Collaboratively engineering for justice in sixth grade STEM

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Schenkel, K., & Tan, E. (2021). Collaboratively engineering for justice in sixth grade stem. Journal of Research in Science Teaching, 58(7), 1010–1040. https://doi.org/10.1002/tea.21691

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Keywords: engineering | equity | ethnography | justice | learning | pedagogy | science | sociocultural

Article:

*****Note: Full text of article below**

Received: 4 May 2020 | Revised: 18 March 2021 | Accepted: 25 March 2021

DOI: 10.1002/tea.21691

RESEARCH ARTICLE

JRST | WILEY

Collaboratively engineering for justice in sixth grade STEM

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Funding information
National Science Foundation, Grant/Award Number: 1502755

Abstract

In this article, it is argued that processes of co-production can support teachers and students in organizing resources for justice through science learning. Drawing upon a critical justice conceptual framework, critical ethnographic data from one urban middle school classroom during a unit focused on engineering for sustainable communities were analyzed. Findings describe how processes of co-production yielded new Discourse threads focused on sustainability, whose ideas matter, and empathy, which were embodied in students' engineered artifacts and how students talked about using those artifacts. Such embodiment positioned students as rightfully present and powerful experts in science and engineering. We discuss how processes of co-production supported justice by supporting new social relationships between the teacher and students that helped to make space for collective engagement of students' political struggles against the oppressive practices of schooling as an integral part of science learning.

KEYWORDS

engineering, equity, ethnography, justice, learning, pedagogy, science, sociocultural

[Correction added on 14 June 2021, after first online publication: Open access statement has been added.]

Analeigh: This is something that is going to help someone in the future.
Mary: We know and think about other people's feelings. . .even though we failed a few times with our lights, we still don't give up.

In these opening quotes, Analeigh and Mary were describing their experiences designing the "Bank of Compliments," a light-up box filled with laminated cards that contained supportive compliments, such as "You're worth a million dollars" and "Your heart is filled with wonder." One could reach into the box to pull out a friendly motivational card while also enjoying the colorful bright lights as they turned a handcrank generator. The four LED lights were hand colored red, green, blue, and pink to reflect the different emotions they and their peers felt during the day. The girls designed and built the Bank during a 6-week STEM unit focused on engineering for sustainable communities. As they wrote in their final project write up:

> The Bank of Compliments solves the problem we identified by making our peers feel good with compliments. Students can reach into the top of the box and get a compliment. They light up the box if they like the compliment they have. If they don't like the compliment, they can grab another compliment. If they like that one, they can light up the box. We used a parallel circuit to power four lights. Our energy source is a handcrank. Students can light up the box by turning the handcrank, transferring energy to the LEDs.

In the quote above, the two girls describe how they built the Bank in order to foster a happier and more just school community. They worried that school had "too much drama" and kids were often "mean" and "bullied" each other. Their analysis of their school-based observations, surveys and interviews of classmates and peers also indicated that school morale was low and this made it "too hard to learn." As the quotes indicate, the girls worked hard on their project, and were proud of their efforts knowing they would help to bring positive change.

When their project was completed, the girls, with their teacher's support, moved the Bank to the restorative justice room, a place where they, and many peers, had spent time in relation to bullying, and a place where they felt agitated. They believed their engineering design would be helpful in the room because it would provide the students with new and different ways to feel better.

1 | RESEARCH FOCUS

This brief vignette show cases how a group of sixth grade girls, with their teacher, used their engineering for sustainable communities project to organize for social justice. The girls identified a problem—low school morale, often caused by bullying—and applied their knowledge of energy transformations and environmental sustainability to design the Bank of Compliments in response. The Bank was a socio-technical solution to a social problem. In building the Bank, the girls responded to the technical dimensions of the task—build something that promotes sustainability, involves energy transformations, and uses ordinary classroom materials. However, in building this artifact they actively sought to change how people in their classroom, and later in the restorative justice room, felt about themselves and each other. They sought to change the legitimate broader discourses of what it meant to be and feel in their classrooms and school. Their engineering design was as much about the technical solutions to problems as it was about critically caring for each other. As their quotes illustrated, the girls really cared about their

classmates' feelings, both now and in the future. Mrs. L., too, commented on how powerful it was that the girls centered their desire to care for each other by repeatedly encouraging the girls and their classmates to "use math, science and their creativity to solve a community problem."

As their project physically moved from their sixth-grade classroom to the restorative justice room, the impact of their work spread. Not only did the girls' learn engineering in ways that mattered to them in the here-and-now, but their work also promoted new social futures for themselves and their schoolmates. The Bank of Compliments was used by youth, teachers, and staff alike across the school year. What was learned, by whom, where, when and how, all mattered as the Bank, materially and symbolically, connected the girls' and their peers' present to the past and imagined futures.

The Bank of Compliments was not the only project that transformed aspects of classroom and school life in their school. Other student projects, such as the Mood Board and the Shining Star, all sought to positively impact how peers and teachers related to each other, even though this community-centered outcome was not an explicit criteria of the design task. We began to wonder how and why it was that the projects in this classroom resulted in transforming classroom *and* school social relationships in just and caring ways.

As we spent time with Mrs. L and her students during a 6-week enactment of an engineering design challenge focused on sustainable communities, we also collectively noticed that throughout the unit and after, as projects were taken up in the classroom and school, there were many moments when Mrs. L, her students, and members of the larger school and neighborhood community substantively contributed to refining the direction and outcomes of the engineering challenge. This included shifts in the overt goals of the unit, how the idea of sustainable communities was defined and operationalized, the materials that could be used in the process, the spaces and locations where projects could be enacted, and who would use the final projects. We sought to examine more closely how these moments unfolded, and what that meant in efforts to work toward justice. Thus, in this manuscript, we ask: *In the context of an engineering for sustainable communities unit, how did Mrs. L make space and create opportunities for students to engineer toward social transformation?*

2 | ADVANCING JUSTICE IN STEM TEACHING AND LEARNING

2.1 | A focus on the sociopolitical in STEM teaching and learning

The study of how to support integrated science learning has gained significant attention in the US since engineering practices were introduced into the national science education reform initiatives. Of significant concern in these efforts is supporting students in engaging in design processes, collaboratively, and with an eye toward solving real-world problems (Cunningham & Carlson, 2014; Moore et al., 2015). For example, teaching engineering at the K-12 level encourages more equitable forms of learning in how it mobilizes students' everyday interests and practices in the context of authentic and project-based experiences (Cunningham & Kelly, 2017).

Despite attention to the social dimensions of learning integrated science in classrooms, there is a lack of agreement in the field on how to authentically incorporate the diversity of student experiences and ways of knowing in engineering design challenges and learning. This is especially obvious when those experiences and ways of knowing have a less direct connection to the technical dimensions of engineering. As Gunkel and Tolbert (2018) point out, much of the focus

of the research on teaching engineering in science classrooms rests on the technical dimensions of engineering, with little attention to "social empathy and care as essential aspects of engineering education and practice" (p. 939).

We were drawn to work with Mrs. L because her teaching of engineering seemed to push back against the dominant narrative that the technical dimensions of engineering matter more than the social dimensions. Care for classmates and the school community were integral to what it meant to learn and do engineering in her classroom. Mrs. L seemed to practice the ideal that because engineering requires attention to social needs and processes, educators need to be mindful of the cultural contexts, assets, and experiences that students bring to engaging engineering design (Secules et al., 2018). We wished to learn more about how this played out in her daily pedagogical practice.

Furthermore, we are concerned that few studies investigate how the teaching and learning of engineering promote social transformation in the here-and-now, and not in some abstracted future. This is an important equity concern because it is well documented that youth, especially those from nondominant communities, experience structural inequities daily in the classroom—not only through expectations for what valued participation in engineering looks like, but also through a lack of critical attention to how the knowledge and awareness of engineers is *always* socially constructed along diverse social, political, and global lines (Calabrese Barton & Tan, 2019). Standard teacher hierarchical Discourses used often in STEM classrooms (e.g., "top," "weak," or "low" students) shape the differential learning opportunities made available to students (Louie, 2020). Likewise, the ideologies of schooling and STEM learning, grounded in White and patriarchal systems, knowledge structures, practices and Discourses, can open up and/or foreclose learning opportunities because of who one is and what they bring to schooling (Ladson-Billings, 2006). They work collectively, across scales-of-activity, to marginalize youth from nondominant communities despite their embodied presence in classrooms. These sociopolitical dimensions of engineering—whose knowledge and experiences matter, how and why, and the role of teaching and learning engineering for social transformation—make it imperative to surface and make visible how knowledge/power hierarchies can be disrupted in classroom practice in support of powerful student learning and social futures.

2.2 | A turn toward critical justice

We turn to critical justice perspectives to make sense of these entrenched challenges in science education and in Mrs. L and her students' efforts to disrupt them. Broadly speaking, critical justice focuses on the importance of making visible and disrupting "entrenched power disparities" grounded in the normalizing processes of the powerful (Annamma & Handy, 2020, p. 2). These power disparities not only foster tensions between the powerful and those with less socially dominant legitimized power, but also inflict injustices upon those furthest from the norm, especially when such distance is amplified by intersectional oppressions (Crenshaw, 1989).

Power dynamics are always at play in science classrooms, acknowledged or not (Nasir & Vakil, 2017). For example, legitimized patterns of participation in science are generally tied to who and what areas of expertise are recognized and valued by dominant culture, fostering power disparities in relation to participation boundaries and knowledge (Calabrese Barton & Yang, 2000). Critical justice thus foregrounds attention to making visible and upending injustices located in current practice but grounded in historical, social, and geographic histories (Balibar et al., 2012).

A focus on justice is important in teaching and learning in order to disrupt entrenched inequities. The field's focus on "equity as inclusion" has fallen short of addressing entrenched injustices as it neglects to excavate inclusion into *what*, and how the undergirding ideologies of a given space, such as a classroom learning community, constrain the liberatory possibilities for inclusion (Calabrese Barton & Tan, 2019; Calabrese Barton & Tan, 2020). Annamma and Handy (2020) puts it this way: "a focus on exclusion misses what is happening even when inclusion occurs ... one can be included and isolated" (p. 6). This last point makes clear why a justice stance must account for both *social* and *spatial* dimensions.

Who one is and how one participates in integrated science class—through knowledge, Discourses and practices—are always bound to people and place. As Gee (2006) asserts, Discourses, which encompass the ways of talking, doing, writing, valuing, reading, interacting and representing oneself, are always and everywhere social. Further, there is no Discourse, knowledge or practice that "stands outside of a social, physical or historical space" (de Saint-Georges, 2004, p. 71). How things and people are organized in space (Soja, 2010) impact what gets done through the different manifestations of Discourses, and by whom. The spatial, such as how bodies are organized in a classroom or what items adorn classroom walls, is shaped through social and ideological relations, such as ideals about whose knowledge matters most in classrooms or how teacher and students interact. These configurations can produce and reproduce (in)justice (Mitchell & Elwood, 2012). This can be seen in how some students' work is publicly acknowledged as worthy of praise, and not others, or in the symbolism of the teacher standing in front of the room leading a demonstration with students sitting in desks observing. We see this as important in an engineering learning environment, where youth are making *things* to solve problems. As youth design, build, iterate and use things, they spatially affect social interactions in classroom life. As Shaw (2020) reminds us, "the spatial ordering of the material world—where people and things *are* in relation to each other—does more than reflect power and politics, it *is* itself a kind of power and politics" (p. 190). These power dynamics exerted through and within the physical environment of the science classroom "impacts perception of self—specifically how we reconcile who we are and who we will become" (Bates et al., 2018. p. 257).

The interconnections between the social and the spatial is deeply connected to young people's opportunities to learn and become in school science. For example, Morales-Doyle (2017), examined how a high school chemistry class investigated local environmental justice issues identified by their communities as a part of their standard chemistry learning: The lasting impact of a recently closed coal power plant on the community's physical environment. As students moved between classroom and community they generated data on concentrations of lead and mercury in neighborhood soil samples, and procured stories of residents as they navigated the impacts of the power plant on everyday living. Throughout the unit, students demonstrated high levels of complex thinking in chemistry. They did so as "transformative intellectuals"—people who had credibility as local youth knowledgeable in science while also having a commitment to their communities (p. 1052). The nature of students' Discourse in this unit reflected the interactivity of the social and spatial in working toward justice. As students physically navigated the complex spaces of community and school, intersecting with the domains of chemistry and environmental justice, they sought to make visible the ways in which injustices were enacted in-the-moment and in historicized ways in their community. They leveraged science, but on their own terms, and through their narratives regarding what matters and why in their community. Their actions led to their own deeper learning and to the social transformation of their community as their findings were taken up by more powerful others. Through the process, new knowledge/power relationalities were made possible.

How people and things are in relation to each other—their spatial ordering—both reflects and enacts power and politics (Massey, 2005) through the kinds of Discourses (Gee, 2006) enacted. There is an interconnectedness among the spatial, social, political, and disciplinary at any given time. Davis and Schaeffer (2017) remind us that making visible the social-spatial is particularly important for Black students who systematically experience oppression "by how power and injustices in science manifest in locally-specific ways" (p. 4). Rubel, Lim, Hall-Wieckert, and Sullivan (2016) further expand on this point when they describe how students read within and beyond mathematical-community maps as they developed a nuanced understanding of how sociopolitical forces intersect with spaces through the Discourses of mathematics. The researchers highlighted the limitations of some students who were constrained to only reading the physical map (where lottery stores and predatory financial services are located in neighborhoods, as shown on the map) by their lack of ability to appreciate the undergirding political script (associated factors related to race and income-levels).

Central to ours and others' stance on justice is that because space is socially produced, *it can therefore be socially changed*. How might a teacher work toward justice in social, spatial ways? Dismantling systemic injustices, rooted in classroom practice, is challenging. Teachers, often unknowingly, mete out injustices through quotidian teaching practices (Esmonde & Booker, 2016). While there has been some work in educational research focused on justice from a social-spatial perspective, as discussed above, many questions remain.

3 | METHODS

3.1 | Partnering for engineering for sustainable communities

Being engaged with justice, we took a critical and participatory methodological approach grounded in Research + Practice Partnerships (RPPs). Our work is critical in that it is rooted in exposing, critiquing, and transforming inequities associated with social structures and labeling devices as fundamental dimensions of research. Our work is also participatory as we seek to include multiple voices at the research and design table, including youth, teachers, and community educators (Cammarota & Fine, 2010). Together, participatory critical ethnography provides insight into the power dynamics in a given community and supports praxis to address inequitable power distributions (Weis & Fine, 2012). Our teacher and student partners, as noted below, significantly contributed to the design and enactment of our research together. As expert insiders, their insights critically challenged how we made sense of social-spatial (in)justice and its enactments in the relationalities of classroom and school life.

3.2 | Research + practice partnership context

We have been working with teachers, youth, engineers and community members in a community-engaged Research + Practice partnership for the last 5 years to co-create tools and materials in support of teaching and learning engineering for sustainable communities. We collaboratively established these RPPs to bridge the gap between research and practice while challenging the historical inequalities experienced by minoritized students in STEM. Our goal has been to design for the teaching of disciplinary core content and engineering practices in such a way that pushes back against the assumptions that the knowledge, practices, and experiences that youth from

nondominant communities is somehow lesser or deficient. Our design work took place with partners over years. We sought to co-create, first in informal spaces with youth, community educators and teachers, and then further refine in school spaces with youth and teachers, new curricular materials that historicizes youths' experiences toward powerful and transformative engagement in STEM. Youth and community educators played critical design roles through co-design activities, and weekly feedback conversation groups. Their imprints can be seen in the design of activities, and in the resources and other images made present in the materials shared with others.

Liberty School, from Great Lakes City, is one our partner schools. It is a prek-6 school with a focus on global studies and Spanish language immersion. It is one of the most racially diverse schools in the city, with 47% Black, 28% white, 18% Latinx, 3% Asian, 3% other, and 1% Native American students. Liberty was converted to a magnet school with a focus on global citizenship 5 years ago in an effort to stanch the flow of students from the district into the local charter school system and other districts allowed by state policies. The school has strong community support and connections across the cultural and linguistic groups it serves. Parents post how much they like the teachers and the school on social media. There are many cultural nights and celebrations at the school. Students are constantly encouraged to share their project work with peers, teachers, and family members beyond their own classroom.

Mrs. L. has taught for over 30 years. She identifies strongly as being a mother and has spent her adulthood in Great Lakes City. She is a white woman, which is reflective of patterns in the national teaching corps and the school district, which is predominantly white women teaching students of Color. She had been teaching in the district for years, and taught many of her current students' older siblings, aunts, uncles, and cousins. Mrs. L enthusiastically welcomed parents, families and other communities members to join in the class community often. Weekly and more as needed, Mrs. L orchestrated whole class conversations about the needs, desires and action plan of the class community. Her students often actively chose to spend their lunch and recess free time with Mrs. L and across interviews students shared that they knew Mrs. L really cared for them. Seventeen of Mrs. L's 19 students participated in this study. The demographic make-up of Mrs. L's classroom reflected that of the school. Of these 17, nine students identified as Black, five students identified as white, one as South Asian, one as Multiracial (Black and Latino) and one as Lebanese.

3.3 | An engineering for sustainable communities approach

We are deliberate in our approach to engineering for sustainable communities. We use the phrase "a sustainable communities approach" to call attention to the integrated challenges of teaching and learning science with and for community in support of building a healthier, happier, and more just world. Supporting a sustainable communities approach is necessary given the global challenges facing young people and their communities today, such as poverty, racism, climate change, health, and potable water scarcity (National Research Council, 2010). A sustainable communities approach considers social, political, cultural, and environmental concerns from community members' perspectives toward sustainable technological solutions. Designing sustainable solutions focuses on the needs and rights of communities as co-designers of their futures.

A sustainable communities approach is important for promoting justice in classroom settings. We take the stance, as have others, that the fields of STEM education, broadly speaking, have often treated epistemologies as set, agreed upon, and/or "settled" (Bang, Warren, Rosebery, & Medin, 2012, p. 302). Therefore, in our framing, a sustainable communities approach refuses the

ways that dominant Western science education has often been positioned as incongruent with youth and their communities' ways of being and knowing. A sustainable communities approach supports confronting issues of injustice. This requires that students integrate both science and community expertise to identify and understand issues that matter and then design long-term solutions.

Thus, a sustainable communities approach supports teachers and students in working with each other and their communities to draw upon a diverse and distributed set of expertise to understand and address challenges at both the local and systemic level. It requires students and teachers to ask, *Whose knowledge counts? Who takes action?* (NRC, 2010). We want students to be able to say, "I can begin to solve this problem collaboratively right here in my community, right now using what I know" rather than waiting to only use their STEM expertise in long-term future career goals or deferring to experts outside of their communities who are positioned as experts. This is important to challenge both the ways that schooling practices have perpetuated epistemic violence on youth marginalized by dominant science education as well as material forms of broader societal oppression.

Lastly, as implied in our comments above, a definition of a sustainable communities approach in science is one that works toward social-spatial transformation. While issues of (in)justice in science education have garnered increasing attention in the past several years, the research focus has remained on *individual cognition* rather than on *social transformation* (Tolbert & Bazzul, 2017). Using a sustainable communities approach, we are concerned with who learns in science classrooms, and how and why such learning matters to youth and their communities. We hold the stance that fundamental to addressing inequities in science education is understanding the consequentiality of learning, including how students are supported in developing science agency toward making change. We also contend that for science teaching to be justice-oriented, it needs to address how historicized injustices manifest in systems of power that play out in local classroom practice as part of science education (Calabrese Barton & Tan, 2019).

3.4 | Curricular context

This study occurred during an engineering for sustainable communities unit grounded in the disciplinary core ideas of energy transformations, sources and systems, and sustainability, alongside engineering practices. This unit was enacted with support of the school leaders and district and in response to the need to incorporate engineering design into the standard curriculum in the sixth grade. The unit consists of two iterative design cycles: (a) design and iterate on electric art for loved ones, and (b) creating sustainable, green-energy powered engineering design solutions for their classroom. In this latter design challenge (and the focus of this article), students were given the design challenge bounded with the following criteria: Students had to innovate something in the classroom in a way that would address a classroom and community sustainability problem. They were required to use a renewable energy source, such as solar panels or hand crank generators, 10-mm LED lights, copper tape, and any materials available in their classroom. We selected these tools because they are affordable, and have been shown to be an accessible pathway into electronics and design. See Table 1 for Curriculum Flow.

3.5 | Positionality

We spent time weekly in partner spaces over years to build the kinds of relationships needed to engage justice-oriented work across positionalities and perspectives. The voices, experiences,

TABLE 1 How can I make my classroom more sustainable? Unit flow (~26 instructional hr)

#	Lesson	Key focus	Integration of community perspectives
1	Introduction	Big ideas in engineering for sustainable communities Lesson 1: Engineering for sustainable communities introduction	Examining and discussing how youth their age use community ethnography as a part of engineering design
2–3	Iterative design Cycle 1	Sustainable electric art: Using iterative design cycles to make electric art cards for family/ friends, powered with green energy sources Lesson 2: Designing electric art Lesson 3: Sustainable electric art	Generating community narratives
4–9	Iterative design Cycle 2	Sustainable classrooms: Defining Problems & Designing Solutions through Community Ethnography Lesson 4: Engineering design challenge intro Lesson 5: Defining the problem: using community ethnography to define engineering challenges Lesson 6: Initial design Lesson 7: Optimize design with community feedback Lesson 8: Prototyping Lesson 9: Refining designs through technical tests and community feedback	Using community ethnography as a part of engineering design Surveys & observations of peers & community members Dialogues with community on project ideas/design Observation
10	Community sharing	Lesson 10: Sharing engineering designs with the community	Community narratives

and lives of those most silenced by the institutions need to be at the research table if such elevation and transformation are to authentically inform a contextualized, equity agenda.

The first author, Angie, who is white and female has experienced a different set of social-spatial relationalities than the youth in our project. As a white female, she literally "blends in" to the power structures of partner schools, where the majority of teachers are also white and female. However, a long-time member of the local community, she has worked to navigate these social-spaces in ways that disrupt her unintended complicity in these powered-dynamics, pushing her to continually question how she may embody the very power structures she hopes to disrupt. For example, she knows many of the participating students and their families at our partner school through her long-time presence at their community center, where community elder, Granny, has informally mentored her in learning with and in the informal networks and epistemologies which sustain community members, and also welcomed her into her family. She also uses her own experiences growing up female in a working-class community to render intersectional problematics of what it means to know and become in STEM.

The second author, Katie, has been learning with the local school district over the last 4 years. She draws on her experiences growing up in the US Midwest to make sense of interactions, but also is continually working to understand how her own education and societal experiences were impacted based on how she was positioned as a white, middle class woman. As a former middle school teacher, she was able to build relationships with Mrs. L and through spending time with the classroom community, she was welcomed by the students into their classroom community. However, given the ways, she has been positioned with power based on her whiteness, class and institutional affiliations, her understandings of the classroom interactions are always limited.

The third author, Edna, is a Southeast Asian immigrant who regularly experiences real and symbolic violence in the academy. Positioned as outsider through "backhanded compliments" (e.g., "Your English is so good!") and experiencing on-going verbal violence as she navigates the geographical terrain of her context ("Chink!"), the social-spatial realities of (in)justice are profoundly embodied, though in different ways from some of the youth (and teachers) in our study. Collectively our experiences have helped us to more critically examine how people are positioned as insiders and outsiders to schooling in STEM through both sociocultural and institutional structures and in local practice. They give us an angle to understand what social-spatial justice may mean in working toward equitably consequential learning in STEM.

3.6 | Data generation and analysis

Data were generated during the implementation of the "How can I make my classroom more sustainable?" unit in one middle school classrooms unit over the course of about 26 instructional hr during the spring 2018. Each session took about 60–120 min per session.

3.6.1 | Fieldnotes

Detailed field notes of classroom interactions were kept for each class session, along with video recordings of select lessons and group interactions. Fieldnotes were kept by more than one researcher for all class sessions to allow for multiple perspectives to inform how we understand the contexts and interactions. Fieldnotes centered on whole group instruction, experiences of small focal groups and student participants' efforts in the design challenge. We paid attention to patterns in the take up (or not) of individual ideas in interactions, ways that students' expertise and participation personas are recognized as contributing to the class community, role distribution, decision making about the social and technical dimensions of the class' efforts, variations in student positioning, resource access, and sources of expertise.

3.6.2 | Interviews

Mid-unit and end-of-unit "artifact interviews" with all focal groups were conducted. Here, the "artifacts" are engineering designs youth prototyped, and included their design sketches, actual prototypes, and written reflections about their prototypes. Interviews focused on understanding the artifact (what is it, how it works, what problem it solves, etc., materials used and why, etc.), participation and engagement (behind the scenes, including a step-by-step description of the

process, descriptions of interactions/support youth received from peers, educators, and community members, resources used), knowledge and practices (STEM knowledge and practice needed [prior and what was learned], and funds of knowledge); and meaning and value (what this project says about oneself, etc.). We also conducted informal weekly conversations with the teachers to make sense of on-going questions, concerns, and feel of the enactments, with a formal interview at the end of the enactment.

3.6.3 | Video

Video records were valuable for analysis of the class community's interactions. We recorded whole class instruction with a fixed camera that captured the teacher's interactions with all students. We used GoPro cameras to video-record focal groups during group work.

3.6.4 | Student work

We collected copies of all student work produced, including activity sheets, sketch-ups, images of projects in various stages of development, and assessments (e.g., "project postcards"). We also generated images of all class produced work during class sessions (e.g., white board notes) and which hung on class walls (e.g., list of sustainability ideas).

We underwent the comparative analysis following the critical grounded theory tradition (Charmaz, 2017), which involves two iterative coding phases: open and axial coding. First, the first two authors, Angie and Katie, perused transcripts of whole class sessions to identify moments where shifts in classroom Discourse (including written, spoken, embodied interactions between students and teacher) reflected negotiations in meaning-making and overall project development. We noticed such shifts in real time, and wrote about them in our field notes, aiding this process. Specifically, the shifts we noticed related to (a) when students ideas, as presented either in classroom dialogue or in project work and presentation, shifted the direction of the overall learning focus, and (b) when questions, tensions and challenges opened up opportunities to renegotiate classroom and project activity. For example, when one student noted that "this was too hard" and "he had no ideas," Mrs. L, responded by telling the class that "We're coming up with ideas that we don't even know we're doing yet!" This was followed by a class conversation on how engineering real designs was new for everyone, and how the students' work mattered in ways they could not predict. We sought then to make sense of not only how the teacher responded, but what happened before that supported these particular shifts in happening.

We then zoomed into classroom transcript to identify *how* those shifts and negotiations transpired, and what this meant for participation in meaning-making. Once these episodes were identified, we open coded them within a set of categories: (1) the role of teacher/students in the discussion; (2) the role of different forms/sources of knowledge and practice; and (3) shift in focus/direction of project work as identified through emergent, critiqued and amplified Discourse threads, (4) what decisions the teacher or students made in project work; and (5) what the above revealed about the kinds of relationalities students brought to bear on their engineering .

Then, all three authors held several analytic meetings to discuss these episodes. Different versions of analytic tables were developed in a sortable spreadsheet. Differences in our analytic

views were debated until new meanings were generated. A detailed list of emergent open codes were kept with analytic memos which we then brought to bear on all of the identified episodes. We developed a coding table to document and codify the how different forms/sources of knowledge and practice in relation to how and why shifts in focus/direction of project work occurred. This is what lead us to consider the importance of the three emergent Discourse threads, and how they developed over time. Angie and Katie then re-coded the data for these Discourse threads, refining the working definition of each thread as the re-coding work occurred. As we did so, we also coded for how these threads took shape over time—through what teacher/student actions/interactions did the thread become thicker and/or change direction? How did these threads become solidified in symbolic and materials ways, in addition to classroom talk? As we noticed that the teacher and students shared authority in shaping these threads in a collective and cumulative way, we sought to try to name this process. At first we named this *co-constructing* Discourses, but this seemed to not fully capture the ways that power was disrupted and transformed in both the process (who contributed and how) and in the outcomes of contributions (the ways in which collective youths' assets and desires became visible and tangible to the Discourses themselves). This led us to the idea of *co-production* as a way to organize what we were seeing in these emergent Discourse threads, and how they layered onto each other. This process led us to further examine the whole class transcripts and student work, for these three Discourse threads to see if, how and why these Discourse threads took shape.

We then examined any relationalities disrupted, or new relationalities enacted specifically with attention to knowledge/power and student engineering work; and the role of the materials artifacts, as contributing elements of the spatial mediated these disruptions/enactments. For example, we highlighted when students moved engineering designs beyond their classrooms and when they led collaborations with adults in the building to ensure the engineering designs were used to address the problems, they deemed necessary to solve. Another example included students addressing pasts pain (e.g., bullying, not being recognized) they experienced or contributed to did to, and rebuilding relationships as they engineered to support others to do the same. This phase of coding led to the major claims we present in our findings.

4 | FINDINGS

We share two main findings. First, Mrs. L supported students in working toward justice through the co-production of three new Discourses. By using the term co-production, we build on the idea, from urban planning studies, that centers how public services better serve the *public good* through making better use of each other's assets and resources to achieve better outcomes and promote power sharing (Loeffler & Bovaird, 2016). Second, we highlight how these Discourses manifested in social *and* spatial ways through students' ongoing engineering design work. We draw on Gee's (2006) notion of Discourse—ways of knowing that are expressed through a myriad of ways, not limited to the verbal.

We first describe the new Discourse threads, including how these threads were introduced and became solidified as they were taken up in different ways. We use the term "Discourse threads" to describe the initial broaching of new ideas through different ways, for example, verbal articulations (e.g., discussions) or through data solicited through engineering surveys enacted by students. In explicating the processes by which Discourse threads became solidified into new Discourses, we trace new manifestations of such through teacher and student co-production of new ways of being through creating physical artifacts, discussing new topics in

science class, expanding the outcomes of doing engineering, including why, where, for whom, and toward what ends. We show how these Discourses manifested spatially in new tools and resources the class made together and used throughout the design challenge. We then describe how the Discourse threads further solidified and became layered through students' engineered artifacts. We discuss how the processes of co-production of new Discourse threads supported justice through the youths' artifacts in the ways new social relations were fostered among Mrs. L and her students. These new social relations allowed for the collective engagement of students' political struggles against the oppressive practices of schooling as a part of science learning.

4.1 | Co-production of new discourse threads

Mrs. L supported the co-production of three new Discourse threads in integrated science learning, including (1) expansive visions of sustainability, (2) the role and importance of community engagement in engineering design or "whose ideas matter", and (3) naming and performing empathy. We focus on how Mrs. L's pedagogical moves supported such co-production by creating new spaces for students' ideas, experiences and expertise to be integral in engineering design, and in disrupting who typically has the power to be science and engineering experts in their class community, and what that expertise looked like. We also show how these Discourse threads were further developed and expanded as Mrs. L widened the range of actors participating in her sixth grade students' engineering knowledge production.

4.1.1 | Expanding discourses of sustainability

Mrs. L created spaces for her students' ideas and experiences to steer their collective work in engineering for sustainable classrooms. Below we show how Mrs. L involved her students in co-producing shared Discourses of sustainability through pedagogical moves that elicited and centered students ideas, while also de-centering her authority. These Discourses extended beyond those prescribed by the curriculum. She also co-produced with her students new tools and resources for making these Discourses visible and concrete for guiding and supporting student project work throughout the unit.

During the second lesson of the design challenge, Mrs. L introduced the idea of sustainable classrooms to her students. Mrs. L shared her view that sustainability "is something that doesn't need a lot of help to continue going on and working." She explained:

> If we're thinking about a project where the materials that we're using, we're gonna have to spend $60 on at Home Depot, that's not sustainable. If we're thinking about a project where someone is gonna have to watch it all the time and make sure it's working, that's not sustainable. It's gonna have to be a self-sufficient, low-maintenance kind of a project.

However, in the 20-min discussion that followed, the students and she developed a more expansive working understanding of sustainability. In addition to sustainability involving the ability to be maintained easily—the ideas Mrs. L introduced, the class's view also included additional criteria: Re-usable materials, practical sizes, moveable, flexible, and accessible to all.

Mrs. L used many pedagogical moves to support the co-production of Discourses. She used long pauses and open ended prompts such as "What else" and "what's something you're thinking?" to thoughtfully solicit for student ideas. She used follow-up questions and statements such as "talk to us about that," "why do you think that" and "tell us more" to encourage her students to explain their thinking. She also revoiced her students' ideas while she also wrote them on a shared large newsprint sticky note. She did this slowly and with long pauses, creating spaces for students to jump in with additions, corrections, and other contributions. These pedagogical decisions were instrumental in how she engaged in co-production of new Discourses with her students. Her pauses, revoicing, wait-time were pedagogical moves that acted to solidify Discourse threads. Mrs. L also continually reminded her students that she was a learner, too.

Consider the following exchange that began with Layla stating, "It has to be simple enough for everyone" in response to Mrs. L's question "what do projects need to be to be sustainable?" Mrs. L, who had been writing the students' ideas on newsprint, paused then asked, "Okay. How can we put that in words as far as how technical it should be?" Another student, Mary, jumped in and said, "simple to use." Mrs. L repeated the idea saying "OK. It should be simple." She then looked around the class, paused and asked, "Can we add to that?"

Several students voiced agreement to the idea at once calling out "yes!" and similar responses. As Mrs. L started to write "simple to use," another student, Kai and Mary, called out a clarifications:

> Kai: *The instructions* should be simple—
> Mary:—So other people can use it.

Again, Mrs. L started to write these new ideas on the newsprint while she revoiced the students ideas, "Instructions should be simple enough so other people can use it." As was the pattern in this conversation, several students called out new clarifications as she was writing, "It has to help people" and "Others have to be able to figure it out." Mrs. L responded and wrote more, "Okay. Others can figure out and use."

In this example, when Layla initially mentioned "simple to use," Mrs. L, by asking how the students wanted to put this into technical language, helped the students to produce new and more specific criteria for sustainability around simplicity of use and instructions, and helpful to others. The students, in a later class meeting, referred to these criteria tied to "accessible for all."

In this next segment, from the same conversation, we show how when the students seemed stuck in generating further ideas, Mrs. L patiently waited, wondered out loud about how the students' ideas might matter, and reminded her students it was okay to be struggling for ideas because "this was hard." Mrs. L used extended pauses several times in this conversation, each time using encouraging language to probe students to share their ideas.

For example, Mrs. L asked, "Can you think of anything else to add?" after students discussed the idea of recyclable materials. She waited patiently for 19 s before gently but enthusiastically saying, "What else!" before one student, Sage, raised her hand with an idea:

> Mrs. L: Sage?
> Sage: It might be sustainable if you can move it from one place to another.
> Mrs. L: If we can move it from one place to another. Why do you think that's important?
> Sage: Because if you can't move something—if you can't move the project, however that you make it, they just have to stay in one spot.

As Mrs. L wrote "movable" on the list, she restated Sage's idea again, "Is it movable? Does it have that flexibility to go from one place to another?" As Mrs. L was doing so, she asked again to the class, "What are you thinking." Mrs. L asked her students why movability and flexibility were important criteria, especially when thinking about how their projects might serve other students in the school.

She also engaged relationally with her students. Questions like "If we're visiting with our kindergarten buddies, can we take it down and show our kindergarten buddies?" centered why movement and relationships might be important. As we noted in the opening vignette, this focus on moveability became an important dimension to the students' projects as the Bank of Compliments was moved from the classroom to the restorative justice room as the girls identified the salient need for their box there.

During this same conversation Mrs. L also reminded her students that their ideas about sustainability were not prescripted in their curriculum, positioning herself as a learner. She told them that she was not sure, herself, on how their work would develop. When the class began to struggle with the conversation, as evidenced by Anthony's comment when he explained that he "did not have any ideas" for sustainability criteria because he "didn't know what to do for his project," Mrs. L centered Anthony's worry and embraced this tension relationally. She held up Anthony's comment with the same importance as the other ideas about sustainability being shared, when she revoiced his worry then stated caringly, "This is the hard part, you guys. We're coming up with ideas that we don't even know we're doing yet!" This element of not-knowing became particularly salient when she called on Anthony, who indicated he was reluctant to share ideas because he was not sure what his "project should be like." She reminded Anthony that "we're working through this together", that there is "no right or wrong" in defining problems that matter to our community.

This episode is not just an example of students and teacher co-producing an initial shared definition of sustainability, although this is important from a science learning standpoint. Rather, what is being co-produced as a part of this Discourse of sustainability is a *set of undergirding values* that shape the practices of engineering for sustainable communities meant to facilitate the changes they sought to make through their work. Mrs. L created spaces for students to adapt and expand her initial definition of sustainability with ideas she had not previously considered, but which then became integral to their design work.

This conversation also yielded both discursive and physical statements of this emergent Discourse thread, essentially *serving as policy for the engineering designs they would collaboratively create*. Mrs. L wrote their ideas down and hung them on the wall, which became an important space where she and students would periodically refer back to throughout the unit. Further, as we will illustrate, these sustainability criteria became central in project designs, and shifted group project outcomes beyond Mrs. L's original plans. This reflects the ideal that co-production supports justice in how it shifts the relationalities among teacher and students because students have important contributions to make to both policy and practice.

4.1.2 | Expanding discourses of whose ideas matter in science

Mrs. L created new and different discursive and physical spaces for many different voices and perspectives to matter in the students' engineering work, co-producing new Discourse threads which challenged whose ideas typically matter in a science classroom, how and why. This occurred, for example, in how Mrs. L created spaces for new dialogues between fifth and sixth

graders around sustainability issues and concerns as the sixth graders sought to survey the fifth graders on their experiences. This also occurred in how she positioned her sixth graders as engineering experts who could help the fifth graders to fully engage in the questions and concerns of sixth grade science.

The processes of co-production of this Discourse thread required pedagogical moves that positioned her students as powerful knowers and doers in science, and whose relationships in community matter in their efforts to work for justice together. For example, at the very end of the class discussion on sustainability discussed above, Mrs. L encouraged her students to read the survey questions carefully to each other and to explain what the questions meant "because tomorrow when we go into Ms. M's class, you are going to be explaining this to Ms. M's students. "Cause they're gonna be reading this, like, 'Oh, what are we talking about, sustainable? I don't know what that means.' Your job is going to be, you are the explainer." This supported students in preparing to bring their expertise to a new space and make it accessible to the fifth graders so they also could support Mrs. L's class in engineering for sustainable communities.

The next day, Mrs. L and her students physically moved to the fifth grade classroom next door. They brought tablets, QR codes for the surveys, and a poster of the Engineering for Sustainable Communities principles. After the sixth graders took seats next to their fifth grade buddies, Mrs. L introduced their purpose for being together: "When you do sustainable community education, you get ideas from your community and you guys are in our community. You are our next door neighbors. We are coming to you today and asking you for your ideas."

With this pedagogical move, Mrs. L emphasized the need for incorporating community members' expertise into the engineering design process. Additionally, as she said, "you guys are in our community. You are our next door neighbors. We are coming to you today and we are asking for your ideas", Mrs. L recognized and valued the fifth graders as valuable members of her class' community with important insights to share.

She then explained, "We are having you take a survey. It is very short, asking you some questions about some concerns that come up here at school and with our project, our final project, is going to be called sustainable." To elaborate on what sustainable meant, she emphasized the students' ideas from the previous day: The projects would re-use materials, not cost much money, and be accessible. She also emphasized that to be sustainable the designs would be used not just when the sixth graders finished them, but also in the future:

> We are trying to design stuff that is not just going to work when my kids get done building this, but hopefully it will be here next year when you come to my room or you come to Mrs. W's room. Whatever we design and make will hopefully be there for next year for you guys to see, and that is what we are talking about for designing for the future.

By emphasizing her hope—"but hopefully it will be here next year when you come to my room"—she stressed the importance of the designs working for a long time as well as the importance of the fifth grade community members being able to use the engineering designs in the future.

We observed teachers across classrooms in our partnership support survey administration to younger classes multiple times, and in various ways. Most often students paired up and quickly gave the surveys to their younger schoolmates after a very brief explanation of the survey. Mrs. L took a different approach. First, she prepared the sixth graders to be experts on the surveys by having them practice explaining the questions the previous day. Then, she ensured the fifth

graders had the necessary background knowledge to have an in-depth conversation based on common understanding with their sixth grade buddies. She positioned her sixth grade students to share their expertise about the different materials that would be used in the design challenge.

For example, Mrs. L prepared many students from her class, not all of whom were viewed as "the top students," to explain aspects of their engineering design challenge to the fifth graders. Adam described how a handcrank provided power. Sage shared how a solar panel provided power. Demarcus explained to the fifth graders how LED lights worked as part of an energy system by demonstrating his electric art card. After each student shared, Mrs. L supported the fifth grade class in analyzing the constraints and benefits of the different energy sources. Throughout this process, Mrs. L positioned the sixth graders as experts as she encouraged them to share their experiences learning about energy sources and systems. Additionally, she treated the fifth graders as capable of understanding sixth grade integrated science by taking the time to not just show them the materials for the engineering design, but also working to ensure that they understood how the materials worked. In so doing, Mrs. L created a space where the fifth graders feedback and ideas could be bolstered to support more coherent dialogue with sixth grader efforts.

As the sixth graders gave the surveys to their fifth grade buddies, many could be observed having conversations with their buddies where they shared experiences and feelings beyond the actual survey questions. For example, as written in the classroom teacher intern's reflection notes, "when Soldier was asked a question, he responded with "I thought that too the first time I took this survey, but then..." and that this led the students to an animated conversation where they talked about ideas and where Soldier also acknowledged "his (fifth grade) student's feelings" about their sustainability struggles. She wrote, "I saw this happen across the board." This is important because it is not just that the fifth graders were invited to participate, but this widening of who participates happened in ways that authentically valued their contributions.

Sage, one of the sixth graders, in an interview shared a perspective common to many of the students, that having the opportunity to do the surveys with the fifth graders helped her to see perspectives different from her own and her sixth grade peers:

> I feel like, at first, the survey and things like that, having other people do it, instead of having just our class to do it, like it gave us more of a variety of what to think about on other people's perspective. I feel like doing the survey gave us more than what we normally get. Normally, we just do a survey in the classroom and we don't go to another classroom. Having the teachers, adults and other students doing the survey helped the group think about what kind of projects we wanted to do related to the topics that we got.

Enacting the survey was an example of co-production in both how new Discourse threads advanced project work, and in how Mrs. L and her students further disrupted and shifted student-teacher and student–student power/knowledge relationalities. Through Mrs. L's pedagogical moves, the students administering the survey became a collective act to identify and name community issues important to fifth and sixth graders. The dialogue on personal experience that students had with each other in small groups became just as important as the survey itself. This was evident in how Mrs. L's students discussed the survey questions and answers themselves as well as when they were interacting with the younger students as well as staff members. Not only in reading the final survey results, but also the process of enacting the survey impacted students. The concerns identified in the dialogues and surveys became

foundational to student project work. Similar to how the sustainability criteria became visible and concrete through the shared criteria poster the class generated, as students represented their survey results in tables and graphs that became the evidentiary basis for their designs, the fifth and sixth grade students more expansive expertise on classroom sustainability concerns, too, became visible and concrete.

4.1.3 | Expanding discourses of empathy

Students spent several weeks sketching up and building their engineering designs to respond to the sustainability challenges identified in the community surveys and dialogues. In this third episode, we look at how Mrs. L leveraged upon insights gleaned from one project group's dialogues about caring for each other's feelings. This particular group, the Mood Board group, identified the problem of overall classroom happiness as an important issue that arose in the surveys. Group members were concerned that many students in the class were feeling sad, angry, and frustrated due to being bullied, having friend difficulties, being tired, and even getting in trouble. As Layla pointed out, she is sometimes sleepy in class because she stays up late to greet her mom coming home from her night shift. Her sleepiness can cause her to get in trouble and feel cranky. The group decided to design a "mood board" as a way for students to express their feelings. As group members explained:

> The problem we investigated was overall classroom happiness. We wanted to find a way for students to express their feelings. This is an important problem to address because kids can't normally express their feelings when they want to. We created an invention to help solve this problem. Students can put their hand in the box and pick a mood that fits how they're feeling. Then they put it on the board. If students want to light up the board, all they have to do is turn the hand crank.

The students noted that people could use the light-up board to draw attention to their posted feelings. They stated that as they iterated their project they had to conduct two tests to make sure this worked: "We conducted two different tests on our invention. First, we tested our lights to see if it worked. Another test we did is we tested if our moods fit everyone."

During the last day of project sketch-ups, where groups sketched out their design with attention to both technical and social specifications, Mrs. L leveraged upon this group project to host a whole class discussion with the students about empathy. She asked her class to consider why and how they should treat people with respect and kindness, in response to ongoing behavioral and bullying issues in the school. After this discussion, Mrs. L read a book to her students about empathy. It explained what empathy was, how to make people feel better, and how to be understanding and helpful.

The students in the Mood Board group responded to this conversation, explaining that their Mood Board would help their class practice empathy. They explained that if a student sees someone put up that they are feeling angry or sad, then "you can practice empathy and try to make them feel better in some way or show you understand" because their project helps call attention to people's moods. The group then explained that they modified how their board was to be used because they "wanted everyone in their class to put how they are feeling up on the board at the beginning of the day, and change it if they want to as the day goes on" (fieldnotes, 3/2). For Mood Board group member, Sage, this project was important because, as she stated:

> When in the classroom or in the school, students normally don't have a way to express their feelings and show how they feel. Normally you can only mainly talk to someone or use your body language. Some people don't feel comfortable doing that. When someone's using the Mood Board, it makes it easier for them to express their feelings.

Also, as Sage further noted that being able to think about and take action on supporting students in practicing empathy was different than how science class typically is:

> Throughout the day, when you're just learning, you don't really think about how you're changing or what you're doing. You're just learning and you don't think about what you're about to do and you don't think about a way to problems that you think should be solved in a solution, because you're focused on learning.

In this episode, Mrs. L leveraged upon the emerging Discourse thread of whose ideas matter to engage her students in conversation on empathy. This is a powerful form of co-production as the Mood Board group and Mrs. L, together, disrupted traditional structures that constrain participation in science class when they re-mediated what is legitimate Discourse in a science classroom, and how people's feelings matter in the process. As Mrs. L introduced the idea of empathy into her classroom Discourse, the students in the Mood Board group took up the idea to explain the importance of their project. They expressed the difficulty many of them have in articulating feelings in school because school is just for learning; but that this project, allowed them to make central the political considerations of being welcomed and learning to welcome all, with all of their complex feelings and experiences. This empathy Discourse is a very different form of expertise in science classrooms.

4.2 | Layering and solidifying discourse threads across the unit

In this next section, we describe how Mrs. L supported her students in leveraging upon the Discourses threads of sustainability, whose ideas matter, and empathy throughout the engineering design challenge. We also show how as she and her students leveraged upon these Discourses, they expanded and strengthened them in conjunction with one another. Table 2 below shows how these Discourses expanded and solidified in relation to each other as the design challenged progressed.

For example, Mrs. L sought many opportunities to build upon whose ideas matter, and how this shaped students' project work. When students began to sketch-up their design ideas, Mrs. L emphasized how both the technical *and* social dimensions of the engineering designs needed to be accounted for in the sketch-ups. She asked students, "So your sketch-up needs the technical aspects. What do we mean by technical?", and "What do we mean by the social aspect." After each question, students shared responses including, "energy," "where the copper tape and the lightbulbs go" for the technical aspects and "Like can other people use it?" and "how does it help people" as the social aspects. By supporting students in further understanding both the technical and social dimensions of engineering designs, she was not privileging technical expertise over other important epistemological dimensions of engineering work.

Mrs. L also supported the class in connecting their design solution to the problems they defined through survey analysis. This was evident when she introduced the lesson's objective,

TABLE 2 Layering and solidifying discourse threads

	Episode	Co-production processes	Expanding discourses
←How co-production processes expanded discourses over ←time	Sustainable classrooms	Created dialogic spaces for students to share ideas through (a) talk moves; and (b) post-it notes	Expanding discourse sustainability discourse to include student generated criteria
	Surveys	Created dialogic spaces between fifth and sixth graders—preparing sixth graders to be caring teaching and fifth graders to engage in sixth grade material	Expanding whose voices matter
	Sketching Up designs	Creating dialogic spaces for students to incorporate technical and social dimensions of design Asking students to provide evidence based explanations (e.g., survey data) in support of why their problem mattered.	Expanding whose voices matter & sustainability: Encouraging students to imagine and sketch their design ideas with survey feedback in mind
	Planning to Build	Creating dialogic space to brainstorm re-usable, accessible, and affordable materials in their school for project use.	Expanding whose voices matter & sustainability: Expanding ideas on what useable classroom materials might be (connecting to co-produced ideas on sustainability)
	Discussion of empathy	Classroom conversation linking a broader school concern with project work, and the theme of empathy	Expanding discourses of empathy
	Interviewing a community member	Creating dialogic spaces for community members and students to talk about their projects.	Expanding whose voices matter: bringing in community members to contribute to student projects
	Project feedback	Creating dialogic spaces for community members and students to talk about their projects.	Expanding whose voices matter and empathy:

"So today, our goal is to create an initial sketch-up of the design solution to the problem your group decided to address." She also supported students in thinking about the problems they defined as an important starting point for the solution they wanted to design when she said:

> We're going to address the problem of what. What's your problem? You're filling that in and you are coming up with reasons why. Why is this a serious enough problem that you are spending your time effort and energy devising a solution? Here's how we want to solve it. Write down how you want to solve it.

Mrs. L scaffolded students opportunities to connect the problem they cared about to their future engineering design solution.

Similarly, when students completed their sketch-ups, Mrs. L arranged for students to share their project ideas with community members (e.g., parents, community STEM professionals, and school staff), further widening whose perspectives matter, to solicit feedback on their designs. Mrs. L worked with students to both be prepared to enact effective interviews and connect the importance of the interviews for the engineering design process. The following class dialogue shows how Mrs. L supported her class in making sense of the purpose of the interviews:

> Mrs. L: We will be getting feedback to make our projects better. That's the design cycle.
> Have we figured out what problems we wanna solve?
> Students: Yes
> Mrs. L: Did we start deciding a solution to that problem?
> Students: Yes
> Mrs. L: That's what we were doing last we worked, we were deciding solutions. We were coming up with the project. Now we are gonna come back to the idea of community perspective? We are gonna ask them for feedback.

In this moment, Mrs. L connected why they were interviewing community members to the process of the engineering for sustainable communities engineering design cycle. By emphasizing "Now we are gonna come back to the idea of the community perspective" and teaching the students how to conduct interviews, she was supporting students in valuing and incorporating community members ideas in the engineering design process.

Mrs. L also supported students in recognizing their own active contribution to this dialogic exchange of ideas. She told the students, "You are gonna think about questions to ask them. 'If you were a sixth grader, do you think the lights flashing in the classroom would be a positive way to get our teacher's attention?' We are gonna propose the questions to them as if they were to be using what you're engineering." By sharing that students were going to define the questions they were going to ask, she was supporting student in having active roles in co-producing engineering designs that mattered both to them and their community.

Mrs. L also expanded and solidified Discourses in conjunction with one another. In another example, during the sketch-up process, Mrs. L hosted a conversation on the materials they may need. In this conversation she draws attention to dimensions of sustainability which emerged earlier in the unit (Re-usable materials, practical sizes, moveable and flexible, and accessible to all) while also encouraging students to not limit their design work to the materials they saw in the moment, expanding whose ideas matter. She told the class:

> Do you think you might come up with some things you will need as you're designing? Do you think as you're designing, you're like "Oh shoot I need rubber bands? Oh shoot we could do this really well if I had like a little piece of wood?" Do you

> think more ideas are going to come up? I would guess so... And I'm sure that our list is going to expand, alright.

Mrs. L provided an opportunity for their designs' materials to be flexible, and to re-use materials found in the classroom and school. In the following exchange, we further see her encouraging students to come up with as many materials ideas as they can.

> Mrs. L: I'm going to go ahead and set out the materials that we have available in the back. Come on back, take a look at what we got. Alrighty?... Now, we've got the copper tape, we've got the lights, we've got all the goodies in this box that I will put out so you can look at. What else do you think we might need?
> Sage: Me? Cardboard
> Mrs. L: Okay you. There you go. We might need cardboard, and cardboard we can get. We have tons of cardboard by the cafeteria. What else might we need?
> Queen: Tape
> Mrs. L: We might need tape. What else? What else might we need?
> Kai: Umm so we can like... Umm fluffballs
> Mrs. L: Like the fluffballs we have in the box? Okay we got those available.
> Nate: Construction paper
> Mrs. L: We might need construction paper. What else?

This exchange, which continued on for several minutes more, further laminated the importance of the co-produced view of sustainability and whose ideas matter. Throughout this conversation, they brainstormed possible sources of those additionally needed materials like the cardboard from the cafeteria, which was a way to reduce waste. These materials were present in the students' sketch-ups and their final prototypes.

4.3 | Engineering design artifacts as embodied discourse toward social-spatial justice

In this section, we show how as student groups drew upon the Discourses of sustainability, whose ideas matter, and empathy, in their design work, these Discourse threads became embodied materially and relationally in tangible forms in classroom life. The processes of co-production of new Discourse threads supported justice in socially *and* spatially in how new alliances among Mrs. L and her students took shape, and allowed for collective engagement of students' political struggles against the oppressive practices of schooling as a part of science learning.

Let us return to the Bank of Compliments. Recall that the three girls created their Bank because they wanted to make school a happier and better place—an issue that emerged in their class' investigation into the issues that mattered to students and staff at their school. The youth created this engineering design by drawing on their own experiences as being bullied/bullying others (e.g., "so I knew something like this would work because I know how it feels to bully and be bullied."), drawing upon insights from their peers and teachers as they interviewed and surveyed them about being bullied, and seeking feedback on ideas they had for addressing this problem using engineering design. Mrs. L invited community experts, including parents and grandparents, community members and university students into their classroom, literally

physically re-organizing who belonged in engineering, to give them feedback. These feedback opportunities played an integral role in supporting the students in making their design more desirable and durable. They were able to create a four light parallel circuit powered by a hand crank generator embedded within a sturdy box. Through their collaboration with each other and others, they optimized their design to ensure that it was durable and easy to use. Throughout this process, they shared many laughs and made sure everyone had an opportunity to try every aspect of their design work. As they worked to stop bullying at a larger classroom level, the girls built stronger and more positive relationships with each other.

Their finished Bank of Compliments materially represented a disruption of oppressive practices of schooling disproportionately impacted youth of color, including playground bullying (Hicks, Jennings, Jennings, Berry, & Green, 2018), STEM classroom marginalization (Gholson & Martin, 2014) and invisibility (Haynes, Stewart, & Allen, 2016). The three girls in the group were not always recognized as the most engaged students in their classroom. While in their classroom, we have seen all three girls, but especially Shunita and Mary, the girls of Color in the group, being corrected by the teacher for not being engaged. They would get in trouble for talking out-of-turn during classroom discussions or moving from their seats to talk to other students. However, when the girls were working together on their engineering design, they were focused, and worked independently. Mary and Analeigh both explained that in other subjects they often would fall asleep because they were bored. They found the engineering challenge much more motivating because it was not just answering their teacher's questions.

Mary and Analeigh explained in an interview that their experience with innovating the Bank of Compliments was different than other science units and other subjects because of how they were able to *use* the knowledge from the sustainable engineering unit to actually "make things better" and "help people" (Discourses of empathy). The girls explained that they "actually got to figure out how to make something work" instead of being told science facts and having to believe that they were true. As they stated in their interview, in reading and other science units, they felt the teacher would ask questions she knew answers to and then have students answer them. However, Mrs. L supported the girls in combining their community concerns (Discourses of whose knowledge matters) with engineering through the challenge of making their community more sustainable (Discourses of defining sustainability). Mary explained,

> it was not something that was given to you like something that we have never thought about, but in like this subject we have kind of thought about things that could make the school better. This is like something we have never experienced before this.

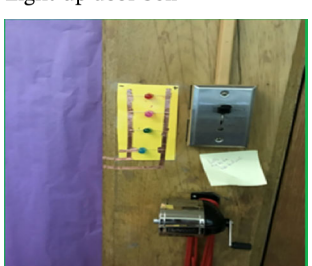
Analeigh agreed by saying, "It was fun, actually fun to think about what we were going to do." The girls were motivated to be able to use their community expertise and find solutions to things that mattered to them and their community. When the girls wished to move the project to the restorative justice room, Mrs. L further encouraged them to do so and gave them the help, time and the space during STEM class that they needed to negotiate this move. This shift in where the project was to be used is important because it shows how the alliance the girls formed with their teacher to promote positive social relationships expanded from the space of their classroom to the space of the restorative justice room. The presence of the Bank in these spaces introduced new social practices of how people might support each other's feeling, and thus oriented toward justice.

TABLE 3 Social-spatial solutions embodying class Community's discourses that emerged through co-production

		Explained in student groups' words		
Projects	**Student engineers**	**The problem(s) addressed**	**Discourse about why the issue matters to the school community**	**Embodied solution**
Bank of Compliments 	Mary Analeigh Shunita	"The problem we investigated is that school needs to be more fun."	"This is an important problem to address because people need to feel good at school."	"Our invention solves the problem we identified by making our peers feel good with compliments. Students can reach into the top of the box and get a compliment. They light up the box if they like the compliment they have. If they do not like the compliment, they can grab another compliment, and if they like that one, they can light up the box."
Mood Board 	Sage Layla Kai Soldier	"The problem we investigated was overall classroom happiness. We wanted to find a way for students to express their feelings."	"This is an important problem to address because kids cannot normally express their feelings when they want to."	"We created an invention to help solve this problem. Students can put their hand in the box and pick a mood that fits how they are feeling. Then they put it on the board. If students want to light up the board, all they have to do is turn the hand crank."
Shining Star 	Queen John Bob Rick	"The problem we investigated was how to recognize people's accomplishments."	"This is an important problem to address because students feel they did work for nothing."	"Our invention solves the problem by having students' names are on the board so when the students use the hand crank to light up the star, they feel good about their accomplishment. Our invention will help our classroom because the students will feel happy because they get to celebrate their

(Continues)

TABLE 3 (Continued)

Projects	Student engineers	Explained in student groups' words		
		The problem(s) addressed	**Discourse about why the issue matters to the school community**	**Embodied solution**
				accomplishments. Our invention is sustainable because we laminated our paper and we are using renewable energy."
Emoji Board 	Xavier Lad Anthony	"We believe there is not enough recognition of accomplishments in our classroom."	"This is important because it helps people get more interested in things we do in class."	"Our invention solves the problem we identified by making people happier when they see the emojis. Our invention will help our classroom by making people feel better. Our invention is sustainable because it will not break very easily."
Light-up door bell 	Nate Star Kiesha	"The problem we investigated is how students get distracted when someone knocks on the door. We created our invention so people stop knocking and interrupting class."		"Our light-up doorbell solves the problem we identified because visitors can crank the hand crank, and the lights by the door inside the classroom will light up."

At the end of the design unit, Mary, who had told us that she rated herself a "zero" on a scale of 1–7 in science (with 7 being the best), wrote the following about her work on the Bank of Compliments, "I am smart and confident." Her two groupmates shared similar sentiments: Analeigh stated, "I take the hard way out." Shunita stated, "I do my best no matter what."

These quotes and their engineering design success highlight how the girls saw themselves as they worked to make their school community a better place. This is particularly telling given how Mary at the beginning of the unit described herself as "a bum" while describing her friend as a "science and math genius." Throughout this engineering unit, the students with support from their teacher, actively drew upon and further developed their science and community expertise to solve a problem that affected them for years. This re-positioned them as experts because of their knowledge of the issues they were addressing, the use of new forms of science knowledge, and the ability to work together to solve a problem that adults could not solve. The youth efforts highlight how they had unique contributions to make that adults in the school could not. This expansive outcome of engineering—addressing social community issues beyond the science classroom space—was important to the girls. For them, the Bank of Compliments was a complemental social zone for students who were not recognized in the restorative program.

The Bank of Compliment group's outcomes aligned with the broader class community's embodiment of the Discourses supporting justice through their engineering design work. As projects were built to support classroom happiness (Mood Board), prevent bullying and promote positivity (Bank of Compliments), recognize each other's wide range of accomplishments toward helping "people feel better" (Emoji Board & Shining Star), and preventing interruptions (Light-Up doorbell), the physical presence and use of these projects re-oriented social-spatial interactions (see Table 3). We view this as a reorganizing of traditional school spaces in ways that disrupt injustice and orient toward new and just social-spatial futures as a part of science learning. The projects, as manifestations of these Discourses, transformed how bodies and lives were perceived through "how the past and present advocate for what the future may look like, or what people should do to shape it" (Watkins, 2015, p. 510) through the social-material practices enacted therein. Across the projects, the youth pushed for ways of representing and enacting their life in their science class and in schools that called attention to the fraught and oppressive past made manifest in schooling, while simultaneously calling forward Discourses of sustainability, whose voices matter and empathy toward disrupting and countering dominant imaginaries.

5 | DISCUSSION

Mrs. L's pedagogy and her students' engineering experiences highlight how supporting co-production of Discourses may support more justice-oriented STEM learning opportunities. Co-production is a powerful idea to makes sense of how teachers and students might organize for justice in science classrooms through engaging in new Discourses. Co-production is of interest to us because schools have been viewed by those in dominant positions as service providers where students are the client/receiver, and teachers/schools offer public services (Osborne, Radnor, Kinder, & Vidal, 2015). In our case, we were interested in how Discourses and artifactual representations of STEM learning were co-produced toward shifting social relationships within classroom learning.

Co-production disrupts the unidirectional power mediated service model. Built around efforts to re-imagine and enact new ethical and just social futures, our study illustrates how the class' co-production focused on continuous learning and transformation of the regularities of

practice through exploration of the richness and diversity of experiences that participants brought to the learning (Raman, French, & Tulloch, 2017). Mrs. L supported her students in working toward justice in science class by fostering co-production of new Discourses threads, and how these Discourse threads solidified into new a Discourse—engineering for social justice in the community—that was pertinent to sixth grade science. The ways in which this new Discourse were made manifest included the design of real-world engineering artifacts, and the pedagogical tools Mrs. L developed in support of them. Mrs. L's commitment to model the importance of taking time to mull over, wrestle with initial ambiguity, and build on one another's ideas nurtured deeper relational solidarity that flattened the teacher-student traditional hierarchy, positioning students as needed co-learners and co-producers of the processes and goals of their engineering unit. Mrs. L and her students co-produced new Discourse threads (with associated values and ways of knowing) that became solidified over time in their work together and as important in science. These Discourses later became embodied in the students' engineered artifacts and how the students further talked about how they used those artifacts. Such embodiment shifted the social spatiality of science classroom activity, positioning students as rightfully present and powerful experts in STEM.

We illustrated how the co-production of these Discourse threads and their embodiments in student projects, supported the formation of new learning social relationships. Not only did Mrs. L and her students shift their relationships and practices through becoming co-learners, the contributions from the teacher, students, and school community were also necessary and worked together to promote social transformation with and in their classrooms and in collective learning in/through science and engineering. This widening of stakeholders is again dependent on the movability and flexibility of science ideas (critical concerns raised by the students themselves in the sustainability discussion), as well as through the new teaching and learning processes and sanctioned engineering artifacts made possible via the disruption of physical and structural borders, previously left untroubled in the school. Such co-production involved the disruption of normative powered relations which tend to position people and communities with less sanctioned power than service providers (Bell & Pahl, 2018).

We further argue that the co-production of new Discourses, through supporting and solidifying initial new Discourse threads, is an important contribution to the work on teaching science for justice in three ways. First, Mrs. L and her students co-produced new Discourses that drew upon an ever-widening range of actors, from her own class, to other classrooms, to community members. In considering why it is important that co-producing Discourses expanded youths' engagement with others, it is important to recognize how power and control in STEM class is unevenly distributed among participants, with power being centralized in the teacher and in the curriculum (Calabrese Barton & Yang, 2000). While Mrs. L's pedagogical moves to foster co-production of Discourses brought in many new people to classroom talk, it also shifted where and with whom power resided. That a grandparent, with little formal technical or educational training, could have powerful insights on a project design, or that a youth could shift the schools disciplinary practices through an artifact meant to promote empathy, speak to the contentious political processes under constant renegotiation through co-production. This is akin to how co-production involves shifting relationalities between those who deliver public services and citizens who receive and pay for the services. This shift is grounded in the ideal that the public has important contributions to make because of their lived experiences, and that require their involvement for such ideals to be realized in *policy* and *practice* (Albrecht, Barbanente, & Monno, 2019). Co-production practices shifts the ownership of services. Even beyond people contributing ideas to how services may be delivered, co-production involved the co-construction

and enactment of services (Loeffler & Bovaird, 2016). We see this in how the teacher and students drew upon the emergent Discourses as policy for guiding their engineering designs.

Further, as the range of actors involved grew, so did the disruptions of the physical and ideational boundaries between school/science and school/community. This movement of people and ideas across these boundaries supported both Mrs. L and her students in seeing their sustainability concerns in more complex ways, for which multiple forms of expertise were needed. Which physical spaces within the school mattered to science teaching and learning, and in what ways, were reconfigured through co-production (Mitlin, 2008). Normalized structural boundaries (e.g., sixth graders separated from fifth graders, restorative justice room processes only under the purview of adult administrators) were questioned, with previously settled relationalities unsettled through co-production. In this sense, co-production not only shifted *who* participated in, but *how* the process of participation expanded attention from the issues to be addressed (a technological approach) to also include political questions about the "normative assumptions underlying existing structures and institutions" (a political approach) (Albrecht et al., 2019, p. 1496).

Second, the introduction, solidification and embodiment of these new Discourses challenged powered relations in the here-and-now and supported justice in science learning—an enduring challenge in science education. This process disrupted unjust patterns of participation in Mrs. L's science classroom, with students like Mary, Analeigh, and Shunita participating at much higher levels. As noted earlier, these youth began to see themselves as science capable and confident, shifting from self-labeled "0s" to "smart" and "confident." Engineering became "fun" and "mattered" such that they were willing to "take the hard way" out. Similar to Morales-Doyle's (2017) point on youth seeing themselves as transformative intellectuals, these shifts in participation and associated views of oneself are fundamental to hoped-for justice-oriented outcomes in science education.

Furthermore, this process also re-oriented and legitimized such patterns of participation (and the forms such participation took) based on new relationalities (e.g., Bang et al., 2012). For Mrs. L, already an admirable teacher in her ability to foster rigorous, empowering learning experiences for all her students, the engineering artifacts created for use in her classroom space (e.g., Mood Board, Emoji Board, Shining Star) heightened justice within the classroom space by re-oriented relationalities: Between teacher and students, and between students themselves who would become more aware and empathetic of one another's socio-emotional well-being. Across school spaces, the provenance of the Bank of Compliments illustrates some ways in which social-spatial justice is consequential not just to rigorous STEM learning but to the quality of middle school life. We see this with the ideation originating from (1) students' experiences in the restorative justice room moving to the science classroom to (2) the creation of the Bank of Compliments taking place amidst the co-production of a new Discourse in the science classroom to (3) the movement of the Bank back to the restorative justice room to seed new relationalities and new social futures in that space to (4) the on-going recognition of the girls' own abilities and expertise in science and engineering among their peers and teachers. These modes of consequentiality are political and rested on political struggle enacted through Mrs. L and her students' co-production in science (Watson, 2014). As noted here, these impacts of co-production built over time and supported consequential science learning. As co-production unfolded across the 6-week unit, moments of social-spatial disruptions/re-orientations built on each other, influencing what, how and why youth engineered authentic projects that mattered to them and their communities. These social-spatial shifts are directly connected to the co-production of new Discourses, as the *new ways of being available to middle school youth in school science*, were recognized and legitimized across new social-spatial boundaries.

Third, the co-production of Discourses led to a new kind of place-making in middle school STEM class in ways that made public and shared the worries and oppressions that students experienced individually. This collective focus made initially visible in the new Discourse threads, and then acted upon through the physical artifacts youth engineered and the social processes such projected introduced to classrooms, facilitated a shared effort to reimagine what a happy, health, and just STEM classroom space could be. For example, when Sage, Layla and their group members created the Mood Board, they created a way for students to engage in sharing and coping with their different emotions within their classroom, during their class time even if those emotions were triggered beyond that time and space. Learning engineering was just as much as about "social empathy and care as essential aspects of engineering education and practice" as it was about the technical dimensions (Gunkel & Tolbert, 2018, p. 93).

In short, co-production made space for and required new ways of interacting with the broader community as students developed and used their science knowledge with community expertise in ways that mattered. Additionally, co-production in science classrooms allowed for imagining and reaching toward social-spatial relations not previously experienced. It shifted the ways that teachers have been positioned as the experts to co-definers and collaborators with students to reach more expansive, justice-oriented learning outcomes.

6 | CONCLUSION

We have shown how a sixth grade science teacher and her students engaged in processes of co-production to disrupt and transform inequities in science learning. Mrs. L and her students recruited a wider range of science stakeholders and innovated engineering artifacts that actively foster new social futures that promote social-spatial justice. These acts of co-production were political, and, in this case, steered with the steady hand of an experienced teacher. The impacts of their collective co-production were not trivial, addressing both rigorous epistemic engagement of students previously disengaged while centering issues of justice in middle school life. As a way to identify and ameliorate local school-related injustices, co-production in community may be a beneficial endeavor for teachers and students to undertake in science class.

ACKNOWLEDGMENTS

This study was supported by the National Science Foundation under Grant 1502755.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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How to cite this article: Calabrese Barton A, Schenkel K, Tan E. Collaboratively engineering for justice in sixth grade STEM. *J Res Sci Teach*. 2021;58:1010–1040. https://doi.org/10.1002/tea.21691