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Heidi B. Carlone
University of North Carolina Greensboro, hbcarlon@uncg.edu

Alison K. Mercier
University of Wyoming, amercier@uwyo.edu

Salem R. Metzger
University of North Carolina at Greensboro, smrainey@uncg.edu

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Abstract

Primary school practices are often bound by traditions that perpetuate compliance and skills-based, decontextualized, rote memorization activities. These histories of practice, prevalent in schools serving mostly Black and Brown children, make it inordinately difficult for students to author themselves as knowledge builders (i.e., with epistemic agency), which is a form of injustice. Engineering is a potentially fertile context to support the creation of epistemic culture, whereby young students' assets are recognized, named, and leveraged as they create and shape the group's disciplinary knowledge. The authors investigated this potential. The primary research question was: How do first-grade students in an urban emergent school author themselves as epistemic agents during an engineering design unit? Using a social practice theory lens and ethnographic methods, the authors studied 29 days of a materials engineering unit focusing on the teacher's epistemic commitments, implicit meanings of knowledge in classroom discourse, and practices that opened space for students' epistemic agency. Data collection included fieldnotes and video of class activities and teacher and student interviews. Class discussions about the properties and uses of materials yielded a rich context for studying epistemic culture. The teacher's epistemic commitments included an eschewing of disciplinary silos, recognizing the nonlinear nature of knowledge-building about engineering, and acknowledging children's thinking as an asset for engineering knowledge production. Examples of students' discursive moves demonstrating epistemic agency included: reminding others about the relevance of previous lessons to the current topic, mirroring the teacher's instructional moves, claiming voice, space, time, and material resources for knowledge-building, translating one another's ideas, and making unsolicited connections to their lives. Young children's intellectual assets can too easily be overlooked in traditional learning contexts. This study demonstrates the affordances of responsive engineering instruction in recognizing and building on youths' intellectual curiosity and enthusiasm for substantively contributing to the classroom's knowledge-generating practices.

Keywords

primary school, engineering, epistemic injustice, epistemic agency, epistemic culture, urban schools, equity

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The Production of Epistemic Culture and Agency during a First-Grade Engineering Design Unit in an Urban Emergent School

Heidi B. Carlone[1], Alison K. Mercier[2], and Salem R. Metzger[1]

[1]University of North Carolina Greensboro
[2]University of Wyoming

Abstract

Primary school practices are often bound by traditions that perpetuate compliance and skills-based, decontextualized, rote memorization activities. These histories of practice, prevalent in schools serving mostly Black and Brown children, make it inordinately difficult for students to author themselves as knowledge builders (i.e., with epistemic agency), which is a form of injustice. Engineering is a potentially fertile context to support the creation of epistemic culture, whereby young students' assets are recognized, named, and leveraged as they create and shape the group's disciplinary knowledge. The authors investigated this potential. The primary research question was: How do first-grade students in an urban emergent school author themselves as epistemic agents during an engineering design unit? Using a social practice theory lens and ethnographic methods, the authors studied 29 days of a materials engineering unit focusing on the teacher's epistemic commitments, implicit meanings of knowledge in classroom discourse, and practices that opened space for students' epistemic agency. Data collection included fieldnotes and video of class activities and teacher and student interviews. Class discussions about the properties and uses of materials yielded a rich context for studying epistemic culture. The teacher's epistemic commitments included an eschewing of disciplinary silos, recognizing the nonlinear nature of knowledge-building about engineering, and acknowledging children's thinking as an asset for engineering knowledge production. Examples of students' discursive moves demonstrating epistemic agency included: reminding others about the relevance of previous lessons to the current topic, mirroring the teacher's instructional moves, claiming voice, space, time, and material resources for knowledge-building, translating one another's ideas, and making unsolicited connections to their lives. Young children's intellectual assets can too easily be overlooked in traditional learning contexts. This study demonstrates the affordances of responsive engineering instruction in recognizing and building on youths' intellectual curiosity and enthusiasm for substantively contributing to the classroom's knowledge-generating practices.

Keywords: primary school, engineering, epistemic injustice, epistemic agency, epistemic culture, urban schools, equity

Why This Study? Epistemic Injustice

Young children are historically underestimated (Varelas et al., 2015). They are too often positioned as receivers rather than contributors, in need of molding rather than molders, and as objects rather than subjects of education. Engineering, taught well, is a potentially fertile context to disrupt these narratives, as it can leverage young learners' proclivities to tinker, problem-solve, explore cause and effect, and understand how and why something works. We investigated this potential, studying how a first-grade teacher and her students co-created a classroom culture that recognized and leveraged students' assets. In this paper, we refer to students' assets as strengths, proclivities, funds of knowledge (Moll et al., 1992), and intellectual resources they brought to the setting that helped them create and shape the group's disciplinary knowledge.

Positioning engineering within the context of elementary schools requires an understanding of elementary schools as "guardians of tradition" and the staying power of the basic curriculum (the three Rs—reading, writing, arithmetic) (Reese, 2011). Primary teachers are pressured to introduce and reinforce how to do schooling, setting a foundation for students' roles as receivers of knowledge, skills, and compliance with the school norms of talking, controlling one's body, participating, and completing work with precision (i.e., "coloring within the lines"). Schools that serve high percentages of minoritized youth who live in poverty are especially prone to position teachers as authoritarians and students as in need of remediation (Haberman, 2010). Yet, we know that young learners bring a wealth of assets to the classroom. They are capable of complex thinking such as mechanistic reasoning (Russ et al., 2008), epistemic reasoning (Metz, 2011), using data as evidence (Hapgood et al., 2004), and engineering design (Cejka et al., 2006). A primary curriculum that privileges low-level thinking, decontextualized skills, and learning norms of rigid compliance perpetuates a form of epistemic injustice.

We think about epistemic injustice "as intertwined with (and reinforcing) relations of dominance and oppression" (Pohlhaus, 2017, p. 16). Knowledge-related practices in classrooms often create two classes of people—knowers and sub-knowers (Pohlhaus, 2017). These categories are heavily tied to larger social structures of race, class, and gender. Knowers are positioned as those capable of and expected to contribute to the knowledge-building endeavors in the classroom and/or already possessing the kinds of knowledge deemed relevant by dominant, White, upper/middle class society upon which U.S. schooling was built. Epistemic injustices are manifest in institutionalized systems like tracking or district-level policies that mandate and surveil heavily skills-based, decontextualized literacy and mathematics curricula especially for "low-performing" schools, which nearly always serve minoritized and/or economically disadvantaged students (Milner, 2014).

Classroom practices also perpetuate epistemic injustices. Brown (2019) provides a poignant example of how students' access and willingness to talk in ways that reflect the dominant culture position them as smart and capable in science classrooms, but he asked, "When students speak eloquently about scientific information in language that reflects the culture that they are from, do teachers hear their brilliance?" (p. 6). Those deemed knowers are typically given access to more interesting, creative, and high-status activities. An example of this is the common practice of pulling out English language learners for extra help during science or engineering time or including engineering only in academically gifted programs where minoritized students are vastly under-represented (Robinson et al., 2018). Black and Brown children are usually deemed sub-knowers in classrooms (Mills, 1997; Mutegi, 2013; Pohlhaus, 2017), yet child development studies since the 1950s demonstrate faster maturation rates and higher scores on intelligence and motor-skill tests of Black babies when compared with the performance of White babies on the same measures (Delpit, 2012). "There is no 'achievement gap' at birth—at least not one that favors European American children" (Delpit, 2012, p. 5).

The deficit-based framings of Black and Brown children are baked into institutional systems. Colonialism, dating back centuries and globally enacted, set up racialized hierarchies that privilege Whiteness. In the USA, settler colonialism normalized the treatment of indigenous peoples of North America and Africa as less than human (Bang et al., 2012). Given these histories, what counts as a good, clever, proper, smart, and well-educated student cannot be disentangled from the racist histories and systems of schooling birthed from settler ideologies (Bang & Medin, 2010). A history of schooling that positions Black and Brown youth as sub-knowers makes the development of academic identities and the charting of robust science or engineering pathways less thinkable (Archer et al., 2010). This pattern is perpetuated through schooling and into knowledge-generating workplaces so that those who have been stereotyped as sub-knowers need incredible resilience to complete epistemic tasks and have disproportionate difficulty getting recognized as knowledge generators and contributors (Pohlhaus, 2017).

Stories of successful Black science, technology, engineering, and mathematics (STEM) professionals reveal that race-based traumas began early in their schooling (McGee, 2020). Minoritized first-grade children are thus extremely vulnerable to epistemic injustice. These youth, in the midst of learning academic and social language, often from cultural and linguistic backgrounds that differ from those of their teachers, express their understandings in ways that teachers may miss if they are not listening and questioning with curiosity, trust, and a core belief that their students can and should be knowledge producers in the classroom. Students' assets—their imagination, creativity, reasoning, and prior knowledge—harnessed in service of the classroom community's knowing are forms of epistemic agency. What does it look like for a classroom to consider their assets as serious resources for knowledge-building during engineering?

Purpose and Research Questions

We shift the lens from deficit-based to asset-based to ask: (1) How do first-grade students in an urban emergent school (Milner, 2012)[1] author themselves as epistemic agents during an engineering design unit? To address this larger question, we asked: (1a) What was the nature of Mrs. Wallingdale's (a pseudonym, hereafter Mrs. W) epistemic commitments? (1b) What implicit meanings of knowledge emerged during classroom discourse aimed at producing knowledge for the final engineering design? (1c) How did the meanings of knowledge produced in classroom discourse open space for youth to author themselves as epistemic agents? The paper's purpose is both practical and theoretical. Practically, we provide specific instructional moves, epistemic commitments, and culture-building norms that Mrs. W initiated to leverage students' assets so they could author themselves with epistemic agency. Theoretically, our goal is to explain why and how these first-grade students emerged as epistemic agents during the engineering unit, what epistemic agency looks like for first-graders engaging in engineering, and why their potential as epistemic agents could be overlooked in traditional learning contexts.

Conceptual Framework

Culture and Agency with a Social Practice Theory Lens

We consider epistemic practices and beliefs about knowledge from a social practice theory perspective, which makes the assumption that shared meanings are produced in everyday activity and shaped by larger social structures of race, class, and gender and historically enduring disciplinary traditions (Carlone et al., 2014; Eisenhart, 2001; Holland et al., 1998). To study what counted as legitimate forms of knowledge production, knowledge, and evaluation of knowledge in this first-grade class, we investigated the implicit meanings of knowledge embedded in whole-group classroom discourse (a primary classroom practice) that became shared ways of thinking about and doing first-grade engineering. Social practice theory's multilayered analytic approach helps illuminate the cultural accomplishment involved in positioning young children as legitimate knowledge producers and problem solvers in engineering.

Everyday classroom practices and artifacts—such as common teacher responses to students' contributions, graphic organizers at the front of the room, turn-taking patterns in whole-group discussion—become "conventionalized or made into culture" (Holland et al., 1998, p. 17). This cultural layer of analysis helps explain how and why certain forms of knowledge are privileged over others. Classroom culture, however, is not created in a vacuum. Thus, it is important to consider the following: broader historical narratives about Black and Brown children; the school's heavy use of scripted curricula (Milner, 2014); mandated uses of time that leave little room for engineering; and pressure to "get students to perform at grade-level" on standardized measures. These meso- and macro-level lenses are yet additional layers of analysis.

A finer-grained analytic lens positions *individual actors* within the cultural and historical narratives. While the students and teacher in a classroom are often ascribed subject positions based on their institutionally and historically defined relationships to power, Holland and colleagues (1998) explain that actors "are not just products of our culture, not just respondents to the situation, but also and critically appropriators of cultural artifacts" produced in practice (p. 17). This lens embraces individuals' agency in reproducing and/or challenging the status quo. Put another way, humans are "social producers" and "social products" (p. 42). In the next sections, we define epistemic culture, agency, and practices. For reference, we envision the constructs as relational (Figure 1). The large arrows pointing inward indicate historical and societal narratives that constrain possibilities for agency in Mrs. W's classroom. The darker grey arrow pointing outward (Mrs. W's classroom epistemic culture) indicates a form of cultural production pushing back against historical and societal narratives.

Classroom Epistemic Culture

We focus on everyday practices, instructional moves, and teacher commitments that co-created meanings of knowledge, knowledge production, and knowledge producer that were meaningful to the children and meaningful to engineering as a

[1] The label of "urban school" has come to mean, problematically, any schools serving mostly Black children, regardless of geographic location (Milner, 2012). The label could mask important race-based demographics, histories, and geographies (Mutegi, 2013). Following Milner (2012), we label the school in this study *urban emergent*, which include schools located in a mid-size city, typically experiencing "some of the same characteristics and sometimes challenges of *urban intensive* schools and districts" (p. 560). The urban emergent school where this study took place served mostly minoritized African American and Latinx students living in poverty and was ranked among the lowest 10% of schools based on students' performance on end-of-grade state-standardized tests. Though principal and teacher turnover were high, the school also had a small number of highly dedicated, loyal "oldtimers," who worked at the school for years, were leaders in the state or district, and consistently partnered with our science teacher network (STEM Teacher Leader Collaborative). They were dedicated to contesting histories of practice characterizing the pedagogy of poverty (Haberman, 2010).

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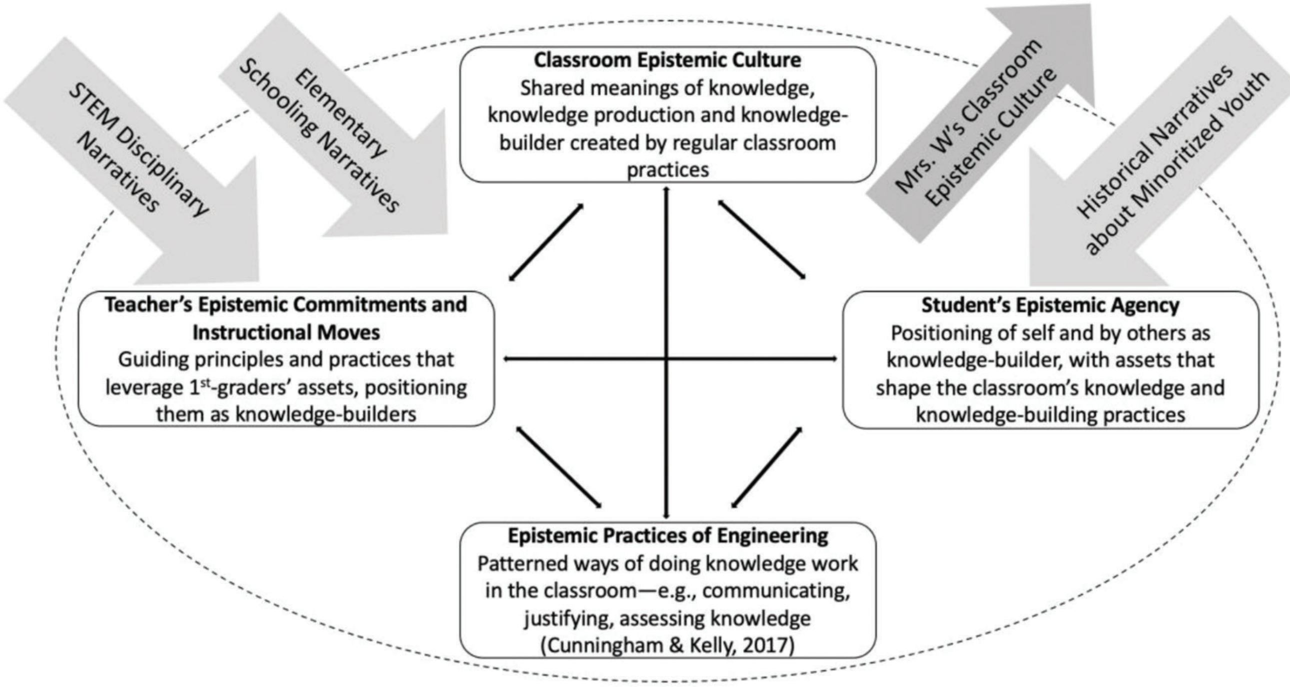

Figure 1. Conceptual framework, informed by social practice theory.

disciplinary field (Berland et al., 2015; Manz, 2015). That is, we focus on the production of an epistemic culture (Knorr Cetina, 1999). While we borrow the term "epistemic culture" from Knorr Cetina (1999), our approaches to studying it are necessarily different. Knorr Cetina studied the epistemic culture of high-energy physics and molecular biology and defined it as: "amalgams of arrangements and mechanisms—bonded through affinity, necessity, and historical coincidence—which, in a given field, make up how we know what we know. Epistemic cultures are cultures that create and warrant knowledge" (p. 1). Though a first-grade classroom's epistemic culture is not as cohesive and stable as that found in a science discipline, we argue that, indeed, there are conventionalized ways of going about producing, evaluating, and contributing to disciplinary knowledge in the classroom that are worth investigating. Manz (2015) argued similarly: "[M]ost studies focus on how students use evidence, rather than how they participate in making it" (p. 574). Studies that examine students' participation in the creation of evidence, Manz argued, require "building uncertainty into students' activity" (p. 575) and "must target the development of epistemic cultures" (p. 554). The uncertainty inherent in the production of engineering knowledge makes it an outstanding context to study the classroom's epistemic culture.

Sandoval's (2005) work is helpful in clarifying our label of epistemic culture. He argued that, instead of studying students' *formal* epistemologies (i.e., the set of ideas about disciplinary science knowledge and how it is produced), a more appropriate goal is to study what he labels students' *practical* epistemologies—"the set of ideas that students have about their own knowledge production in school science" (p. 636). When studying students' practical epistemologies, he argued, one should investigate: classroom practices that are authentic to the discipline, students' discourse as they construct and evaluate knowledge artifacts, and students' reflections about the nature of knowledge and knowledge-generating practices in the classroom. While these recommendations inform our study, we chose not to solely examine students' practical epistemologies because of slight differences in our analytic lens. Sandoval (2005) makes the assumption that "epistemological beliefs…guide practice" (p. 648). Our study, informed by social practice theory, assumes that beliefs are co-produced in practice. Patterned classroom practices give rise to meanings of knowledge which then iteratively shape what knowledge and knowledge-producing activities are lauded and marginalized and the space students have to participate in and shape knowledge production. Thus, epistemic culture is a better label for our study than practical epistemologies, but we see overlaps in these constructs.

Epistemic Agency

Epistemic culture includes the epistemic practices that become conventionalized ways of doing engineering and producing and evaluating knowledge which create implicit, shared meanings of what and whose knowledge counts.

However, this cultural perspective is not deterministic. The children had the choice to take up, reject, or transform norms as they participated. While the teacher's commitments and the classroom norms promoted a certain way of participating, the students had agency in how they would author themselves—as contributors, joiners, distractors, silent observers—and those choices, iteratively, influenced the production of culture. Students' contributions to and maintenance of the *classroom* culture were also acts of agency that spoke back to *larger, enduring cultural narratives* about elementary schools, minoritized children, what counts as legitimate school STEM knowledge in typical classrooms, and who historically counts as legitimate STEM contributors (see large arrows pointing inward in Figure 1). Using social practice theory, we view students' contributions in knowledge-generating discussions as evidence of epistemic agency.

There are nearly as many definitions or markers of epistemic agency in the literature as there are definitions of agency. How do we know when or how students are granted or seize epistemic agency? Based on existing literature, we can ask: Do students have the ability to not only participate in, but "shape and evaluate knowledge and knowledge building practices in their classroom" (Miller et al., 2018, p. 5)? Do students leverage and revise existing resources in service of their own goals (Dotson, 2014)? Does students' participation change activity structures or norms (Varelas et al., 2015)? Do students get positioned or author themselves with intellectual authority, as local experts on a topic (Engle et al., 2014) or with authority to validate and legitimize knowledge (Kawasaki & Sandoval, 2019)? Do students have "opportunities to build a knowledge product" that is useful to others (Miller et al., 2018, p. 6)? These questions informed our initial analysis, but we were initially unsure of their relevance for this first-grade classroom. There are so few studies of engineering in primary-grade classrooms that we had to create a grounded definition that was true to the data and reflective of the literature.

We defined epistemic agency with the following markers: students' participation in knowledge-generating practices reframe what and whose knowledge counts as compared with traditional schooling narratives; first-grade students' ways of participating in disciplinary practices are rendered meaningful to the classroom community's knowledge generation; students have opportunities to shape knowledge-building practices in the classroom (Miller et al., 2018). Our assumption was that, as the group engaged in knowledge-generating practices, the implicit messages about what counted as legitimate knowledge opened the door for students to consider their ways of thinking, their connections, and their ways of expressing their understandings as assets for the group's knowledge production.

Epistemic Practices of Engineering for Education

An epistemic culture promotes practices that are meaningful to the field of engineering and meaningful to youths' knowledge production for engineering (Berland et al., 2015). Cunningham and Kelly's (2017) work is helpful here. They outlined 16 epistemic practices of engineering that emerged from empirical studies of professional engineering settings and are also relevant for school-based engineering. Epistemic practices are patterned ways "that members of a group propose, communicate, justify, assess, and legitimize knowledge claims" (p. 487; from Kelly, 2008). The practices they identified were framework tools for our analysis (see Table 1). We mapped the epistemic practices that were prominent parts of each classroom activity across the unit (see Figure 2) to demonstrate the epistemic nature of the activities in the engineering unit. The meanings of epistemic practices emerge in practice and are evaluated by their usefulness and purposes (Cunningham & Kelly, 2017).

Methods

We employed ethnographic methods to study all 29 days (40 hours of instruction) of a first-grade engineering unit in Mrs. W's classroom of 15 students. Wexford Elementary School has a diverse student population (58% African American, 29% Latinx, 7% White, 6% Asian), with 99% receiving free- or reduced-priced lunch. Mrs. W's first-grade class had 12 girls and three boys, nine of whom were African American and six of whom were Latinx; six students were institutionally labeled "English language learners" and one student received speech and language services. Mrs. W, a White female in her late 40s, had 12 years of experience teaching in a variety of settings in grades Pre-K through fourth grade.

The authors, all cis-gendered White women, have each worked in elementary schools serving mostly minoritized youth in various roles (teachers, researchers, professional developers) for 15 years or more and are currently working in higher education—two as professors of STEM education and one as a professor of literacy education. The authors have worked closely with Mrs. W in various capacities for the past six years, including co-designing and facilitating professional development focused on engineering for elementary teachers through a teacher network that Mrs. W co-founded with Carlone. In short, Mrs. W was fully committed to and knowledgeable about engineering instruction and had a breadth of life and professional experiences to draw on for her teaching.

We studied the enactment of an engineering unit from Engineering is Elementary (EiE) called *A sticky situation: Designing walls* (EiE, 2008), where students investigated the properties and purposes of earth materials (e.g., sand,

Table 1
Epistemic practices of engineering education.

Epistemic practice	Description
Considering problems in context	Engineers develop engineering knowledge and solutions through a set of practices that are defined and shaped by parameters and constraints communicated by clients and the problem's unique context
Making trade-offs between criteria and constraints	Recognizing that proposed solutions cannot meet all needs of a problem at hand and that solutions must balance various safety and ethical considerations, engineers design solutions, processes, or system components to meet desired needs within realistic constraints
Assessing implications of solutions	Engineers evaluate proposed solutions and designs from many perspectives while considering multiple criteria and/or contexts. Technical, social, environmental, and ethical implications are, ideally, considered when evaluating designs
Communicating effectively	Effective engineering requires engineers to think and communicate in many ways and to a variety of audiences
Working effectively in teams	Engineers work together in teams; collaboration and the need to bring together expertise across working groups are important
Seeing themselves as engineers	As engineers learn and engage in their work, they develop identities as professionals, which shape their values, perseverance, belonging, problem solving, teamwork, and learning
Making evidence-based decisions	Engineers use data and evidence to make decisions throughout the design process. Evidence-based decisions are informed by empirical data, scientific knowledge, mathematical models, and are heavily shaped by the social contexts in which engineers work
Developing processes to solve problems	Engineering work is fundamentally about solving problems; therefore, engineers work to solve a problem, design a product, and research new systems and materials
Applying math knowledge to problem-solving	Engineers connect ideas across disciplinary domains to apply mathematical concepts and practices when solving problems
Applying science knowledge to problem-solving	Engineers connect ideas across disciplinary domains to apply scientific concepts and practices when solving problems
Investigating properties and uses of materials	As they create, test, and improve technologies, engineers investigate and consider materials and their properties, which can include the materials' environmental impact, performance in the design, cost, durability, and aesthetics
Using systems thinking	Engineers understand that engineered products become part of larger systems; they consider how their solution affects the overall function of technical, environmental, and human systems
Constructing models and prototypes	To make informed decisions, engineers typically use models and prototypes in a design project to test and examine one or more parts of a system or proposed solution under certain conditions
Envisioning multiple solutions	Engineers and design teams often deliberate about the advantages and disadvantages of various solutions and work to envision multiple solutions to a problem given the materials, information, and tools they are able to access
Innovating processes, methods, and designs	Engineering requires creativity to innovate, solve problems, and generate new ideas
Persisting and learning from failure	Failure plays a prominent role in engineering design. Engineers often test their designs to the point of failure as part of the evaluation process. Failure provides a unique opportunity for learning and improvement

Note. Adapted from Cunningham and Kelly (2017).

soil, clay) before embarking on a design challenge to use a combination of student-designed mortar and stones to build a wall that would withstand a model wrecking ball (i.e., a ping pong ball on a string). The teacher used the EiE unit as a guide; she added and adapted lessons to meet her students' needs (see Figure 2, which is coded to illustrate her adaptations). Researchers were moderate participant-observers (Spradley, 1980), which means that we occasionally jumped in to help the students and the teacher, asked questions, distributed, and cleaned up materials, but we mostly observed. Students knew the research team well enough to greet us enthusiastically by name daily. During engineering activities, the research team took field notes, videotaped whole-group conversations, and audiotaped pre- and post-interviews with the teacher and students. Primary sources of data were: (1) three teacher interviews designed to elicit Mrs. W's description of classroom norms and epistemic commitments and (2) video recordings during whole-group discussion. Interviews with all 15 students and multiple member-checking interviews with Mrs. W were secondary forms of data.

Data Analysis

To study the classroom's epistemic culture, we investigated: (1) the teacher's epistemic commitments, since she had primary authority for the establishment and reinforcement of norms; (2) the implicit meanings of knowledge produced during whole-class discourse, since that provided evidence about the opportunities for students to enact epistemic agency; and (3) evidence of students' epistemic agency. We embraced Saldaña's (2015) approach to coding qualitative data as a cyclical process. Coding decisions were made *in situ*, based on our emergent conceptual framework and depending upon the research question and type of data. Led by social practice theory, we privileged the analysis of classroom activities and

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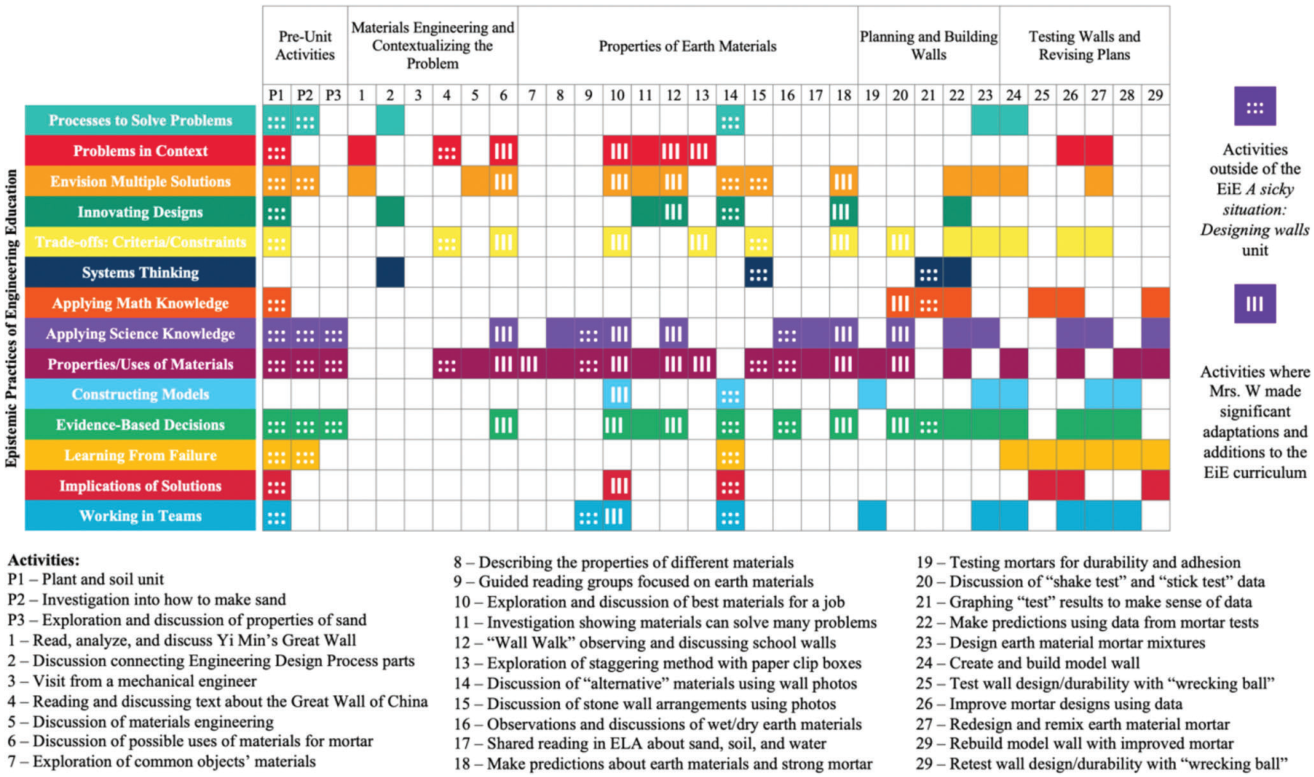

Figure 2. Unit map: activities aligned with epistemic practices of engineering.

practices. To ensure that classroom activities gave students ample opportunities to participate in epistemic practices of engineering (Cunningham & Kelly, 2017), we reviewed all activities on video, transcribed them, created event maps for each day of instruction, and then created a matrix listing all activities with the primary epistemic practices of engineering that were included in each activity (see Figure 2). This was a deductive approach.

Once we established that the unit was rich with epistemic practices, we analyzed video and transcripts of whole-group discussion to identify the implicit meanings of knowledge embedded in classroom discourse (research question 1b). Privileging excerpts of video that were richest in epistemic activity based on the matrix, we engaged in a form of structural coding (Saldaña, 2015) to code and categorize the meanings of knowledge that undergirded classroom discourse. We made assumptions that students' decisions to author themselves with epistemic agency were partly dependent upon implicit messages about what and whose knowledge counted and whether or not students found those meanings compelling and accessible enough to take up. For example, we identified messages about knowledge that we iteratively tested out on multiple days of group discourse to ensure those messages were prevalent throughout the data. Examples of knowledge messages were: peers' thinking helps your own and helps the group's knowledge production; knowledge is emergent and uncertain; and the teacher is not the only one with epistemic authority. Working iteratively, we collapsed knowledge statement codes until nearly all teacher's questions and comments and students' contributions could be coded with the knowledge statements. We also coded student interviews and found that the knowledge statements were evident in their meaning-making about engineering (Table 2).

We then created a comparison chart of the teacher's instructional moves and knowledge statements. Inspired by Schwarz et al.'s (2020) expansive teacher moves, our goal was to identify the moves that opened up space for students to co-create and evaluate knowledge (Table 2). This was a part of identifying how and why students emerged as epistemic agents in the classroom (research question 1) and the teacher's epistemic commitments (research question 1a), which we then supplemented with an analysis of Mrs. W's interview data. In the first round of coding, we mapped knowledge statements identified in the video coding with statements from her interview transcripts. These statements mapped onto the data quite well, but we wanted to identify the overall commitments that enabled these expansive views of knowledge. Also, we shared our results with Mrs. W throughout the months of data analysis, and she emphasized that so much of what she did before the engineering unit, like building classroom community and classroom norms for discourse, enabled the outcomes we saw during the engineering unit. Thus, we asked these kinds of questions of the data: Who is a person obligated to be in this

Table 2
Meanings of knowledge, teacher's instructional moves, and students' discursive moves.

Culturally produced meanings of knowledge and knowledge-building	Teacher's instructional moves that support students' epistemic agency	Student discursive moves that demonstrate their epistemic agency
• Students have good thinking • Students' everyday experiences have disciplinary knowledge production value • Good thinking can take many forms • Collectively we can build disciplinary knowledge • Knowledge is emergent and uncertain • The teacher is not the only one with epistemic authority	• Being responsive to students' thinking • Framing students' contributions and idea play as sensemaking resources • Making space for idea play and sensemaking • Inviting students to share ideas publicly • Recognizing students as knowledge contributors • Deferring epistemic authority to students • Pressing students to work on and with ideas • Helping children recognize knowledge that comes from their families	• *Reminding* peers and teacher about the relevance of previous lessons to the current topic • *Mirroring* the teacher's instructional moves with one another • *Claiming* voice, space, time, and material resources for knowledge-building • *Translating* one another's ideas for others • *Making connections* to their own lives

classroom? What counts as successful enactment of engineering practices? What kind of knowledge and thinking is valued? What ideas deserve space and time in this classroom? This generative thinking allowed us to distill two primary commitments that drove Mrs. W's practice and guided the production of epistemic culture: (1) attentive love; and (2) heterogeneity, which included eschewing disciplinary silos, recognizing that students' good thinking takes many forms, and that knowledge production is emergent and uncertain. We explain these commitments in the results.

Returning to whole-group discourse data and the question of epistemic agency (research question 1c), we looked at instances of discourse where students' voices were prominent, which turned out to be a majority of the classroom discussion. We focused on discussions about investigating the properties and uses of materials because that was the most prominent epistemic practice throughout the unit (Figure 2). We questioned, during these moments, what students were doing, saying, and how they were contributing, and identified six primary student moves after iterative coding (Table 2). Examples include: *translating* peers' ideas for the group, *claiming voice* within the discussion, and *connecting ideas* from previous lessons. We interpreted these moves as evidence of students' epistemic agency.

Results

Mrs. W's Epistemic Commitments

In this section, we address research question 1a: what was the nature of Mrs. W's epistemic commitments? Mrs. W's classroom stands out as a disruption to the epistemic impoverishment story so often depicted in urban and urban emergent schools. Her classroom was lively, joyful, privileged youths' ways of knowing and doing, and a productive space to learn and grow. She knew her classroom community was special: "I feel like I've managed to reach my students…they love being in school when we have this community that we've built together."

Before going further, we acknowledge that Mrs. W's classroom, like any, was not perfect. "I think to the casual observer, my classroom probably looked chaotic. There was always a hum." She did not pick up on every nugget of good student thinking, sometimes lessons went awry, and some days classroom management was a challenge.

> And, no, not everything always worked out perfectly. There were always lessons where you plan it to go one way and then they go in the other direction. Then you have those moments where everyone gets really excited and talks over each other, so you stop, regroup, and start again…there were always bumps along the way… There were definitely moments where I missed opportunities to leverage student thinking because I was distracted by running out of time, students' actions, and other distractors.

She recognized engineering as a productive context to surface youths' knowledge, enthusiasm, communication, and creativity. "Engineering…requires the children to learn listening skills and speaking skills and collaborative skills and ways of building on each other's thinking." She emphasized that engineering and productive learning were dependent upon the classroom culture she and her students developed together. There are many ways Mrs. W and her students created a culture that cultivated students' epistemic agency, but we distilled two themes prevalent through all the data: attentive love and heterogeneity.

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Attentive Love

Though engineering educators may not position love at the center of good pedagogy, we argue, following hooks (2010), that teaching in asset-based ways demands love; "a combination of care, commitment, knowledge, responsibility, respect and trust," which work interdependently (hooks, 2010, p. 159). This is not love in the romantic sense, but an attentive love (Liston, 2008) that also requires a skill set and willingness to listen to children and understand and embrace their ways of thinking. This is the epistemological aspect of loving children. Mrs. W recounted a story when describing her vision for teaching young children:

> I think one of the things that inspired me was…my father-in-law had sent me a news article…[that] talked about a school district in which there was a funny bubble of kids across a number of high schools who were unusually successful… [A] group of researchers decided to track this bubble back to see if they could find any common ground and there was nothing, there was nothing, there was nothing, but it was hundreds of students in this district over time and eventually once they sifted through all the data, they discovered that every one of those kids, regardless of what high schools they'd wound up and over a 15 to 20 year period of time, they'd all had the same kindergarten teacher. When they found this woman who had long since retired, she had no idea what they were talking about. When they told her that there was this funny anomaly going on with these students and it all tracked back, she was ground zero and they said, "What did you do?" And she said, "Well I don't think I did anything special. I just loved them." And that was all she had. She just loved them and so I think if I feel like if I can make my students feel loved and feel that support so that they feel comfortable taking any kind of academic risk in our classroom that they will leave me knowing that they can do it.

Mrs. W's epistemological and ontological commitments reflected an unwavering belief that her students could be or do anything, and it was her job to recognize, nurture, and celebrate students' assets—their varied ways of thinking, being, and creating. The center of her practice was, in fact, love. She lived and remade this value and belief each time she had an in-depth class discussion with youth about their meanings of evidence, the properties of everyday materials, their ideas for improving their designs, and the multiple, including troubling, meanings of "wall."

Mrs. W never framed youth in terms of their deficits; her discourse was focused on their strengths and potential.

> I think for me one of the greatest things I want to accomplish as a teacher is to have each of my students walk away, knowing they can. Whatever it is that they come to, if it's something that they want to put their minds to and address that whatever it is, they can…I want them to become lifelong learners. I want them to love to learn. I want them to be problem solvers, and critical thinkers. I want them to be able to collaborate and lead.

Engineering, according to Mrs. W, was an outstanding context for students to see their potential.

> He felt proud of himself [during the engineering unit] because he is a child [whose] circumstances outside of school, I think are pretty heavy. And he didn't have much confidence in himself. He was a struggling reader and writer. And that just overlapped into everything, he didn't even want to try anything else…he would hide under his sweatshirt…And I think for him, [engineering] helped him realize that there's a lot of things he does really well, and if he can be successful here, then I've seen him try to be successful in other things this school year…I feel like [the engineering] really helped.

When Mrs. W heard that this child named himself as one of the best engineers in the class during our interview with him, she was pleased. "See that? That's exactly what I'm talking about."

Love as an epistemological commitment goes beyond a naive belief that children can be anything as long as they are loved. In discussing critical pedagogy and attentive love, Liston (2008) explained the intersections of love and recognition of students' goodness, faith, and trust in students' ways of making sense of the world.

> Attentive teachers can speak volumes about their students. In order to see and speak those volumes, these teachers have to suspend temporarily their own expectations, bracket their agendas, and set aside their concerns so as to apprehend the student's reality on his or her own terms. This is not an easy task; it requires effort, discipline, and sacrifice. (p. 390)

Mrs. W did this regularly, allowing the children to take the floor, ask questions of one another, and take the discussion in an unanticipated direction. To take on that kind of epistemic agency, they had to have a foundation of mutual trust among one another. Community-building was an essential component of that trust.

> The cornerstone of much of my strategy is building a classroom community. 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 [also] use my morning meetings as a way of building community…a place where we first acknowledge each other and get to know each other…[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. I really work hard on creating a space where my children want to be, where they want to come and learn.

This is a humanizing approach, in direct opposition to the skill and drill, carceral curriculum that is too often present in schools serving mostly Black and Brown children. In this space, students' celebrated one another and the resources they each contributed to the learning community.

> We also build community by having throughout the day lessons where we embrace dialogue and conversation between partners and students or sharing in whole group. Teaching how to give our teammates effective feedback that is productive and doesn't hurt their feelings, and we learn how to talk to each other in a kind way so that it's useful. We basically celebrate each other as we go.

Love and engineering were mutually beneficial for the classroom's epistemic culture. Without the loving community that encouraged risk-taking, curiosity, voice, and problem-solving, the ambitious engineering design unit they enacted may not have been as successful in cultivating youths' epistemic agency.

Epistemological Heterogeneity

Mrs. W valued and nurtured multiple kinds of knowledge and ways of expressing and evaluating knowledge, which expanded historically narrow definitions of academic competence. Tzou et al. (2019) refer to this kind of "epistemic openness" (p. 309) as epistemological heterogeneity. Broadening what counted as valid knowledge and what it meant to participate productively in knowledge-generating endeavors opened spaces for young learners' epistemic agency. We provide multiple examples below.

Eschewing Disciplinary Silos

Engineering design lends itself to multiple ways of thinking. Planning, imagining, empathizing, deciding on materials to use, balancing criteria and constraints, coming to consensus about which plan to pursue, and deciding what counts as legitimate data and a successful design are examples of first-grade engineering practices that eschew a convergent, right-answer approach. Mrs. W capitalized on heterogeneous thinking by providing multiple representations of the content—e.g., storybooks about soil, sand, walls; photographs of brick/stone and mortar configurations; discussions about the social, political, and historical meanings of walls; hands-on explorations about how sand is made; encouragement for building walls out of pine needles, twigs, and mud during recess; math lessons about interpreting data from a graph. Engineering provided a unique way to examine the problem of a "good wall" with mathematical, historical, cultural, political, artistic, playful, and scientific lenses.

> I feel like these silos, they negatively impact a student's ability to generalize or make connections across curriculum. In the real world, we do not function just in math and, okay, now I'm going to read. We integrate everything we know and we build on those skills across disciplines.

When the curriculum was not siloed, she noticed increased motivation for students to read and write. Once you spark their interest in a problem, "the children just want to know more and more [and] they will start to go out and do that reading on their own. They're reading because they can't stop themselves." She told similar stories about reluctant writers who, during the engineering unit, began to write paragraphs using word banks and inventive spelling.

Students Have Good Thinking, Which Takes Many Forms

Mrs. W was committed to having students leverage one another's ideas in service of developing joint understandings of the problem. She believed all students have "good thinking," which comes from various sources—their lives, creativity, the personal resources they share, and the connections they make from one part of the day to the next. In every class discussion, Mrs. W used the phrase "good thinking" multiple times. In reflecting on the engineering unit, she said, "I have been thrilled just with their thinking, seeing that thinking come into other areas of our curriculum, in terms of problem solving and their use of language."

Mrs. W made space for their idea play, no matter their form. For example, in whole-group discussions, students repeated others' contributions, repeated the same phrase multiple times, and made unexpected connections that at first seemed off-topic. She did not praise students for having the right answer; she praised them for their good thinking. She was committed to providing many avenues for idea sharing.

> [C]ommunicating effectively like I said, we have sort of set that up over the course of the school year in various other areas using Paideia Seminars and class discussions and our classroom meetings. But [engineering] gave yet another authentic context for them to learn to articulate their thinking, both in a larger group, but also one on one, or in a small group, or to adults. It gave a variety of opportunities to try different forms of communication and in writing.

A belief in and practice of children as good thinkers takes the focus of learning away from normative schooling practices of getting the right answer; it is an invitational, asset-based, and accessible practice which students readily took up. We often observed one child say to another, "Oh, Kayla! I like your thinking! That makes me think of—." While Mrs. W noted students' impressive use of academic vocabulary in an interview, and word banks were strategies to assist the students' academic vocabulary development, the vocabulary use was not the sovereign marker of success. Students' good thinking, a much more achievable and inclusive marker, garnered the most recognition from Mrs. W.

Knowledge Production is Emergent and Uncertain, Not Linear

Mrs. W framed students' good thinking as having disciplinary knowledge production value. To do so, she listened carefully to students' ideas and was willing to temporarily relinquish control of the direction of the discussion: "There's a piece of me that goes with the flow, particularly when the students notice an overlap in our curriculum," she said. We witnessed regularly how she deferred epistemic authority to students ("What do you all think?") and framed their responses as valuable contributions to the class's knowledge-building. Engineering was a particularly rich context for sharing knowledge and divergent thinking, but Mrs. W's willingness to give these ideas air and space made room for youths' epistemic agency. Her commitments to centering youths' sensemaking are reminiscent of Kincheloe's (2008) words here:

> The authority of the critical teacher is dialectical; as teachers relinquish the authority of truth providers, they assume the mature authority of facilitators of student inquiry and problem posing. In relation to such teacher authority, students gain their freedom—they gain the ability to become self-directed human beings capable of producing their own knowledge. (p. 17)

Children's "own knowledge" did not come packaged up like adults' knowledge. They needed to talk for quite a bit of time before getting to the point of their story, repeated others' contributions, practiced what they were going to say by quietly whispering to themselves, or repeated the same phrase over and over. These ways of being were recognized as contributions because Mrs. W understood knowledge as emergent and nonlinear.

> They've really made those connections where they realize that when we go to set about a task, it's not necessarily black and white, and done in just one moment, but rather something that takes place over time, that you build on, and even decompose and then compose again…as you try to achieve whatever it is you're working to understand.

This kind of knowledge production also demands "entering and embracing the reality of the other" so that "we know and are known as members of one community" (Palmer, 1993; quoted in hooks, 2010, p. 160). In short, Mrs. W positioned youth as trusted epistemological partners.

Knowledge and Epistemic Agency in Practice

In this section, we address research questions 1b (what implicit meanings of knowledge emerged during classroom discourse?) and 1c (how did meanings of knowledge produced in classroom discourse position students and open space for them to author themselves as epistemic agents?). To begin, we provide a summary of the meanings of knowledge evident in practice and the teacher and student moves that sustained those meanings throughout the unit. We then outline three intensity cases (Russ, 2018) to illustrate the meanings of knowledge as they emerged in practice. We signal to readers that Mrs. W's epistemic commitments to attentive love and heterogeneity are easily visible within these discursive moves.

We identified six primary meanings of knowledge, enacted regularly in whole-class discussion, that shaped and were shaped by the teacher's instructional moves and the students' discursive moves. We summarize these findings in Table 2.

Table 3
Examples of students' narrated meanings of the knowledge statements.

Students have "good thinking" and good thinking can take many forms	"Mrs. W said, 'I'll be happy with 1,000 ideas, but I also sure will be happy with three ideas.' [A good engineer] thinks about many ideas. No one is happy with one idea." (Daniela) "Kayla and Quanisha always say good things and important things. They give us ideas…" (Bibiana)
The teacher is not the only one with epistemic authority; other students "have the answer"	"It's important to share ideas here because if she shares ideas it will give someone else an idea and she'll say, 'You gave me an idea. Thank you, Nylah.' And she'll give people more ideas because if she kept ideas to herself, she'll be like, 'I don't want to talk. I'm going to keep mine to myself.' And others wouldn't have an idea, they would be like, 'I don't get this.'" (Ester)
Collectively we can build disciplinary knowledge (peers' thinking helps your own and the group's knowledge production)	(In response to a question about whether it is more important for a good first-grade engineer to listen more or speak more) "It's kind of both. Listen more, so like if she was working with somebody, she would have to listen to the person who was speaking so she could really know the ideas. And speaks more, so…other people can know what she's thinking, what's on her mind." (Quanisha)
Knowledge is emergent and uncertain and knowledge production is not linear	"You're not the only person in the classroom. It has to be more people in the classroom. Everyone has to have a chance to do their best. It doesn't matter who wins. It's not a right or wrong answer." (Taliyah)
Students' experiences have disciplinary knowledge production value	"Because when you think about many ideas you go like, 'Hey! I know that!' Or you go, you could say, you got to raise your hand and then you say, 'I know that part!' And then everybody know that part too." (Nylah)

We also analyzed student interviews to determine the nature of alignment between classroom practice and expressed meanings (Table 3). Their meaning-making as expressed in the interviews aligned with the meanings of knowledge in practice we identified in earlier analysis.

To provide further illustration of the nature of discourse during class discussion, the teacher's instructional moves, and the students' discursive moves that illustrated epistemic agency, we provide three intensity cases, a method adapted from Patton (2002) and Russ (2018). Intensity sampling is a re-examination of the data after analysis to choose "excellent or rich examples of the phenomenon of interest, but not highly unusual cases" (Patton, 2002, p. 234). The intensity cases here contextualize how implicit meanings of knowledge and knowledge-building shaped students' participation, the kinds of knowledge they deemed relevant, and the ways other students evaluated and legitimized the knowledge.

Intensity Case 1: Warm Paper

This case illustrates a discussion focused on whether or not paper had insulating properties. Identifying properties of materials and their possible uses is a central disciplinary practice in primary engineering (Cunningham & Kelly, 2017). Youth employed multiple kinds of reasoning that included learning to see familiar objects differently, making abstract inferences about a material's suitability for different purposes, and engaging creativity to envision expansive possibilities for the material. The disciplinary question that frames this case, "Can paper keep something warm?" is fodder for rich knowledge-building. This classroom exchange (Table 4) occurred during a longer discussion designed to bring students to consensus about whether or not different materials (e.g., hay, paper, wood, cloth, bricks) were well-suited for sitting on, and cleaning with, and/or keeping something warm (Lesson 2 of the EiE unit).

In asking why some students changed their minds about paper's insulating properties (00:06), Mrs. W signaled the emergent and uncertain nature of knowledge, opening up space for curiosity about students' emerging ideas. Kayla's creative contribution, that paper is warm just out of the printer, demonstrates a manifestation of enacted epistemic agency we identified throughout the data—*making connections* to everyday life experiences without explicit prompting from the teacher to do so. Mrs. W, however, did not immediately recognize Kayla's contribution (00:09) as having disciplinary production value. Her response, a skeptical question (00:27), could have been an invitation for the student to say more, but Kayla's shrug (00:30) was tentative, likely indicating that she read in Mrs. W's voice skepticism about her idea. At this point in the exchange, Kayla's everyday experience did not yet have disciplinary value. Other students, however, began to lift and validate Kayla's idea as valuable when they bantered about her idea while the teacher was otherwise occupied (00:37), restated her idea (00:39), credited her with giving them an idea (00:42), and translated her idea (00:55). We note that the students' bantering about and *translating* Kayla's idea for the teacher is additional evidence of their epistemic agency.

Intensity Case 2: Sticky Mortar and Bendy Walls

These two episodes took place during a discussion about properties of mortar and a wall. Students had just finished an investigation comparing the effectiveness of sand, soil, and clay in holding two porcelain tiles together. After combining each material with a small bit of water, they placed each mixture between two porcelain plates like a sandwich, left them to dry overnight, and then compared how each sandwich held together during a "shake test" (i.e., shaking the sandwich back

Table 4
"Warm paper": meanings of knowledge and epistemic agency in practice.

	Classroom discourse	Meanings of knowledge and knowledge-building (K) and students' agentic moves (A)
00:00	Mrs. W: Thumbs up if I should put a check mark here [on the class's data chart up at front of room]	(K): Collectively we can build disciplinary knowledge
00:02	Mrs. W: I notice some of you changed your mind [about paper being able to keep you warm]	(K): Knowledge is emergent and uncertain
00:06	Mrs. W: Explain to us the new thought you had that changed your mind	(K): The teacher is not the only one with epistemic authority
00:09	Kayla: Like, if you were printing it, and it would keep warm. Sometimes when you just print it, it could be warm. The printer might have some ink that is a little warm? And you could rub it against your skin to make you warm	This experience is not *yet* recognized as having disciplinary knowledge value (A): *Connecting* to everyday life
00:27	Mrs. W: Wait a minute, so you're telling me you think the ink is something that will make you warm?	(K): Students' everyday experiences *might have* disciplinary knowledge value
00:30	Kayla: Shrugs shoulders	Student defers to teacher's epistemic authority
00:31	Mrs. W: Hmmm… (She is immediately distracted by a student up front who needs her attention)	
00:33	Alejandro: "When you print it out" (directed to teacher)	(K): Students' everyday experiences have disciplinary knowledge production value (A): *Connecting* to everyday life
00:37	Boy and girl arguing with one another while Mrs. W is distracted with a student: (The boy expresses disbelief, and she says, "Uh huh! The paper will make you warm!")	(K): Knowledge is emergent and uncertain
00:37	Alejandro (overlapping with above): "It's almost like, when you print it out!"	(K): Collectively, we can build disciplinary knowledge (A): *Translating* one another's ideas
00:39	Alejandro repeats: When you print it out (directed to teacher)	(K): Students' everyday experiences have disciplinary knowledge production value (A): Claiming voice
00:42	Quanisha: "Oh, Mrs. W! Kayla! Kayla, you just gave me a great idea! Sometimes the paper's already warm because, kind of like what Kayla said…	(K): Collectively, we can build disciplinary knowledge (A): *Translating* one another's ideas
00:55	Quanisha: "You know when you print out, it'll print out the paper's hot?"	(K): The teacher is not the only one with epistemic authority (A): *Connecting* to everyday life
00:69	Mrs. W chuckles and nods. "I got it! Now I understand where you're going with this"	(K): The teacher is not the only one with epistemic authority
1:02	Mrs. W: I understand now. So, when I take the paper that's warm out of the printer, if I then put it on me, okay. Now I get the change of mind. Okay, interesting	(K): Knowledge is emergent and uncertain. Collectively, we can build disciplinary knowledge

and forth on a paper plate) and a "sticking test" (i.e., picking the sandwich up by holding only the top tile). They discussed the word "properties" and did some initial brainstorming about properties of mortar (e.g., strong, sticky, bendy) based on their results. Mrs. W and students referred to their jointly constructed graphic organizer prominently displayed at the front of the room during the discussion. Students, with teacher prompting, began to come up with everyday examples of effective walls that have these properties.

The teacher's role was more visible in these excerpts than in the previous one (Table 4), illustrating the construct of attentive love (Liston, 2008), which signaled to students that their everyday experiences have disciplinary value, deserve classroom space, and contribute to the group's sensemaking. In *sticky mortar* (Table 5), when Nylah began to answer the question about properties of mortar with a question about her favorite movie, it might be hard to immediately see the relevance of her response. The teacher simply quietly shook her head, leaving space for Nylah to continue. Nylah began to describe tree sap, an imaginative example and connection that Quanisha validated and leveraged for her own creative connections. Mrs. W noted this discussion as "interesting"—not right or wrong. Later, not evident in this excerpt, the class had a discussion about the benefits and drawbacks of using sap as a mortar. They concluded that some of the animals might want to eat the sap and, though sap is solid and "kind of like plastic" when it is cold, it is "gooey and sticky" when hot outside and therefore might not be a good mortar material. During this whole discussion on sap, seven students contributed different insights about their observations of the behavior of sap, animal interactions with sap, and the benefits or drawbacks of sap as a possible material for mortar.

When we debriefed this example with Mrs. W, she noted many different experiences that may have prompted students' sap connections. Since the beginning of the engineering unit (late April) and through to the end of the school year, the

Table 5
"Sticky mortar": meanings of knowledge and epistemic agency in practice.

	Classroom discourse	Meanings of knowledge and knowledge-building (K) and students' agentic moves (A) in practice
1:01	Mrs. W: Does anyone want to build on [what Kaliyah just said]? (no one raises hand) Or go back to this question?	(K): Collectively, we can build disciplinary knowledge
1:03	Mrs. W: Nylah, what are you thinking? What does a mortar need? What properties make a good mortar? (points to graphic organizer they are co-creating)	(K): Students have good thinking
1:09	Nylah: Properties? Like, you know, you know, like uh, my, uh, my favorite movie I watch?	(K): Students' everyday experiences might have disciplinary knowledge production value (not yet established) (A): *Connecting* to everyday life
1:13	Mrs. W shakes her head no, but does not say anything	(K): Students have good thinking, and good thinking can take many forms (teacher opens space for Nylah to say more)
1:17	Nylah continues: I see that there's a tree that has lots and lots of s— uh, sap. You could maybe use that as a mortar. Like, get a little paper wall together?	(K): Students' everyday experiences might have disciplinary knowledge production value (A): *Claiming* voice
1:29	Mrs. W writes that idea on the graphic organizer up front. Gives no other verbal affirmation	(K): Students' everyday experiences have disciplinary knowledge production value
1:31	Quanisha: Oh Nylah! I see what you mean because tree sap is very, very sticky!	(K): Collectively we can build disciplinary knowledge and validates Nylah's idea as valuable (A): *Translating* one another's ideas
1:35	Multiple students call out synchronously with Quanisha, "Sticky!"	(K): Collectively we can build disciplinary knowledge
1:37	Quanisha: I saw a spider got stuck in it. And a bird. I helped the bird, but then I got stuck, so it's very sticky	(K): Students' everyday experiences have disciplinary knowledge production value (A): *Connecting* to everyday life
1:46	Mrs. W is quiet up front but smiles and chuckles	(K): The teacher is not the only one with epistemic authority
1:46	Quanisha: So, if you would take a brick and paint it on, and you would, um, kind of put the tree sap on the brick, and you would take the other brick and paint it on top, it's very hard to take it back apart (arms moving in and out) because I did that once	(K): Students' everyday experiences have disciplinary knowledge production value. Collectively we can build disciplinary knowledge (A): *Connecting* to everyday life
2:00	Mrs. W: So— (she gets cut off and lets Quanisha speak)	(K): The teacher is not the only one with epistemic authority
2:01	Quanisha: It's very, very sticky	(A): Claiming voice, time, and space
2:02	Mrs. W: That's interesting. I wonder, does a mortar need to hold up in different weather? Kayla, we haven't heard from you, do you want to build on that? What were you thinking just now?	(K): Students have good thinking

students were enthralled with walls and materials of walls. They used pine needles, twigs, rocks, and mud concoctions to make walls at recess, which was frowned on by some other teachers. Students would come in after recess with muddy hands or sap stuck to their hands, which was not easy to wash off. Their play time became a resource for their ideas about mortar and properties of mortar, relevant to their final design challenge.

After a lesson where students observed and discussed photos of walls made with different materials, in varied configurations, and with multiple kinds of mortar, her students began to notice walls everywhere, from the classroom to hallways to their homes. When they found out the Great Wall of China used sticky rice as one of the materials for mortar, they got curious whether honey or jam would be a good ingredient for mortar but decided that the bugs might eat it and compromise the structure of the wall. At their prompting, Mrs. W opened space for them to discuss their worries about the wall at the USA/Mexico border, ways to climb over or walk around the wall if it was built, wonders about what the wall would be made of and if it might crumble if enough people tried to climb it. After hearing about the main problem in the EiE storybook, building a wall that could keep rabbits out of the garden, they shared stories about the ways their parents kept animals out of their own gardens, as some families grew some of their own food. It was important to Mrs. W that her students knew that they learn a lot from their families, and this knowledge could help the rest of the class.

In *bendy walls* (Table 6), their everyday knowledge took on disciplinary value and encouraged others' contributions as in *sticky mortar*. The logic of students' connections was not always immediately visible to Mrs. W or us, the researchers in the room. Sometimes, Mrs. W would wait for the child to keep talking and, often, the connections would become clearer. At other times, a student's peer made the connections, *translating* the child's ideas for others. In this case, Mrs. W let the students play with the idea of a bendy wall—she used their term, bendy, side-by-side with the word flexible. When Daniela mentioned a fort as an example of when a bendy wall would be helpful, Mrs. W pressed for more information, sending a message that Daniela's ideas were worth classroom time. Once again, another child, Quanisha, saw the connection and

Table 6
"Bendy" or flexible walls: meanings of knowledge and epistemic agency in practice.

	Classroom discourse	**Meanings of knowledge and knowledge-building (K) and students' agentic moves (A) in practice**
00:06	Mrs. W: Bendy or flexible (repeating student's contribution). Is there an example of a wall that we might want bendy and flexible? (There is one hand up)	(K): Collectively we can build disciplinary knowledge
00:11	Mrs. W: Again, there are no right or wrong answers here. I'm just asking. (Nylah's hand shoots up, and Daniela tentatively puts her hand up)	(K): Knowledge is emergent and uncertain; Students have good thinking
00:16	Mrs. W: Daniela, we haven't heard from you yet	(K): Collectively we can build disciplinary knowledge
00:25	Daniela: Like the ones that we build from our forts	(K): Students' everyday experiences might have disciplinary knowledge production value (A): Connecting to everyday life
00:30	Mrs. W: Why would a soft wall be useful or bendy? What kind of fort? Like a play fort?	(K): Students' everyday experiences have disciplinary knowledge production value
00:37	Quanisha gasps and her hand shoots up at the same time the teacher asks the question	(K): Collectively we can build disciplinary knowledge
00:38	Daniela: Yeah, because whenever we put the cloth it like bends	(K): Students' everyday experiences have disciplinary knowledge production value
00:42	Quanisha: Ohhhh! I see what you mean, Daniela. (She goes on to tell a story about her fence needing to be flexible for her brother to play basketball by himself when she can't play with him. The segment lasts a full 45 seconds)	(K): Collectively, we can build disciplinary knowledge (A): *Mirroring* teacher's instructional moves; *translating* one another's ideas
01:25	Mrs. W: Interesting! Do you want to build on that, Jaheim?	(K): Collectively, we can build disciplinary knowledge

Figure 3. Classroom artifacts. (Left) Example of students' wall design, tested with a prototype "wrecking ball" (ping pong ball on a pendulum). (Right) Students use graphic organizers created in previous lessons to decide how to write about their wall designs.

validated it by *mirroring* a discursive move that Mrs. W might have used ("I see what you're saying"). Quanisha also *made connections* by bringing up her own example of the benefits of a bendy wall and, even after nearly a minute of Quanisha's storytelling about a bendy wall and a basketball, the teacher continued to entertain Jaheim's idea play and connections to the bendy wall idea. Daniela, a quiet, emergent bilingual student, was able to see that her idea was relevant for a chain of connections other peers made to the idea of a bendy wall. Students' musings warranted precious instructional time.

We wonder if other teachers might be solely guiding students toward thinking about a mortar/brick or mortar/rock configuration, with sand, soil, and/or clay as materials, which was the final design challenge (see Figure 3 for a photo of one of the students' final wall designs). Why open precious class time for students' ideas about a bendy wall or using sap as a mortar that may not have immediate relevance to the sand/soil/clay sandwich investigation or to the final design challenge? Mrs. W's instructional moves in these excerpts provide a glimpse of her commitments to attentive love and heterogeneity by opening up space for students to perform themselves as legitimate contributors to the class's knowledge. In these two excerpts we see, for example, Mrs. W's commitments to hearing the voices and ideas of multiple students, leveraging intellectual resources from multiple students, and giving students a platform to articulate their thinking and express their ideas publicly. Her instructional moves—being responsive to students' thinking, making space for idea play and sensemaking, inviting students to share ideas publicly, and recognizing and leveraging students' ideas with attention to relationships across ideas—demonstrate an asset-driven approach. She trusted students to make contributions that were

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meaningful for the group's ongoing sensemaking. This was her default position, which is why we never heard her say, "That's off topic." She might have said, "Ok, we have to move on," but she nearly always followed that with, "I like your good thinking."

Discussion

First-Grade Engineering to Support the Production of Epistemic Culture

When primary education prioritizes developing children's skills so that they learn how to be compliant, it mutes possibilities for intellectual risk-taking that builds confidence in their abilities to belong in, contribute to, and enrich their learning communities. In traditional contexts, it is difficult to portray youths' contributions as recognizable assets because academic or canonical language or normative speech patterns are not typical for young children (Murris, 2013). From a normative lens, their contributions might be viewed as meandering, off topic, too lengthy, and/or inaccurate. For example, when Daniela says that a wall should be "soft" or when Quanisha spends nearly a minute describing why a wall should be "bendy," we can see a ready scenario where a teacher might gently redirect towards more "accurate" descriptors instead of getting curious about what they mean by soft (e.g., a fort made of sheets in the living room) and bendy (i.e., a wall that is flexible and will not crack when hit). When Nylah answers a question about the properties of a good wall with, "Do you know my favorite movie?", it would be easy to jump to a conclusion that she is off topic if one took a more diagnostic stance (Rosebery et al., 2016). Mrs. W, on the other hand, took an interpretive stance (Rosebery et al., 2016), making space for Nylah's contribution to become a resource for others' learning by quietly giving Nylah space to continue to explain. Indeed, Nylah forwarded a creative idea about sap as a potential material for mortar which resonated with others and spurred a productive conversation about the changing properties of sap when its temperature changes.

Classroom interactions are cultural activities, shaped by histories of "settled hierarchies" (Rosebery et al., 2016) or "settled expectations" that loom large in determining the disciplinary value of children's contributions (Bang et al., 2012). Schooling's pervasive discourse routines such as initiate–respond–evaluate (Mehan, 1979), for example, are so ubiquitous and taken for granted (i.e., normative) that they shape what kinds of youth contributions are rendered meaningful in primary school classrooms across the United States. Contributions that are pithy, use correct vocabulary, move the class toward the correct answer envisioned by the teacher, and expressed in standard English are most valued. This pattern unceasingly positions young, minoritized learners' contributions in deficit-oriented ways and requires intentional "desettling" (Bang et al., 2012) and teachers who can recognize and act on the disciplinary value of students' diverse sensemaking (Rosebery et al., 2016).

There is solid consensus among equity scholars about the importance of responsiveness to students' ideas and broadening what counts as valuable disciplinary knowledge to include students' everyday reasoning (Warren et al., 2001), lived experiences, and science stories (Colley & Windschitl, 2016; Ko & Krist, 2019; Thompson et al., 2016). Rosebery and colleagues (2016), drawing on Ball and Cohen (1999), label this recognition as interpretive power, which is a form of teacher attunement that recognizes, inspires, makes visible, and builds on students' contributions as "generative intellectual resources" (p. 1572).

Mrs. W's interpretive power positioned young learners with epistemic agency, which involved attentive love and a recognition and embrace of heterogeneity (research question 1a). Indeed, these two constructs were relational—one could not exist without the other and together, they made space for students' risk-taking and epistemic agency. Her teaching moves (Table 2) and epistemic commitments ran counter to settled narratives about young, minoritized learners and schooling's practices that narrow and guard boundaries of what counts as a meaningful contribution. She was a masterful listener, muting her own voice, adapting her pre-planned agenda on the spot, and trusting students to solve problems and create and evaluate knowledge. Her decisions to teach engineering in an urban emergent school pressured to raise test scores is its own notable form of resistance (Wright et al., 2019). That she spent nearly 30 days of instruction on the unit speaks to her commitments to enacting engineering rigorously. We have seen many other teachers implement similar units in five days.

Similar to Rosebery and colleagues' (2016) idea of interpretive power is Watkins et al.'s (2018) notion of responsive teaching. They argued that engineering's uniqueness as a learning context requires elementary teachers' keen attention to students' ideas, connecting students' thinking with disciplinary practices, and an ability to adapt instruction in response to students' ideas. The intensity cases demonstrate Mrs. W's responsive teaching with the space she provided for students' ideas and the regularly occurring message that students' ideas have disciplinary value. Evident in her epistemic commitments, she knew when and how to "go with the flow" to respond to students' emerging ideas and when to offer support she deemed necessary.

Our findings made visible the *sense-making discourse* aimed at understanding properties and uses of materials, which was indicative of knowledge building in engineering design (Wendell et al., 2019a). Students' epistemic agency was easy to see when they were evaluating properties and uses of materials; it was the most prominent epistemic practice of the unit (Figure 2), opening space for students' creativity and ideas to be positioned as resources for the class's collective knowledge-generating. Mrs. W brought in concrete representations of the materials they discussed (e.g., bricks, hay), and students often picked them up to show the rest of the class when making a point—i.e., they used them to claim voice and space. Her graphic organizers became co-constructed knowledge artifacts that the students regularly consulted as a resource (Figure 3). Identifying properties and uses of materials became a productive resource "for constructing knowledge of the designed world" (Wendell et al., 2019b, p. 978). Wendell and colleagues (2019b) note that, rather than solely emphasizing epistemologies *for* engineering, framing activity to encourage understanding about epistemologies *of* engineering is a productive avenue for engineering education.

First-Graders as Co-Producers of Epistemic Culture

Students played an active role in co-creating the classroom's epistemic culture. They authored themselves as epistemic agents, evidenced by their participation in whole class discourse (Tables 4–6) and patterned discursive moves (Table 2). Their willing and enthusiastic participation and the epistemic practices of engineering evident in their discussions (Figure 1) are two indicators that the classroom activity was meaningful to them and aligned with epistemic practices of engineering (Berland et al., 2015). They felt comfortable making bids for recognition, holding the floor, and interrupting the teacher if they wanted to contribute an idea. In each of these examples, students seemed to understand the relevance of one another's ideas to the disciplinary ideas, sometimes better than the teacher did (e.g., *warm paper*). They helped translate their peers' ideas for the teacher so that she could recognize them as valuable to building knowledge. By seizing opportunities to make connections to everyday experiences, their contributions opened up space for others to chime in (e.g., continued discussion about warm paper while the teacher was otherwise occupied and sap as a potential mortar material). Students took up Mrs. W's speech patterns that contributed to the epistemic culture—e.g., "Oh Nylah, thank you. I like what you said. You just gave me a good idea." We note the visibility of the *collective* nature of the knowledge-building and epistemic agency in the class; the children, in other excerpts in our analysis, frequently credited a classmate with giving them an idea, stated that they wanted to "build on" a classmate's idea, and openly and respectfully agreed or disagreed with their peers' ideas. In doing so, they easily acknowledged their peers' contributions as assets for their own thinking. Carlone et al. (2011) noted this kind of joint knowledge building as critical to supporting students' disciplinary-linked identity work.

Lingering Tensions: Mrs. W's Case and First-Graders' Engineering and Epistemic Agency

Engineering, with skilled teacher facilitation, can be an excellent context for subverting traditional schooling practices that undermine children's epistemic agency. The work includes a valuing of multiple interpretations and solutions, creativity to design and build, a need to work through failure, and is situated in real-life scenarios (Cunningham, 2018). This is a striking juxtaposition with historically enduring schooling practices like getting the right answer, memorizing factoids and vocabulary, and completing skill-based, low-level tasks. Not surprisingly, the inclusion of engineering is not the *sine qua non* for the development of epistemic, just cultures in elementary schools.

Engineering can easily reproduce settled practices of schooling that devalue youths' experiences and emerging ideas in favor of traditional schooling and/or narrow interpretations of disciplinary ideas (Varelas et al., 2011). For instance, in a study of five African American fourth- and fifth-grade students' engagement in engineering design, Wright and colleagues (2018) found that youth framed their engineering abilities by emphasizing their good behavior, direction-following, and getting correct answers. Histories of schooling bore down on students' activities, and they responded with "reactive coping mechanisms" (p. 296) to minimize chances of getting in trouble and the perceived risks associated with getting the wrong answer. Histories of engineering education, too, can perpetuate perspectives that position engineers and their work as unproblematically good (Rodriguez & Shim, 2020) and overly technocratic and utilitarian, which mutes the social and political dimensions of engineering problems and solutions (Gunckel & Tolbert, 2018). Gunckel and Tolbert (2018) argued that a more complete, responsive, and responsible engineering education centers empathy, care, justice, ecological stability, and the sociopolitical contexts in which engineers do their work.

Rodriguez and Shim (2020) point out that without skilled facilitation, the EiE curriculum could inadvertently promote colonized thinking, too-rosy portrayals of engineers, and culturally inauthentic connections. In some ways, Mrs. W's pedagogy avoided some potential pitfalls of engineering education mentioned by Rodriguez and Shim (2020). Mrs. W adapted the curriculum (see Figure 2) to intentionally weave in interdisciplinary and student-driven connections that provided multidimensionality to engineering. They discussed sociopolitical meanings of walls that impacted their lives, devoted time to exploring materials for walls that were sustainable and recycled, connected their explorations of materials engineering to a bird's nest they had observed for weeks before the unit started, played with wall construction and materials during recess when other teachers discouraged it, and had space to make creative connections to their lives to deepen their evaluations of the properties of materials and their suitability for mortar.

Yet, the disruptions to schooling practices were partial; the enacted curriculum placed boundaries on students' epistemic agency. For instance, children had little say in problem scoping (i.e., identifying the problem, defining criteria and constraints, and/or redefining the problem) (Tan et al., 2019; Watkins et al., 2014). They had few choices about the kinds of materials they chose for their design, and they did not make substantive choices about how to test the wall prototypes. These limitations, however, enabled comparisons of data across designs and in-depth, disciplinary discussions of the affordances and constraints of materials' properties for their designs. Since all students used similar materials, comparisons were easier to make and helped guide children's decisions about their second prototype designs. Mrs. W used the curriculum as a guide to enact pedagogy that aligned with her epistemic commitments of attentive love and heterogeneity. Youths' willingness to take up knower roles, a social positioning that goes against histories of practice in urban emergent schools, is a form of agency that enabled the stability and predictability of the class's epistemic culture.

Conclusion

We did not begin our study with a rigid definition of epistemic agency because we were unsure what such agency might look like for first-grade engineering. We looked closely at knowledge-generating and knowledge-evaluating discussions, the norms that supported those discussions, students' roles during those discussions, and the implicit messages about knowledge conveyed in those discussions. From that analysis, we could see that students were active knowledge-builders who shaped their peers' knowledge and participation, influenced the direction of a class discussion, and altered the teacher's instructional plans. The questions that became most relevant for our definition of epistemic agency were: Did students have opportunities to shape and evaluate knowledge and knowledge-building practices in their classroom? Did students' participation in knowledge-generating practices reframe what and whose knowledge counted? Were first-grade students' ways of participating in disciplinary practices rendered meaningful to the community's knowledge generation? Did students have "opportunities to build a knowledge product" that was useful to others (Miller et al., 2018, p. 6)?

When we investigate agency in the spirit of redressing epistemic injustice, questions about the immediate and distant social and cultural arrangements that bear down on the setting bubble to the surface—agency to do what? To be whom? Amidst what kinds of odds? With what kind of space to navigate? Keeping in mind the importance of reflexivity and current calls for elementary teachers to include ethics, care, and sociopolitical contexts in engineering (Gunckel & Tolbert, 2018; Rodriguez & Shim, 2020), we will push ourselves and encourage others to ask additional questions about epistemic agency, like: Whom does the knowledge benefit? How could the knowledge perpetuate or disrupt social and environmental injustices? How can the knowledge children create fuel their motivation and imaginations to create technologies for more just futures?

We focus on first-graders' epistemic agency because the construct allows us to highlight the youths' knowledge contributions as assets and as a way to *speak back* to the historical deficit-based narratives that accompany urban intensive and urban emergent schools (Milner, 2012; Nasir & Vakil, 2017). Engineering, with skilled pedagogical practice, can push back against historically worn grooves of the traditional elementary curriculum. This classroom's vibrant epistemic culture, emboldened and sustained by students' agency, the context of an engineering design unit, and a responsive teacher committed to attentive love and heterogeneity, conjures an image of the possible to begin to redress injustice in urban schools.

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Author Bios

Heidi Carlone is the Hooks Distinguished Professor of STEM Education at the University of North Carolina at Greensboro. Dr. Carlone's research focuses on culture, identity, and equity in and for science, engineering, and environmental education. Email: hbcarlon@uncg.edu.

Alison Mercier is an assistant professor in the College of Education at the University of Wyoming. Dr. Mercier's research focuses on elementary teachers' professional agency and supports for teaching science and engineering. Email: amercier@uwyo.edu.

Salem Metzger is an adjunct professor in the School of Education at the University of North Carolina at Greensboro. Dr. Metzger's research focuses on supporting and researching teachers' efforts to cultivate student agency in the classroom. Email: smrainey@uncg.edu.

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