scientific decision-making by opening up curricula (Ko & Krist, 2019). This work to open up curricula brought teachers' own sense of uncertainty to the surface (Hammer, 1997). Preservice teachers were not always sure when to let children take the lead and when doing so

might move children further from their learning goals. Individual teachers navigated this differently, but often did so by seeking ways to control the flow of discussion and manage children's sensemaking, as in the examples of Amber and Xavier. Of all the focal teachers, Amber and Xavier expressed the most uncertainty around their own knowledge and expertise in science. They each wrestled with this either during their interview or within their science methods reflection journal, which we analyzed as a secondary data source. Monica and Junto, on the other hand, both described either taking advanced science coursework or working in a research lab during their undergraduate programs. Their previous experiences and sense of confidence in science may have supported them to make more impromptu decisions to open up curricula and support children's epistemic agency. With or without these experiences, preservice teachers may benefit from additional opportunities to unpack when and where they might shift decision-making to children during a lesson or unit.

Related to this is a tension around how teachers conceptualized agency. It is possible, for example, that Xavier viewed certain forms of decision-making, like adding in creative touches, as epistemic in nature. While these types of decision-making opportunities may influence children's engagement or sense of ownership within a lesson, they do not necessarily give children space to make *scientific* decisions, thus limiting their engagement in science practices and their potential for constructing new knowledge (Miller et al., 2018). The ways preservice teachers conceptualize agency may affect how they plan for and adapt curricula to support children's scientific decision-making. Teachers may need particular support in differentiating between types of agency. They may also benefit from better understanding where and how they can support children's epistemic agency without feeling like they no longer have control over the lesson or learning goals (Manz & Suárez, 2018). Connecting epistemic agency to decision-

making within science practices may aid early career teachers in positioning children as agentic in ways that promote expansive sensemaking.

Beginning with implications for teacher education, Table 7 includes considerations and recommendations for teacher preparation programs and teacher educators interested in supporting preservice teachers to promote expansive sensemaking. The first portion of Table 7 presents ideas about how teacher education programs might support the development of teachers' beliefs for supporting children's expansive sensemaking. We developed these ideas by identifying where our focal teachers seemed to express clearer commitments to aspects of expansive sensemaking in particular and justice-oriented science education in general within the class as a whole. We also developed suggestions based on what seemed challenging for teachers, especially where their approaches or beliefs seemed to diverge from one another. The second portion of Table 7 focuses on how teacher education programs might provide opportunities for preservice elementary science teachers to practice and gain feedback on strategies that support expansive sensemaking. Similar to the first portion, we developed these ideas by attending to areas where some or all focal teachers made attempts to support children's expansive sensemaking, but where these efforts were not fully realized and may have benefitted from more explicit practice.

Table 7
Considerations for supporting expansive sensemaking within teacher education

Teacher preparation programs may support preservice teachers to critically reflect on…
• How their implementation of varied participation structures might challenge rather than reify dominant norms of scientific discourse • Their own perceptions of 'successful' or 'effective' participation in science • Their use of multiple modalities as a means for both presenting information to children and supporting children to demonstrate their own understanding • Their own ways of knowing, assumptions about non-dominant onto-epistemologies, and how to avoid othering these onto-epistemologies

- Various forms of children's agency (e.g., epistemic, creative, aesthetic) and the implications of these differences

Teacher preparation programs may provide specific opportunities for preservice teachers to…

- Incorporate a range of practices associated with translanguaging (e.g., supporting children's use of home languages and/or recognizing 'everyday' language like the use of metaphor or gestures as valid and valuable forms of communication)
- Connect to or experience non-dominant ways of knowing and doing science
- Practice adapting curricular resources to incorporate a range of onto-epistemologies
- Experiment with when, where, and how to position children as scientific decision-makers

---

Understanding how teachers' beliefs are connected to a range of equity-oriented practices, as well as where these practices may fall short of promoting equity and justice, is key in supporting preservice teachers to provide more just and equitable learning experiences for all children, especially those from marginalized groups (Esmonde & Booker, 2017).

7 Conclusion

Early career teachers face a range of challenges as they enter the profession. This can be even more true for elementary science teachers who may not yet feel confident in their own subject matter knowledge or understanding of science practices. In this study, we shared examples of what early points on a trajectory might look like for elementary science teachers, particularly as relates to their beliefs and practices that promote expansive sensemaking. Teachers' beliefs and practices will continue to shift over time as they gain experience, develop relationships with children and the community, and adapt to their particular school contexts (Davis et al., 2020). We hope that this study, and particularly the connections we illustrated among teachers' beliefs and practices in Figure 6, can provide a framework for thinking about and supporting elementary science preservice teachers' development as justice-oriented educators who work to support expansive sensemaking in elementary science. We leave this

work interested in exploring how continued support for teachers' critical reflection across a range of contexts—on their own onto-epistemologies, conceptions of agency, and approaches to supporting collaboration—may influence their practices and deepen their commitments to justice and equity.

8 Acknowledgements

Work on this paper was partially funded by the National Science Foundation (DRK12 grant number 2246607), the ASSETS project (Advancing, Supporting, and Sustaining Equity among Elementary Teachers of Science). However, all findings, conclusions, and recommendations expressed herein are those of the authors. We are grateful to the preservice elementary teachers who allowed us to study their practice and to learn from them. We would also like to thank Chauncey Monte-Sano, Natalie R. Davis, and Jamaal S. Matthews for their valuable feedback.

9 References

Alim, H. S., Paris, D., & Wong, C. P. (2020). Culturally Sustaining Pedagogy. In N. S. Nasir, C. D. Lee, R. Pea, & M. McKinney de Royston (Eds.), *Handbook of the Cultural Foundations of Learning* (pp. 261–276). Routledge.

Ball, D. L., & Forzani, F. M. (2009). The Work of Teaching and the Challenge for Teacher Education. *Journal of Teacher Education*, *60*(5), 497–511. https://doi.org/10.1177/0022487109348479

Bang, M., Brown, B., Calabrese Barton, A., Rosebery, A., & Warren, B. (2017). Toward More Equitable Learning in Science: Expanding Relationships Among Students, Teachers, and Science Practices. In C. Schwarz, C. Passmore, & B. J. Reiser (Eds.), *Helping students*

make sense of the world using next generation science and engineering practices (pp. 33–58). National Science Teachers Association.

Bang, M., & Medin, D. (2010). Cultural processes in science education: Supporting the navigation of multiple epistemologies: Improving Science Learning for Indigenous Students. *Science Education*, *94*(6), 1008–1026. https://doi.org/10.1002/sce.20392

Bang, M., Warren, B., Rosebery, A. S., & Medin, D. (2012). Desettling Expectations in Science Education. *Human Development*, *55*(5–6), 302–318. https://doi.org/10.1159/000345322

Barajas-López, F., & Bang, M. (2018). Indigenous Making and Sharing: Claywork in an Indigenous STEAM Program. *Equity & Excellence in Education*, *51*(1), 7–20. https://doi.org/10.1080/10665684.2018.1437847

Bautista, J., & Davis, E. A. (2024). Preservice Teachers' Support for Children's Epistemic Agency in Elementary Science. In C. Hoadley & X. C. Wang (Eds.), *General Proceedings of the 4th Annual Meeting of the International Society of the Learning Sciences 2024*. International Society of the Learning Sciences.

Bautista, J., & Davis, E. A. (in press). *Preservice Teachers' Support for Children's Epistemic Agency in Elementary Science*. International Conference of the Learning Sciences, Buffalo, NY.

Bricker, L. A., Reeve, S., & Bell, P. (2014). 'She Has to Drink Blood of the Snake': Culture and prior knowledge in science|health education. *International Journal of Science Education*, *36*(9), 1457–1475. https://doi.org/10.1080/09500693.2013.827817

Bryant, A., & Charmaz, K. (2007). *The SAGE Handbook of Grounded Theory*. SAGE Publications Ltd. https://doi.org/10.4135/9781848607941

Bryant, A., & Charmaz, K. (2012). Grounded theory and psychological research. In H. Cooper, P. M. Camic, D. L. Long, A. T. Panter, D. Rindskopf, & K. J. Sher (Eds.), *APA handbook of research methods in psychology, Vol 2: Research designs: Quantitative, qualitative, neuropsychological, and biological.* (pp. 39–56). American Psychological Association. https://doi.org/10.1037/13620-003

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

Calabrese Barton, A., & Tan, E. (2020). Beyond Equity as Inclusion: A Framework of "Rightful Presence" for Guiding Justice-Oriented Studies in Teaching and Learning. *Educational Researcher*, *49*(6), 433–440. https://doi.org/10.3102/0013189X20927363

Carlone, H., & Johnson, A. (2007). Understanding the science experiences of successful women of color: Science identity as an analytic lens. *Journal of Research in Science Teaching*, *44*(8), 1187–1218. https://doi.org/10.1002/tea.20237

Carlone, H., Mercier, A., & Metzger, S. (2021). The Production of Epistemic Culture and Agency during a First-Grade Engineering Design Unit in an Urban Emergent School. *Journal of Pre-College Engineering Education Research (J-PEER)*, *11*(1). https://doi.org/10.7771/2157-9288.1295

Cochran-Smith, M. (2010). Toward a Theory of Teacher Education for Social Justice. In A. Hargreaves, A. Lieberman, M. Fullan, & D. Hopkins (Eds.), *Second International Handbook of Educational Change* (pp. 445–467). Springer Netherlands. https://doi.org/10.1007/978-90-481-2660-6_27

Corbin, J., & Strauss, A. (2008). *Basics of Qualitative Research (3rd ed.): Techniques and Procedures for Developing Grounded Theory*. SAGE Publications, Inc. https://doi.org/10.4135/9781452230153

Damşa, C. I., Kirschner, P. A., Andriessen, J. E. B., Erkens, G., & Sins, P. H. M. (2010). Shared Epistemic Agency: An Empirical Study of an Emergent Construct. *Journal of the Learning Sciences*, *19*(2), 143–186.

Davis, E. A. (2022a). Supporting Preservice Elementary Teachers in Teaching Science for Equity and Justice: A Practical Framework. *Innovations in Science Teacher Education*, *7*(4). https://innovations.theaste.org/supporting-preservice-elementary-teachers-in-teaching-science-for-equity-and-justice-a-practical-framework/

Davis, E. A. (2022b). *Teaching for Justice in Elementary Education: A Practical Justice and Anti-Racism Framework*. Elementary Teacher Education program at the University of Michigan.

Davis, E. A., & Haverly, C. (2022). Well-Started Beginners. In J. A. Luft & M. G. Jones, *Handbook of Research on Science Teacher Education* (1st ed., 1–y, pp. 83–96). Routledge. https://doi.org/10.4324/9781003098478-9

Davis, E. A., & Marino, J.-C. (2020). Practice-based elementary science teacher education. In D. Stroupe, K. Hammerness, & S. McDonald (Eds.), *Preparing science teachers through practice-based teacher education*. Harvard Education Press.

Davis, E. A., Zembal-Saul, C., & Kademian, S. M. (Eds.). (2020). *Sensemaking in Elementary Science: Supporting teacher learning*. Routledge.

Erickson, F. (1986). Qualitative Methods in Research on Teaching. In *Handbook of research on teaching* (3rd ed., pp. 119–161). Macmillan Press.

Esmonde, I., & Booker, A. N. (2017). Introduction. In *Power and Privilege in the Learning Sciences: Critical and Sociocultural Theories of Learning*. Taylor & Francis Group.

Espinoza, M. L., & Vossoughi, S. (2014). Perceiving Learning Anew: Social Interaction, Dignity, and Educational Rights. *Harvard Educational Review*, *84*(3), 285–313. https://doi.org/10.17763/haer.84.3.y4011442g71250q2

González-Howard, M., & McNeill, K. L. (2020). Acting with epistemic agency: Characterizing student critique during argumentation discussions. *Science Education*, *104*(6), 953–982. https://doi.org/10.1002/sce.21592

Gunckel, K. L. (2019). What does queer theory have to do with teaching science in elementary schools? In W. Letts & S. Fifield (Eds.), *STEM of Desire: Queer Theories and Science Education*. Brill | Sense. https://doi.org/10.1163/9789004331068

Gunckel, K. L., Davis, E. A., & Bautista, J. (2024). Moving Beyond Equity-as-Access to Expanding What Counts as Science in the Elementary Classroom. *Science and Children*, *61*(1). https://doi.org/10.1080/00368148.2023.2292392

Gutiérrez, R. (2013). The Sociopolitical Turn in Mathematics Education. *Journal for Research in Mathematics Education*, *44*(1), 37–68. https://doi.org/10.5951/jresematheduc.44.1.0037

Hammer, D. (1997). Discovery Learning and Discovery Teaching. *Cognition and Instruction*, *15*(4), 485–529. https://doi.org/10.1207/s1532690xci1504_2

Haraway, D. (1988). Situated Knowledges: The Science Question in Feminism and the Privilege of Partial Perspective. *Feminist Studies*, *14*(3), 575–599.

Haraway, D. (2018). *Modest_Witness@Second_Millennium. FemaleMan_Meets_OncoMouse: Feminism and technoscience* (Second edition). Routledge, Taylor & Francis Group.

Harding, S. (1986). From Feminist Empiricism to Feminist Standpoint Epistemologies. In *The Science Question in Feminism*. Cornell University Press. https://hdl.handle.net/2027/heb32980.0001.001.

Haverly, C., Calabrese Barton, A., Schwarz, C. V., & Braaten, M. (2020). "Making Space": How Novice Teachers Create Opportunities for Equitable Sense-Making in Elementary Science. *Journal of Teacher Education*, *71*(1), 63–79. https://doi.org/10.1177/0022487118800706

Jones, M. G., & Park, S. (2023). Science Teacher Attitudes and Beliefs. In N. G. Lederman, D. L. Zeidler, & J. S. Lederman, *Handbook of Research on Science Education* (1st ed., pp. 1101–1122). Routledge. https://doi.org/10.4324/9780367855758-40

Kang, H., & Zinger, D. (2019). What do core practices offer in preparing novice science teachers for equitable instruction? *Science Education*, *103*(4), 823–853. https://doi.org/10.1002/sce.21507

Ko, M. M., & Krist, C. (2019). Opening up curricula to redistribute epistemic agency: A framework for supporting science teaching. *Science Education*, *103*(4), 979–1010. https://doi.org/10.1002/sce.21511

Krist, C. (Stina), Machaka, N., Voss, D., Mathayas, N., Kelly, S., & Shim, S.-Y. (2023). Teacher Noticing for Supporting Students' Epistemic Agency in Science Sensemaking Discussions. *Journal of Science Teacher Education*, *34*(8), 799–819. https://doi.org/10.1080/1046560X.2022.2155355

Ladson-Billings, G. (1995). Toward a Theory of Culturally Relevant Pedagogy. *American Educational Research Journal*, *32*(3), 465–491. https://doi.org/10.2307/1163320

Learning in Places Collaborative. (2021). *Classroom Storyline*. Learning in Places. http://learninginplaces.org/seasonal-storyline/classroom-storyline/

Lee, C. D., Spencer, M. B., & Harpalani, V. (2003). "Every Shut Eye Ain't Sleep": Studying How People Live Culturally. *Educational Researcher*, *32*(5), 6–13. https://doi.org/10.3102/0013189X032005006

Liboiron, M. (2021). *Pollution is colonialism*. Duke University Press.

Louie, N. L. (2017). The Culture of Exclusion in Mathematics Education and Its Persistence in Equity-Oriented Teaching. *Journal for Research in Mathematics Education*, *48*(5), 488–519. https://doi.org/10.5951/jresematheduc.48.5.0488

Louie, N. L. (2018). Culture and ideology in mathematics teacher noticing. *Educational Studies in Mathematics*, *97*(1), 55–69. https://doi.org/10.1007/s10649-017-9775-2

Luehmann, A., Zhang, Y., Boyle, H., Tulbert, E., Merliss, G., & Sullivan, K. (2024). Toward a justice-centered ambitious teaching framework: Shaping ambitious science teaching to be culturally sustaining and productive in a rural context. *Journal of Research in Science Teaching*, *61*(2), 319–357. https://doi.org/10.1002/tea.21917

Manz, E., & Suárez, E. (2018). Supporting teachers to negotiate uncertainty for science, students, and teaching. *Science Education*, *102*(4), 771–795. https://doi.org/10.1002/sce.21343

Mensah, F. M. (2022). Educating Klaren: Neoliberal ideology in teacher education impacting candidate preparation and the teaching of science to Black students. *Cultural Studies of Science Education*, *17*(1), 9–29. https://doi.org/10.1007/s11422-022-10111-w

Miller, E., Manz, E., Russ, R., Stroupe, D., & Berland, L. (2018). Addressing the epistemic elephant in the room: Epistemic agency and the next generation science standards.

Journal of Research in Science Teaching, *55*(7), 1053–1075. https://doi.org/10.1002/tea.21459

Moll, L. C., & Greenberg, J. B. (1990). Creating zones of possibilities: Combining social contexts for instruction. In L. C. Moll (Ed.), *Vygotsky and Education* (1st ed., pp. 319–348). Cambridge University Press. https://doi.org/10.1017/CBO9781139173674.016

Nasir, N. S., Rosebery, A. S., Warren, B., & Lee, C. D. (2022). Learning as a Cultural Process: Achieving Equity through Diversity. In R. K. Sawyer (Ed.), *The Cambridge Handbook of the Learning Sciences* (3rd ed., pp. 581–601). Cambridge University Press. https://doi.org/10.1017/9781108888295.036

National Academies of Sciences, Engineering, and Medicine. (2022). *Science and Engineering in Preschool Through Elementary Grades: The Brilliance of Children and the Strengths of Educators*. The National Academies Press. https://doi.org/10.17226/26215

National Research Council. (2012). *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. National Academies Press. https://doi.org/10.17226/13165

O'Connor, C., & Joffe, H. (2020). Intercoder Reliability in Qualitative Research: Debates and Practical Guidelines. *International Journal of Qualitative Methods*, *19*, 160940691989922. https://doi.org/10.1177/1609406919899220

Odden, T. O. B., & Russ, R. S. (2019). Defining sensemaking: Bringing clarity to a fragmented theoretical construct. *Science Education*, *103*(1), 187–205. https://doi.org/10.1002/sce.21452

Penuel, W. R., Krumm, A. E., Pazera, C., Singleton, C., Allen, A., & Deverel-Rico, C. (2023). Belonging in science classrooms: Investigating their relation to students' contributions

and influence in knowledge building. *Journal of Research in Science Teaching*, tea.21884. https://doi.org/10.1002/tea.21884

Philip, T. M., & Azevedo, F. S. (2017). Everyday science learning and equity: Mapping the contested terrain. *Science Education*, *101*(4), 526–532. https://doi.org/10.1002/sce.21286

Rogoff, B. (2003). The Cultural Nature of Human Development. In *Orienting Concepts and Ways of Understanding the Cultural Nature of Human Development* (pp. 3–36). Oxford University Press.

Rosebery, A. S., Ogonowski, M., DiSchino, M., & Warren, B. (2010). "The Coat Traps All Your Body Heat": Heterogeneity as Fundamental to Learning. *The Journal of the Learning Sciences*, *19*(3), 322–357.

Rosebery, A. S., Warren, B., & Tucker-Raymond, E. (2016). Developing Interpretive Power in Science Teaching. *Journal of Research in Science Teaching*, *53*(10), 1571–1600. https://doi.org/10.1002/tea.21267

Saldaña, J. (2016). The coding manual for qualitative researchers. In *The coding manual for qualitative researchers*. Sage.

Sanchez, A. (2023). Just worlding design principles: Childrens' multispecies and radical care priorities in science and engineering education. *Cultural Studies of Science Education*. https://doi.org/10.1007/s11422-023-10197-w

Schwarz, C. V., Braaten, M., Haverly, C., & de los Santos, E. X. (2021). Using Sense-Making Moments to Understand How Elementary Teachers' Interactions Expand, Maintain, or Shut Down Sense-making in Science. *Cognition and Instruction*, *39*(2), 113–148. https://doi.org/10.1080/07370008.2020.1763349

Solomon, F., Champion, D., Steele, M., & Wright, T. (2022). Embodied physics: Utilizing dance resources for learning and engagement in STEM. *Journal of the Learning Sciences*, *31*(1), 73–106. https://doi.org/10.1080/10508406.2021.2023543

Stroupe, D. (2022). Naming and disrupting epistemic injustice across curated sites of learning. *Journal of the Learning Sciences*, *31*(2), 317–334. https://doi.org/10.1080/10508406.2021.1977647

Suárez, E. (2020). "Estoy Explorando Science": Emergent bilingual students problematizing electrical phenomena through translanguaging. *Science Education*, *104*(5), 791–826. https://doi.org/10.1002/sce.21588

Suárez, E., & Otero, V. (2023). Ting, tang, tong: Emergent bilingual students investigating and constructing evidence-based explanations about sound production. *Journal of Research in Science Teaching*, tea.21868. https://doi.org/10.1002/tea.21868

Vossoughi, S., & Gutiérrez, K. D. (2017). Critical Pedagogy and Sociocultural Theory. In I. Esmonde & A. N. Booker (Eds.), *Power and Privilege in the Learning Sciences*. Routledge.

Vygotsky, L. S. (1978). Interaction Between Learning and Development. In *Mind and Society* (pp. 79–91). Harvard University Press.

Warren, B., Vossoughi, S., Rosebery, A. S., Bang, M., & Taylor, E. V. (2020). Multiple Ways of Knowing: Re-Imagining Disciplinary Learning. In N. S. Nasir, C. D. Lee, R. Pea, & M. McKinney de Royston (Eds.), *Handbook of the Cultural Foundations of Learning* (pp. 277–293). Routledge.

Wright, C. G. (2019). Constructing a Collaborative Critique-Learning Environment for Exploring Science Through Improvisational Performance. *Urban Education*, *54*(9), 1319–1348. https://doi.org/10.1177/0042085916646626