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Keywords: engineering culture | justice | middle school girls | rightful presence | sustainability

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"We actually made something and solved a problem": Exploring relationships between middle school engineering culture and girls' engineering experiences

Aerin W. Benavides[1] | **Edna Tan**[1] | **Angela Calabrese Barton**[2]

[1]Department of Teacher Education and Higher Education, The University of North Carolina at Greensboro, Greensboro, North Carolina, USA

[2]Department of Educational Studies, University of Michigan, Ann Arbor, Michigan, USA

Correspondence
Aerin W. Benavides, Department of Teacher Education and Higher Education, School of Education, The University of North Carolina at Greensboro, 1300 Spring Garden St, P.O. Box 26710, Greensboro, NC 26170, USA.
Email: awbenavi@uncg.edu

Abstract

As historically construed, both engineering culture and school science culture marginalize girls. With the focus on engineering in the Next Generation Science Standards (NGSS), engineering education researchers have called for a more targeted investigation of how girls at the K-12 level engage in engineering. This study investigates, through critical participatory ethnography, how 6th grade girls engaged in an Engineering for Sustainable Communities unit (EfSC) guided by conceptual frameworks centered on Cultural Ways of Learning and Rightful Presence. Three in-depth cases are presented that explore the kinds of engineering problem spaces girls chose to address through iterative design of functional prototypes. Findings reveal, first, how anchoring engineering in girls' embodied experiences supported new forms of participation, new roles for embodied experiences and new making present practices, thereby solidifying a more equitable culture. Second, as the girls moved and hybridized embodied community/STEM ideas and resources, they organized and put into action (through decisions made while "doing" engineering) their values, ideals and desires and that of their communities.

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KEYWORDS

engineering culture, justice, middle school girls, rightful presence, sustainability

1 | INTRODUCTION

We solved the problem because a lot of girls in the bathroom didn't have privacy when they used the bathroom… with the Pride Slide people can't peek over anymore. We feel successful, we [got to] experience how engineering feels like, working together. (Zari, Mandy and Deira—6th-grade girls who engineered a bathroom cubicle door extender with a decorative, solar-powered slogan "GIRL POWER").

> "[T]here is a need to find a new engineering image, one in which professional values, ethics and sensitivity to the effects of engineering outcomes in the world at large are emphasized," (Bastalich et al., 2007; p. 397).

Systemic barriers to meaningful opportunities to learn and become in engineering for girls and women, persist (Wilkins-Yel et al., 2019). While studies have documented the problem space from the standpoint of individual girls – for example, girls exhibit a loss of interest or declining attitudes towards engineering (Cooper & Heaverlo, 2013) – the problem is systemic in nature. Racial and gender stereotypes, limited access to meaningful pedagogical and curricular precollege experiences in engineering, and identity dissonance all limit girls' opportunities for meaningful engineering education (Buontempo et al., 2017; Cheryan et al., 2015). As historically construed, engineering culture at the tertiary education levels and in the professions is grounded in narrow White, masculine norms (e.g., Seron et al., 2018) with women perpetually consigned to the status of "outsider" regardless of how they perform (Bastalich et al., 2007).

Engineering education researchers have called for a more targeted investigation of how girls at the K-12 level engage in engineering (e.g., Prieto-Rodriguez et al., 2020), specifically for qualitative studies that could shed insight on how girls might consider how "designing, inventing, or developing things could be rewarding" (Ing et al., 2014; p. 8). Diversifying the composition of the engineering community is key to expanding and diversifying engineering design (Buechley & Perner-Wilson, 2021). While the Next Generation Science Standards (NGSS) has emphasized engineering design as a core component of K-12 science and called for more intentional engineering education at the K-12 level (NGSS Lead States, 2013), there are limited frameworks and approaches for how to teach engineering in ways that recognize, amplify, and leverage what girls bring to engineering learning and how a more expansive engineering culture might be nurtured.

In this manuscript we investigate how 6th grade girls engage in engineering (as a part of middle school integrated science) in an Engineering for Sustainable Communities (EfSC) curricular approach. While the study took place in co-educational classrooms, our focus for this study is on girls. The two related research questions undergirding this study are:

- 1a. What engineering problem spaces do 6th grade middle school girls take up in an Engineering for Sustainable Communities (EfSC) unit?
- 1b. How do these problem spaces shape girls' engineering process and the resultant learning outcomes?
- 2a. What is the nature of the emerging engineering culture fostered in the 6th-grade classrooms as a result?
- 2b. What are the implications of this culture on girls' learning and doing engineering?

We analyzed data within and across ethnographic case studies of three, all-girl groups, paying attention to how, why and for whom girls engineer (in defining the problem space), what they do during the iterative engineering process, and their intended outcomes for their innovations' prototypes. We conjecture on how girls' engagement seeded a rightful presence for themselves, and others, in middle school engineering. We explore the impact of such on the emerging engineering culture in their middle school science classroom.

2 | SURVEYING THE ENGINEERING EDUCATION LANDSCAPE

2.1 | Women in engineering and engineering culture

When considering gender representation in engineering, engineering education literature at the college level points to the connection between the low number of women students in engineering (National Center for Science & Engineering Statistics, 2017) and the dominant culture of engineering. This culture is grounded in White, patriarchal values, specifically meritocracy and depoliticization. This prevailing culture reflects and reinforces the epistemologies of engineering—who decides what counts as engineering and what engineering values—to be White male-centered and alienating to women (Adams et al., 2011; Cech, 2013, 2014). These epistemologies manifest in practices that reflect recurring tropes of canonical engineering culture. In particular, the tropes “technical thinking, merit and individualism” lead to “a depoliticized culture of engineering [that] also constitutes a degendered space where issues that may be of social concerns to women in science are also devalued and marginalized” (Seron et al., 2018; p. 137). At the college level, women are socialized into such an engineering culture that continues into professional engineering work culture (Cech, 2015). This leads women engineering students and women engineers to “interpret their experiences through the cultural lenses, value preferences, and epistemologies that are historically hegemonic within the profession” (Seron et al., 2018; p. 134).

Such a culture begets at least three justice-related issues. First, even as engineering culture has historically been grounded in White, patriarchal values, it is presented as one that is benign, value-free and objective (Cech & Waidzunas, 2011), where anyone might succeed with sufficient effort (Sharone, 2013). Thus framed, any cause for one's inabilities to advance in engineering is a problem located in that individual, who is simultaneously inured to such unjust positionings through being socialized into such an engineering culture. An insular, individual problem-locating gaze shields the larger engineering culture from scrutiny, and preserves its continued existence.

Second, what get sanctioned as legitimate engineering practices and legitimate engineering problem spaces become contingent on who is the doer and framer of such. If students have license to include community problems and user voices in design thinking curriculum, new student roles and participation in engineering can emerge (Wallisch & Paetzold, 2022). Traditional engineering education teaches students to value “hard” over “soft” technologies, to be technology-focused rather than people-focused, as these are markers of “objectivity” (Cech, 2014; Faulkner, 2009). Women engineering students and women engineers, therefore, learn that to be concerned about issues of marginalization – be it their own positioning in engineering or of the engineering-related issues they may care about—does not align with what engineering is supposed to be about.

Third, these twin pillars–objectivity and techno-centrism—anchor engineering culture work to maintain unequal power dynamics between the “expert engineers” and the “vulnerable communities” they engineer for. They reinforce and reproduce inequitable power dynamics. Such unequal yet normalized power differentials between the "privileged server" and the "underprivileged served" (Henry, 2005) are in need of critique in engineering education (Nieusma & Riley, 2010). When considering K-12 engineering with middle school girls as a part of NGSS integrated science, we see this problem space as dual focused. Engineering education needs to systematically account for the needs of communities in which girls are key members, especially if girls are to be prepared to have a voice in broad socio-engineering concerns that will define their futures. What girls care about and want to explore needs to be considered as an integral part of engineering education.

One way to consider how these challenges intertwine is in how engineering is a people-centric discipline –how engineering is done for people, with people, and as people (Hynes & Swenson, 2013). Hynes and Swenson argue for framing the humanistic side of engineering, as one engineers *with people*. This view calls attention to how engineering education should focus not only on the knowledge and practice of the engineering itself in ways that connect to girls' interests and experiences, but also on the needs of people who will be impacted by design solutions. It should focus on how people can work together across different backgrounds, expertise, and stakes in such work. However, few studies investigate just how these social aspects of engineering by and with people may contribute to disrupting inequities, thus transforming engineering education and engineering culture.

2.2 | K-12 engineering as a part of integrated science

Engineering design is a core component of the Next Generation Science Standards (NGSS) that include "practices and ideas about engineering design considered necessary for literate citizens" (NGSS Lead States, 2013, Appendix I, p. 3). Integrating engineering into K-12 science addresses the need to better prepare students to tackle interdisciplinary problems via engaging in real-world informed learning (NRC, 2012). Another key impetus for raising the visibility of engineering at the K-12 level is the belief that "from a pedagogical perspective, the focus on engineering is inclusive of students who may have traditionally been marginalized in the science classroom or experienced science as not being relevant to their lives or future" (NGSS Lead States, 2013, p. A1.2). This is in line with the main tenet of the Changing the Conversation (National Academy of Engineering, 2008) report which focused on engineering's role in both recruiting and retaining women and underrepresented groups into STEM fields.

While in theory integrating engineering design as a part of K-12 science might bring about the benefits espoused by the NGSS, in practice, schools and teachers are often left to their own devices to figure out how to teach engineering (Hammack & Ivey, 2017). Cunningham and Kelly (2017) found that K-12 engineering, through a more explicit focus on students' everyday interests grounded in project-based learning experiences, might foster more equitable forms of learning. However, others note that research on K-12 engineering has neglected to investigate "social empathy and care as essential aspects of engineering education and practice" (Gunckel & Tolbert, 2018, p. 939) in favor of an overt emphasis on studying the technical aspects.

The assumption of engineering's potential to broaden inclusivity as a part of K-12 integrated science deserves unpacking. As we described, canonical engineering culture is one that actively gate keeps, and keeps at the periphery, students who are not White males. Moreover, the culture of school science (in which engineering is now a part of as outlined in the NGSS) has also been shown to be hostile to girls (Archer et al., 2013; Calabrese Barton et al., 2008, 2012), with girls' interest in science waning from age 11, and continuing a downward trajectory through middle and high school (Stoeger et al., 2013).

Given these gender-specific challenges baked into the cultures of engineering and school science, it is questionable if simply including engineering in K-12 science would draw girls into science and engineering more, without considering the design of a more girl-centered engineering culture at the K-12 level, and what that might entail. Researchers Allen-Ramdial and Campbell (2014) found that the STEM 'pipeline' is dependent upon more than student effort to assure increased diversity in STEM fields, and that success for underrepresented groups (including girls) may require intervention strategies and practices that support and build on students' strengths in other areas that were heretofore not central in school science.

What are the practices, values and symbols of engineering education at the middle school level that are authentic to the concerns and interest of girls? In short, it is "time to stop seeing girls as the problem [in STEM]" (Prieto-Rodriguez et al., 2020, p. 1157) and to explore "engineering endeavors, shaped primarily by men, from the perspectives of marginal and less powerful social groups, including women" (Seron et al., 2018, p. 154). We attempt to do so in this study. We investigate why, how, for whom, with what resources 6th grade girls engage in middle school engineering when their voices and concerns are centered and prioritized.

3 | CONCEPTUAL FRAMEWORK

3.1 | Cultural ways of learning

A Cultural Ways of Learning (Gutiérrez & Rogoff, 2003) theoretical perspective uses a cultural-historical approach (Engeström, 1993) to counter the idea that culture, for the individual learner, fits a stereotype or is static. It centers social interaction and human activity as core to the analysis of learning and development (Engeström & Sannino, 2010). Culture is not static but rather, dynamic and emergent, where learning is "conceived of as a process occurring within ongoing activity" that imbricates with the "histories and valued practices of cultural groups" (Gutiérrez & Rogoff, 2003, p. 20) without essentializing people on the basis of categories or labels. This focus on understanding processes without essentializing characteristics is important. We are not essentializing "girls" into a homogenous group. Neither are we assuming that there is one particular kind of girl-empowering engineering culture. By using a Cultural Ways of Learning theoretical perspective, we seek to "shift from the assumption that regularities in groups are carried by traits of a collection of individuals to a focus on people's histories of engagement in practices of cultural communities" (Gutiérrez & Rogoff, 2003, p. 21).

This view highlights the relational nature of learning. Learning is shaped by the relationality between bodies, ideas, tools, resources, and relationships as "multiple systemically interacting elements" (Engeström, 1999, p. 9) that move across spaces and time. This cultural view of learning in an activity system reveals the process of transformations in collective practices and organizations (Engeström, 2001). This process widens repertoires of practice, what is considered as legitimized expertise and keeps in view where and when learning occurs, potentially shifting the epistemological and ontological underpinnings of STEM (Bang et al., 2013). Therefore, what it means to engage in middle school engineering, for whom, with what resources, in which spaces and to what ends –in essence manifestations in practice of a culture – become key to investigating the processes of learning engineering. This framing is productive for investigating the culture of middle school engineering given that the canonical cultures of engineering and school science have been marginalizing to girls. We seek new insights into the roles of new repertoires of practice, ideas, and communities that a more girl-centered, emergent engineering culture in middle school science might entail.

3.2 | Rightful presence

Given that our focus is to look for how engineering culture in middle school classrooms might shift away from White, male norms to seed new practices and norms that center girls' engineering engagement, we also ground our study in the Rightful Presence framework (Calabrese Barton & Tan, 2020). Rightful Presence calls attention to how focusing on "equity as inclusion" is insufficient in working towards justice in science education. Even if students are provided access and opportunities for high quality science learning in ways that value their cultural knowledge and practice, this does not necessarily challenge the undergirding power relations which frame what it means to know, do, and become in science. Teachers need support and tools for not only noticing and leveraging upon students' cultural knowledge and practice, but also for negotiating new norms for learning with students, in ways that centralize these assets as rich in epistemic potential and integral to expertise in science. This re-negotiation is a fraught process. It must call explicit attention to how the current set of rights to science learning – that is what it means to know, do, be, and become in science – are exclusively grounded in systems of privilege and oppression. This involves a process of perturbing these underpinning hierarchies of White supremacy and patriarchy, which tend to benefit already privileged groups.

Rightful Presence asserts that for students to be legitimately welcomed in a community requires them to be positioned as more than guests. The challenge is in imagining and enacting what a more rightful presence may look like. There are rich ideas in the literature which give texture to what teaching towards rightful presence may look like. For example, a Rightful Presence approach would counter the erasures manifested by exclusive rights, foregrounding an assets-based stance that centers and amplifies youth and community voices (Calabrese Barton, 2003; Morales-Doyle, 2017; Vakil, 2020). It would also foreground the political dimensions of learning, including the agency to leverage disciplinary knowledge and practice in conjunction with one's cultural repertoires towards individual/community empowerment, and social transformation (Bang et al., 2012; Calabrese Barton & Tan, 2009a). Rightful Presence supports students in developing critical awareness of and strategies for navigating the sociohistorical and political dimensions of learning science. Students supported in establishing Rightful Presence in school science would have opportunities to engage in “making-present practices” (Calabrese Barton & Tan, 2019), where student concerns, ways of engagement, and reasons for doing science that were elided before are “made present” and integral to school science.

Establishing a rightful presence for girls who have been historically marginalized in K-12 integrated school science demands movement beyond equity as only an inclusion project. Rightful Presence is where girls are at best, invited and inducted into an established school science culture that traditionally denies them opportunities to have say in the how, why and for whom they might want to engage in school science. This is beyond what is prescribed in standards and content-specific objectives. Such girl-centered approaches would require a willingness to shift existing norms of how K-12 integrated science is usually done. Girls would be given opportunities to draw on their ideas and experiences to shape their school science experiences in ways that matter to them. Working towards Rightful Presence is contingent on shared political struggle involving the teacher (who holds power) who allies with students (who have less power) in reauthoring their rights in the middle school science classroom. What it means to do engineering, including what counts as engineering (what problem spaces are valid), the nature of the engineering process (who, what, where, why, when of engineering) and the hoped-for outcomes of engineering (to what ends, for what and for whom students engineer) would all be an open question.

Taken together, working towards Rightful Presence in K-12 integrated science necessitates new ways of being, doing, and new relationalities between teacher, students, materials, and spaces. These new ways operate by disrupting established norms of the integrated science classroom, in turn shifting the culture of the learning space.

4 | METHODOLOGY

4.1 | Participatory critical ethnography

We engaged in participatory critical ethnography in two 6th grade classrooms at Sage. With critical ethnographic methods, we were able to center power dynamics as integral to impacting middle school engineering. Our focus is on girls' engagement as juxtaposed against canonical engineering and middle school science cultures which have historically alienated girls. Critical ethnography also complements our focus on documenting middle school engineering culture, which necessitates a close interrogation of ethnographic foci including norms, practices, and social interactions between people.

Participatory methodologies were relevant to our commitment to disrupt power dynamics between researchers, teachers, and students. In addition to researchers, we actively participated as teacher assistants in Mr. M. and Ms. S's classrooms, interacting with students such as when they had questions for us and working with individual groups to give feedback to their iterative design during the unit. When students had to leave the classroom for onsite investigations elsewhere in the school, we either accompanied them or remained in the classroom while Mr. M. or Ms. S. went out of the classroom to sites with groups. To delve into the three girls' group work presented here, we conducted ethnographic case study analysis embedded within a participatory critical ethnography. Such an ethnographic approach is necessary as we are interested in the cultural dimensions of learning. Relatedly, even as the data presented here is drawn from 50 researcher contact hours of the EfSC unit, we have a years-long partnership with Sage, 1 year before this study and 2 years subsequent to this study, and we are privy to the norms and practices of the school over time, which complements our ethnographic approach.

4.2 | Context

The 3-week EfSC unit was conducted at Sage Middle School, a public Title 1 school built in 1957, in a metropolitan area of a coastal southeastern state. Sage served a diverse population of students: 43% Black; 38% White; 11% Hispanic; 5% Biracial; 3% Asian; and less than 1% each Native American and Native Hawaiian; 58% came from low-income families; and 21% were students with a range of disabilities.

Sage's school administration was led by a dynamic school principal and the school won the "Most Improved Middle School" award in the district and region, both based upon improved end of year standardized test scores. Sage students' grade level proficiency on test scores in Science (83.2% of students scored proficient at grade level in Science the year of our study) exceeded grade level proficiency in other subjects for the same year (58% in Math, 63% in English/Language Arts/Reading).

Improving end-of-year test scores was part of the cultural context and everyday conversation at Sage, either in daily announcements made by the principal on the loudspeaker system or in what was said among and by teachers and students. There were overt positive displays of school solidarity placed strategically around the school building, such as posters that said, "This school serves ALL students". But, incidences of bullying regularly occurred.

We worked with two 6th-grade science teachers on the same teaching team and focused on case studies in Ms. S.'s and Mr. M.'s classrooms. Ms. S., a White woman, had taught for 7 years, the last 2 years at Sage. She taught 6th grade Science and Math and valued hands-on learning. She had a calm and measured demeanor, was organized in her teaching, and students showed they trusted and admired her. Mr. M., a Black man, had been teaching for 27 years, was well loved and respected, and recognized on schoolwide announcements as an outstanding teacher. Mr. M. taught only science and had an enviable double-sized room equipped as a science lab. Ms. S. had a regular-sized traditional classroom. Before implementing the EfSC unit, neither teacher had taught engineering in middle school before. Both teachers engaged in a 2-day 10-h professional development, and 3 additional hours of monthly professional development exploring the curriculum before classroom implementation. The students in this study included both Black and White girls. All of them were described as "average students" by the teachers in the sense that there were no "top students" or "weak students" as depicted in the grades students were making in 6th grade science. Before the EfSC unit, none of the students had experienced learning engineering in middle school or elementary school.

4.3 | Curriculum

The Engineering for Sustainable Communities (EfSC) curricular unit taught in both classrooms was focused on the importance of community welfare and sustainability, across two design challenges. A chart of Engineering for

Engineering for Sustainable Communities (EfSC) Principles:
Uses community members' ideas in engineering.
Helps the community solve their problems through engineering.
Cares about the environment.
Designs solutions for now and in the future.

FIGURE 1 Engineering for Sustainable Communities (EfSC) principles used as an epistemological tool in the I-Engineering Curriculum.

Sustainable Communities principles (Figure 1) was visible in all participating classrooms, and is a tool meant to generate co-constructed epistemologies in the engineering learning space (Tan et al., 2019). The scope, methods, and what counted as valid in knowledge production in the classroom were guided by these EfSC principles. Thus, the production of scientific and engineering knowledge in the EfSC unit classrooms reflects not only the cultural contexts in which learning occurs, but also challenges traditional normative power dynamics which operate within such contexts (e.g., Calabrese Barton & Tan, 2009a; 2009b; Nasir & Vakil, 2017).

In the first design cycle, students were introduced to the principles undergirding EfSC and relevant NGSS disciplinary core ideas including energy sources and energy transformations (NGSS Lead States, 2013). They designed and made an electric art card incorporating both social and technical specifications in their designs. In the second phase, they surveyed the community to find important issues to address through engineering, used their learned disciplinary core ideas knowledge and skills, and utilized green energy sources in designing and building functional prototypes. The design cycle process for the second phase included feedback from peers and community experts throughout the process.

Core tenets in the EfSC unit included: Social dimensions of engineering (such as identifying issues and ideas for solutions that came from the students' community); technical dimensions of engineering (such as engineering LED light circuitry in their creative solutions' iterative designs); constraining problem spaces and designing solutions through considering trade-offs informed by both social and technical dimensions; choosing solutions that were good for the environment (e.g., using recycled materials); and seeking out sustainable solutions by using 'green', renewable energy sources.

4.4 | Data generation and analysis

4.4.1 | Data generation

Data were generated during the implementation of the engineering unit in Mr. M. and Ms. S.'s classrooms over the course of about 20 instructional hours in each classroom (40 h total of data) of daily 6th grade science lessons. Each lesson lasted 70–75 min. Students in this study also sometimes stayed behind after school or during lunch time to work on their prototypes.

4.4.2 | Fieldnotes

Fieldnotes were recorded, along with video recordings of all classroom sessions. Fieldnotes focused on whole class instructions and experiences of focal groups of students that the researcher worked with during lessons. We looked at what the girls were doing while learning, paying attention to what ideas, tools, and resources they drew upon, and with whom they interacted as part of the iterative engineering process (relationships). We noted for whom their engineering projects were intended, where the prototype is meant to be used, and how.

Focusing on girls' participation, the three groups featured in this study had a set of fieldnotes dispersed across the 24 instructional hours focused on their interactions. Attention was paid to the kinds of ideas taken up and parsed by students in their meaning-making pertaining to (1) which community issues identified through the survey and interviews were compelling, and why; (2) new kinds of texts (issues relevant to classroom science discourse) including their sources (e.g., community data, students' personal experiences, related information they've heard); (3) how students considered social elements dialectically with technical elements in identifying and refining a problem space, then constraining their iterative design prototyping; (4) what kinds of material, spatial, and human resources students drew on and the ways these were leveraged; and (5) how teachers facilitated students' engineering experiences.

4.4.3 | Interviews

At the end of the unit, we conducted "artifact interviews" with all focal groups. Artifacts included the engineering prototypes students created and design sketch ups. Questions focused on students' vision for the artifact, the knowledge, practices, and resources they drew upon to create it, the meaning and value of the artifact to them, and their emerging understandings of what engineering entailed. We also conducted reflection interviews with students describing what was compelling, challenging and novel, about the engineering unit in the ways they learned and engaged in school science. With Mr. M. and Ms. S., we engaged in weekly informal conversations for check-ins on how they thought the unit was progressing and if they felt that any changes needed to be made. At the end of the unit, we conducted formal interviews with both teachers focused on what was challenging and novel in terms of teaching science, ways students participated, and students' learning outcomes as related to the curriculum. Interviews were transcribed for the teachers and for the three groups in this study.

4.4.4 | Video-Audio

Both teachers and researchers wore Go-Pro cameras in a harness or digital audio recorders on lanyards around their necks during each lesson. This allowed for analysis of whole class interactions and small group discussions. Pertinent sections from perusal of audio recordings and video footage were transcribed for more targeted analysis.

4.4.5 | Student work

Copies of student work produced were collected, including daily journal entries, activity sheets, sketch-ups, images of projects in various stages of development, and summative "project postcards" that students created to explain what their projects were about and why they chose specific problem spaces.

4.5 | Data analysis

Data were analyzed in the grounded theory tradition, using a constant comparative approach (Strauss & Corbin, 1998). Drawing from the data sources described above, the first phase included writing detailed narrative cases of each group from a Cultural Ways of Learning perspective (Aerin Benavides wrote two of the narratives, Edna Tan wrote one, all three authors discussed and edited the narratives). We paid attention to power dynamics, such as: what part did the school administration and/or teachers play in allowing for student agency in the design process and how the innovations were implemented. We specifically paid attention to (a) how each group arrived at their problem space, informed by what kinds of information and their sources; (b) the range of resources, material and human, that girls utilized during their iterative design process, including where, how, when, with whom and with what, girls leveraged on to conduct more observations to further refine the problem space; (c) the nature of the functional prototype and how particular features might map onto which insights girls derived from considering social and technical elements. Looking across all three narratives, initial codes included: (1) a survey quote, “community's need to feel safer in school” as integral to the problem spaces; (2) girls' personal embodied experiences related to the problem spaces as integral to both refining the problem space and lending directionality to the iterative design process and; (3) the out-of-classroom locales where problem spaces reside and where the designed prototypes were to work to address these issues.

The axial coding phase involved a more nuanced parsing of what previously invisible aspects of girls' and community members' experiences in school were made visible. This was done by focusing on: particular problem spaces and why, how, and for whom that might matter in engineering; how resources were remixed and how they moved across space (e.g., out of the classroom): and seeking potential relationships between how girls' practices during the unit impacted their learning outcomes in what kinds of ways. Data thus coded for each project were holistically analyzed to build project narratives for all the EfSC project groups in the teachers' classrooms. Three project narratives of all-girl groups were selected for this focal analysis on girls' engagement in middle school engineering.

5 | FINDINGS

In this section we introduce three claims in response to our research questions, the first two supported by data in the form of individual group vignettes. First, related to research questions 1a and b, we show how girls anchored the engineering problem spaces and ensuing activities of the engineering process in their school-based, and embodied experiences. Centering embodied experiences supported new forms of participation, new roles for embodied experiences in middle school engineering and new making present practices, where experiences salient to girls' everyday negotiation of school spaces were made visible, and integral to 6th grade engineering.

In particular, we show how the girls perturbed and made visible inequities in their school community by redefining the technical, objective work of engineering in two ways. First, they leveraged upon their embodied knowledge and practice as interpretive lenses for (a) what community problems technology could help to solve; and (b) identifying critical decision-making points in problem refinement and solution design. Across the cases we show how the girls' embodied knowledge and practice were taken up in ways that highlight their interpretive power, being "intellectually generative” (Rosebery et al., 2016, p. 1572) and lending directionality to the girls' iterative engineering process. The EfSC curriculum allowed for embodied experiences to be recognized by teachers as integral in engineering education; and the girls gave a role to embodied knowledge and practices in their self-directed design process.

These forms of knowing helped the girls move from broadly defined problem spaces such as, in one case to be discussed, “we need more privacy in the bathroom” to specific technical dimensions, specifically the length of doors (too short bathroom doors), how privacy is invaded (girls look over bathroom doors), and differential impact on students. These forms of knowing helped the girls functionally break down the design process into solvable technical components that more precisely responded to social needs. Learning outcomes expanded and deepened to not only include community data as integral to middle school engineering but also in what ways community data might interact and shape iterative engineering design practices.

Second, related to research questions 2a and b, and in line with our Cultural Ways of Learning theoretical framework, as the girls moved and *hybridized* (blended into a composite) community and integrated science ideas and resources, they organized and put into action (through decisions made during the "doing" of engineering) their values, ideals, and desires and that of their communities'. We show below how the actions they took up made visible the nature of their experiences with particular problem spaces in ways that illuminated for teachers and peers the struggles they encounter daily as 6th graders at Sage. This created opportunities for their teachers to ally with the students as their designs re-organized who has authority to solve problems and what kinds of problem spaces are legitimate in middle school engineering. This also created opportunities for teachers to extend their discussions and lessons with youth on the intersections of the problem space itself and the context in which the problem occurs, with how a technical solution might respond to the problem space. This was particularly important, for example, when the girls sought to address problems in spaces that were unfamiliar to the teacher, such as the girls' bathroom – a place where the male teacher had never been in, nor been able to observe the challenges the girls described. These processes of leveraging embodied knowledge and practice as interpretive lenses, and moving/hybridizing embodied community/integrated science knowledge, worked together to create increased opportunities to iterate designs in integrated science-rigorous, meaningful ways.

In what follows, we offer three vignettes that illustrate the first two claims in nuanced ways. Each vignette is organized by first introducing the problem space the girls identified and why. We explore how the girls' embodied experiences anchored their problem space identification and lent particular directionality to their iterative engineering design processes. We then show how the girls moved, hybridized community and integrated science, and reorganized resources as they put into action their and their communities' values, ideals, and desires through their engineering design (i.e., new practices).

5.1 | Vignette 1: Hall stoplight, by Lacey and Tanaiya

Lacey and Tanaiya identified and refined an engineering problem space regarding school safety by designing a stop sign for addressing the crowding and shoving in hallways during classroom transitions. They leveraged upon specific community data and their embodied knowledge/practice. They had embodied knowledge of being jostled by being some of the last students to exit the classroom, using this as an interpretive lense for what community problems technology could solve.

5.1.1 | Vignette 1: Identifying the engineering problem

In this first section we show how Lacey and Tanaiya first analyzed quantitative survey data to determine key patterns in community concerns, which affected the problem they chose to solve. They used the open-ended survey responses to identify specific problems to solve within the patterns they cared about. However, it was how they were supported by their teacher to draw upon their embodied experiences that helped them to refine the problem space they identified into one that they could solve with the technical requirements of their design challenge, their developing STEM knowledge, and with the social nuance that supported real change in their 6th-grade lives.

Lacey and Tanaiya were compelled by their class's EfSC community survey data which showed that 25% of the 165 school community members' top concern was the "need to feel safer at school". While analyzing the data, students pointed to open-ended responses in the survey related to safety concerns, including responses such as "we need everyone to be safe," "us students need to watch our surroundings and be cautious of what is going on", and the "need to make school spaces safer." Mr. M. supported these classroom discussions on how school spaces are not safe. This further opened up opportunities for students to delve deeper into how they have felt unsafe, in which particular school spaces. This supported students in using their embodied experiences as interpretive lenses for making sense of their data.

For example, Lacey brought up the hall doorway issue as a matter for discussion: "Well, Mr. M.'s room is always crowded when we're leaving. And his [homeroom] kids are always staying there [in the doorway], and it's hard for us to get out. And it was really hectic, it just got on your nerves." Lacey pointed out one of the open-ended survey responses directly related to class transition stress, when students were often late, resulting in disciplinary punishments because of these "traffic jams." Here she leveraged her embodied experiences with these traffic jams to offer further contextual detail that provided texture to the boundaries of the problem space she and Tanaiya were beginning to identify for their project. They considered how traffic controllers at school crossings and workers doing road work used signage to control the flow of traffic. Lacey commented, "I was like, "Well, maybe we should make a stop sign to stop those kids so we can get out, and then Mr. M. can just lift it up, and then his kids can come in."

Tanaiya and Lacey's assigned seating was the farthest from the doorway in Mr. M.'s large room. As some of the last ones to exit each day, they explained how they were being shoved when leaving the room after class caught in the "traffic jam" with incoming students. They designed the Hall Stoplight to help the community, as Tanaiya explained, "… it's much better because we don't want kids to shove, and then, you know, cause a whole scene. We just want them to, be safe!".

5.1.2 | Vignette 1: Hybridizing the engineering solution

In this section, we show how hybridization of community concerns and integrated science occurred. Mr. M was unaware of the safety problem in the hallway during class transitions, or how the girls felt about it. As he learned more, he opened up opportunities for further exploration of the problem space, through the dialogs and feedback he facilitated. These spaces supported iterative design with increasingly specific technical dimensions that the girls took up. Mr. M. became a teacher ally and the girls' project ultimately positioned him as a critical user of their engineering solution to this problem space.

When the girls decided to address the issue with the stop sign, Mr. M. reflected that he did not know that there was shoving at the doorway or how this affected the girls. Mr. M. stated that his first reaction to their design was "[T]hat one where they had the stop sign going down, I was like, how are you all going to do that?" As it turned out, Lacey and Tanaiya had in mind a key role for Mr. M. The hallway STOP sign design required that Mr. M. would drop and lift the hall stop sign arm manually (Figure 2) to, as they put it, "slow kids down". Lacey and Tanaiya engineered a prototype that required Mr. M.'s presence and authority as a teacher ally to wield the sign, since students are less likely to run around or jostle a teacher. The need for safe bodily boundaries at the doorway was made visible to their teacher and to the school community, when they addressed this problem space via their engineering prototype.

As the girls sketched up their design (Figure 2), measured, constructed, and tested their backing board stop sign in the hallway (Figure 2), with feedback from Mr. M. and Dr. Benavides along the way, they went through three different iterations of specific parts of the STOP sign design. First, with regard to the LED-light circuitry, the original design on the sketch-up had one LED light on a simple circuit powered by a hand crank, which worked, until the surge in voltage from the hand crank blew out the light bulb. As Tanaiya described it, in order for the circuits to work they "busted" eighteen bulbs before they got the single light to work without blowing it out. They discovered the hard way that they could only turn the hand crank extremely slowly and gently if they did not want to blow out a single LED light bulb.

Next, with regard to the attachment-deployment mechanism of the STOP sign: Lacey and Tanaiya measured the prototype swing arm to make sure it fit in the existing space in the hallway, which they did at the site (Figure 2). While testing how the sign might be put to use, they observed the existence of 0.5 cm diameter holes already drilled

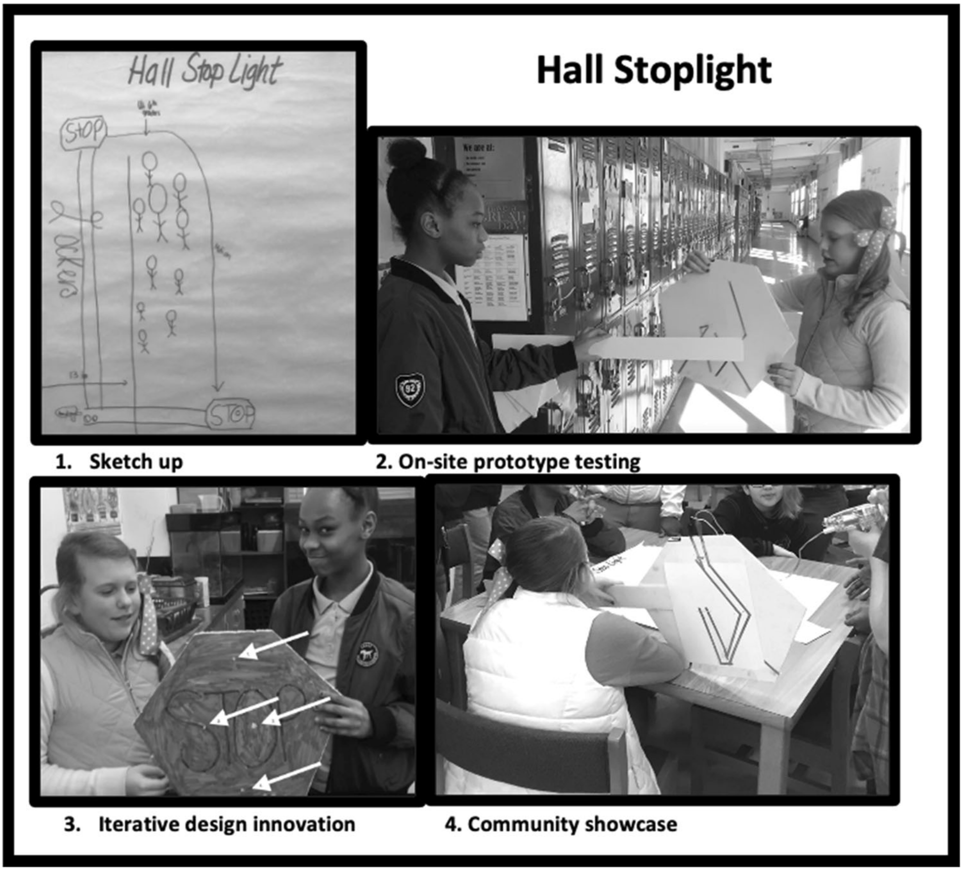

FIGURE 2 The Hall Stoplight innovation design process.

into the side of the metal locker next to the doorway, where they had wanted to attach the end of the stop sign swing arm. In addition, the holes were at the preferred height, approximately 1 m from the floor, which would give them a good pivot point from which to drop and raise the stop sign on the outer edge of the swing arm. This complemented their plan for Mr. M. to deploy the stop sign when it was time to change classes, when students had to stay in the hall. Mr. M. was a key factor in their engineering solution to this problem space.

They punctured a hole into the end of the swing arm and attached the arm of the stop sign to the locker by inserting a metal brad through the aligned holes of the swing arm and locker wall (Figure 3), and then opened the 2 brad prongs on the inside wall of the locker to secure the pivot point. They tested the attachment-deployment functionality, pulling the arm down and back up to rest against the wall. Further, the girls duct taped extra pieces of their display board (using their cutout scraps) on the outside of the locker below the arm, to act as a drop barrier, to prevent the arm from swinging lower than a level at which it would be parallel to the floor (Figures 2 and 3).

They were among the first groups to finish their prototype, with a single light on a simple circuit. On taking their sign out to the hallway for testing, the girls determined that the single light was not visible enough to be seen when one was more than a couple of feet away from the sign. This observation led to more iteration. To increase visibility, they re-worked their circuit to allow for 3 more lights (Figure 2) in a second iteration which necessitated a shift from a simple to a parallel circuit, so the sign would be more noticeable to students in the hall. The girls struggled with getting all the LED lights in the parallel circuit to light up. As Tanaiya explained, before the hands-on experience of

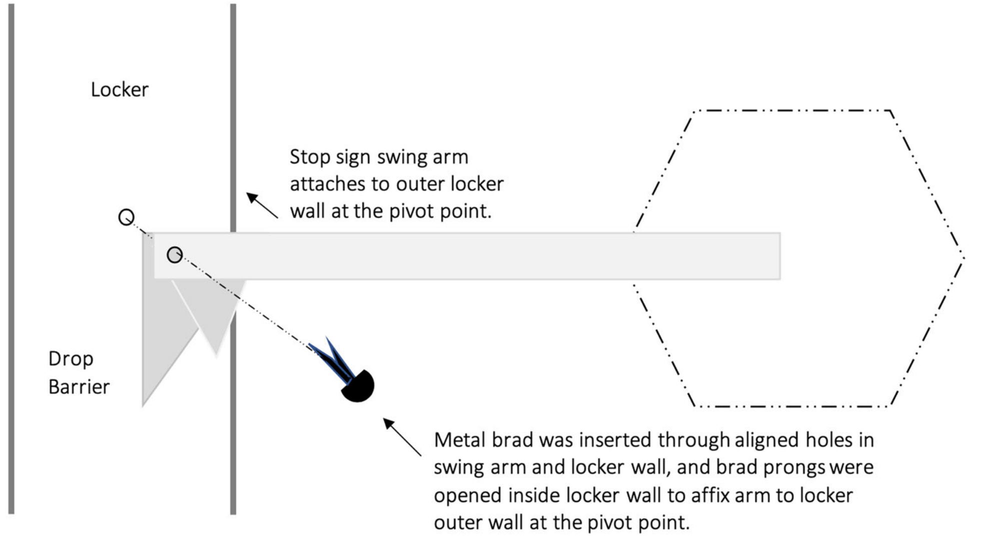

FIGURE 3 The Hall Stoplight swing arm was attached to the outer side of the locker with a brad at the pivot point.

making the circuit, she had thought that if you just put the copper tape down to make a circuit on the backing board, then the electricity would automatically flow through it, because the copper tape was in place.

She said she'd originally thought, "As long as it's copper tape on there, it's a complete circuit!" and that it would light up the lights. But, when actually putting the tape down to make the circuit, it was not working. She then found that it took more than making sure the circuit was constructed correctly. "I just put it [copper tape] on there, and it had bubbles in [it], and it was creases, and it was crunched up". She realized after the fact that if she did not put the copper tape down correctly – flat without wrinkles – trapped air bubbles would break the circuit or thickly folded areas would cause too much resistance and stop the flow of electricity. She found out for herself that how she put the copper tape down mattered.

When first testing the parallel circuit with four lights it was hard for them to get the lights to all light up. When they did, then it was hard to get them to continue to light up after having tested them with the hand crank. When the lights would stop working, they put new ones in, but they still would not all light up. Tanaiya and Lacey stayed after school the day before the showcase to put in extra time working on the prototype. Tanaiya said, "… we had to figure out on our own, ourselves, how to do it, because it was at the last minute". Even with the limited time, their goal of increasing visibility of the Stop Sign with more LED lights pushed them to persist with working on the circuitry. With researcher support in the end, and new circuitry, a third iteration parallel circuit was made on cardstock, then glued to the back of the stop sign (Figure 2).

The finished Hall Stoplight mechanism featured the following technical features, each thoughtfully designed and built with specific social elements in mind:

- Five pieces of backing board, one cut as a stop sign, another as a swinging lever arm, and three scrap pieces to tape to outside locker wall to act as a drop barrier for the arm.
- Metal brad to connect swing arm to outer locker wall at pivot point.
- Swing arm attached to stop sign, and backing board scraps attached to outer locker wall using thick package tape and/or glue gun.
- A hand crank to power the circuitry as green energy source.

During the first round of showcase presentations their whole group gathered around the Hall Stoplight and showed others how it worked, and they had a large noisy group around their table. They explained how their innovation would fit into the existing structure of the hallway lockers, using their sketch up, as well as described the design and making process. They explained Mr. M. would swing it down and raise it when needed, and they showed how someone would need to crank the hand crank to light up the four lights on the stop sign. "We can use this for now and in the future because we used a hand crank, which is a renewable energy source, so we can use it many times", they wrote.

5.2 | Vignette 2: Look this way, too tall for the stalls bathroom lights in the girls' bathroom by Paris, Hannah, and Kelsey

In this vignette we show how this group made the Look This Way project to address the too short cubicle doors in girls' bathroom resulting in a lack of privacy when girls peer over to see if stalls are occupied. Paris, Hannah, and Kelsey corroborated specific community data with their own embodied knowledge and practice as 6th grade girls who use this designated bathroom daily.

5.2.1 | Vignette 2: Identifying the engineering problem

In this second case, the girls' embodied experiences in the bathroom provided detailed insight into how to refine the problem space for engineering. We explore how the girls' embodiments extended beyond how they experienced the problem space to how they could functionally break down the problem into solvable technical components that more precisely responded to social needs.

Like the Hall Stoplight group, Paris, Hannah, and Kelsey were also compelled by the community survey data on the need for school to feel safer. However, their safety issue focused on bathroom privacy concerns in the 6th grade girls' bathroom. Sage Middle School had been built over 60 years ago and the bathroom stall doors were shorter than many of the current 6th-grade girls. The open-ended responses to the survey indicated that too-short cubicle doors were a shared concern. Example responses include, "there could be a light indicating if the bathroom is full to avoid crowding" and "in the girls' bathroom the doors are so short, we want more privacy and not to feel like we don't have privacy."

The lack of privacy in the stalls was an issue of concern for Paris, Hanna, and Kelsey personally. As they described their own experiences in class discussions, taller girls would peek over the too-short cubicle doors to see if a stall was occupied, or sometimes because they were tall enough to look into the cubicles even when there was no overt intention to do so. During classroom discussions, students described significant discomfort and worry of such privacy violation, even if it may not be intentional given just how short the stall doors were.

Paris, Hanna, and Kelsey's group chose to design vacancy/occupancy lights for the 6th grade girls' bathroom stalls that would draw the gaze of bathroom goers away from the cubicle doors. The group's design involved wiring up solar powered girls' bathroom stall lights, with lights and switches on the wall above each stall, to signal when a stall was occupied–so that no one would have to look over the doors of the stalls to determine vacancy.

5.2.2 | Vignette 2: Hybridizing the engineering solution

The girls' embodied experiences in their school community with the too short bathroom stalls made visible how they experienced the bathroom on a daily basis in their science classroom. In this section we show how the girls' embodied experiences, and their efforts to move them from the bathroom to the classroom, created opportunities for their teacher to figure out better ways to help them, something he felt particularly stuck with. This was important because, as a male teacher, he had never been in the girls' bathroom, nor been able to observe the challenges the girls described.

Mr. M. voiced that initially he could not see how to help some groups, such as this one, because of the size of their ideas. So, with consistent good humor, he would sometimes send the groups with ideas he could not immediately visualize how to prototype for help from Aerin Benavides, one of the researchers in the room.

> When they first said it, I was like, "Okay. Well, y'all let Dr. Benavides, " I was like, "Let her tell you that you all can't do that." "That's too big. It's out of …" [and] you Dr. Benavides were just like, "Oh, yeah. That's great." I was like, "Oh, really?" (Mr. M.)

Mr. M. said he was not familiar with the girls' bathroom, or issues there, as he definitely steered clear of the girls' bathroom space and had never seen it. Issues in the girls' bathroom were made visible through the community ethnography survey results as the class went through them to choose their 'top 10' ideas to address. The girls in the Look This Way bathroom occupied lights group described what they wanted to do to Dr. Benavides, and came up with an idea to make a scale model prototype, as a means to show their idea with the materials they had on hand (cardboard boxes, copper tape, small solar panels, and small LED lights). They went into the girls' bathroom with Dr. Benavides (female) with yardsticks, paper, and pencils, and made the necessary measurements. They decided on a scale of 1":1' (one inch on the model would represent one foot in real life) and learned a new skill--how to measure a room with yardsticks.

The girls had a hard time at first wrapping their heads around the idea of how these measurements they wrote down on notebook paper in the girls' bathroom would be used on the model; and it was through the embodiment of using the foot measurements they took to convert to inches for the model that they truly understood those measurements' meanings. Through their model, they made the "girls-only" space and problems within it visible to their teacher and to the whole community. As Mr. M. reflected,

> So, I was really shocked. As they were getting it, and making it [the model], I was like, "Oh my gosh! They're actually doing this!" So, I was shocked. I really was. On a lot of them, I was shocked. I thought this was too big … the bathroom one was *big*. (Mr. M.)

The process of making the Look This Way bathroom occupied lights model began with the sketch up design (Figure 4). To build a to-scale model, the group used a box for three outer walls and the floor, then measured and cut the other model pieces to scale on their own, without any help (stall walls and doors were affixed with a glue gun, and the window cutout size and its placement on the side wall was measured by the group). They measured accurately to scale. As a final touch, they painted the model the same color as the actual 6th-grade girls' bathroom with spray paint.

To build their lighting system which involved creating a parallel circuit to support 6 LED lights, one above each stall, the group spent time figuring out this technical specification that included how to build a parallel circuit and where to insert individual switches for each of the LED outputs. They found it challenging and in their first iteration sketch up (Figure 4) they did not specify any switches' locations.

With feedback from Mr. M. and Dr. Benavides, the team then co-designed a second iteration of the circuitry on notebook paper to insert a switch for each individual LED light. In this circuit design any one or all the LED lights along the parallel circuit could be switched on at any time (Figure 5). They then tested the circuit and LED lights in the classroom space with a flashlight on the solar panel (Figure 4) and re-constructed on white cardstock before attaching the circuit to the "wall above the stalls" of their model. During this process of iterative design of the circuit, the girls discovered that copper tape applied directly on corrugated cardboard could cut the circuit, perhaps because it was a slightly uneven and fuzzy surface.

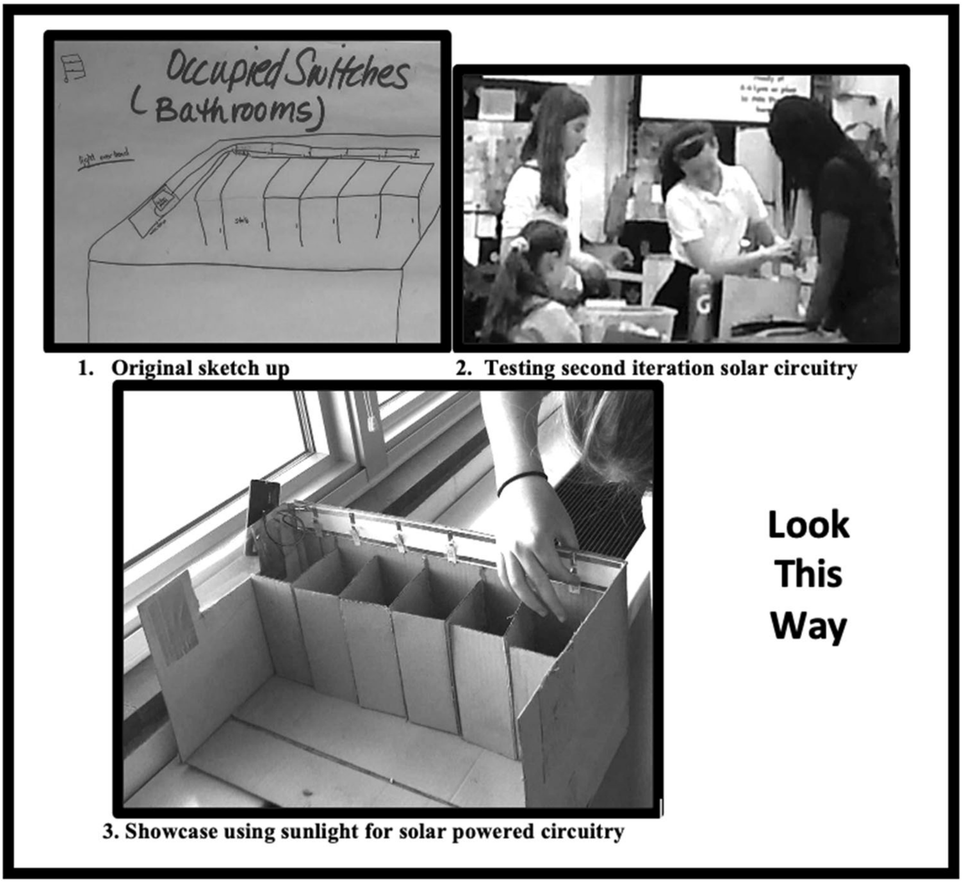

FIGURE 4 The Look This Way bathroom occupied lights design process.

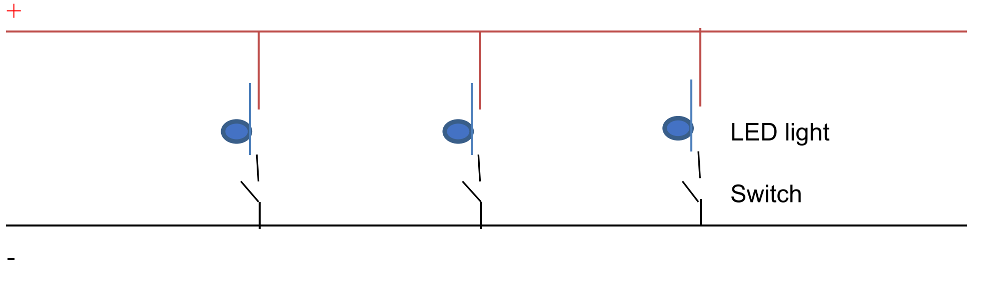

FIGURE 5 Final iteration of circuitry on scale model of girls' bathroom.

When the group took their prototype to the community showcase, they took along a flashlight and chose a table in the center of the room. They used the flashlight at first to power the solar panel as they explained their innovation, but it was not working well. Then they took the model to the windowsill, it was a sunny day, and the first time they tried the solar panel in real sunlight, one of the girls gasped in awe as the light on the model lit up. It lit from the power of the sunlight hitting the solar panel (Figure 4).

The finished Look This Way bathroom lights scale model featured the following technical features:

- One to-scale cardboard box with top and one side cut out.
- Cardboard pieces cut to scale and glued together to construct bathroom stalls and doors.
- Clear plastic to simulate window and foil to simulate mirror.
- A cardboard to-scale sign on the inner bathroom wall to remind girls to observe lights as a signal that a stall is occupied (not visible in Figure 4).
- Parallel circuitry designed to be put onto the existing wall space to permit any one or all of the LED lights to be switched on at any time.
- Solar panel attached to circuitry and taped outside of the window as green energy source.

During the showcase, local community members including science teacher educators talked extensively with the group. A local Technical Education teacher from another school voiced his admiration for how the bathroom model was "so precise and to scale", noting how the girls explained their process figuring out scale dimensions with specific measurements. He further noted that the group created a "really good model, proof of concept of a great idea." The teachers had organized the showcase schedule such that students could rotate and visit with one another's presentations. Kelsey noted that every group getting to do a different engineering project was more "creative" than having every group do the same thing, and that she could "see how everyone else's ideas come to life" from the survey stage to the finished prototypes.

5.3 | Vignette 3: Pride slide, by Mandy, Zari, and Deira

In this case three girls designed the Pride Slide to address a similar problem as above –too-short cubicle doors in girls' bathroom resulting in lack of privacy when girls peer over to see if stalls are occupied. However, their design tackled this problem from a different perspective. Out of the three girls, Mandy and Deira were both too tall for the doors. As Mandy explained, "when I stand up in the inside [of the cubicle] you can see me above the door." The group then wondered "Can we make the door longer?" While analyzing community data, they further corroborated specific data with their own embodied knowledge and practice. They were excited to learn from the community survey that other 6th-grade girls shared similar concerns about too-short cubicle doors in the 6th grade girls' bathroom.

5.3.1 | Vignette 3: Identifying the engineering problem

In this section we show how the girls' re-enactments of their embodied experiences helped them to make sense of how engineering designs are dynamic and respond to complex experiences people encounter, rather than a more static, specific problem. With the Pride Slide, the problem was about more than doors being short, but how short doors impacted how girls specifically used the bathrooms, and how this usage shaped design ideas.

Consider how, when the class was analyzing data from their community survey on specific issues the Sage community indicated that they were facing, at least four students in Ms. S.'s class brought up issues related to the students' bathrooms. They pointed to specific survey responses, including "CLEAN THE BATHROOMS!!!!!!!" and "In the girls' bathroom the stalls are too short. We want more privacy and not to feel like we do not have privacy." Mandy spoke at length about the lack of privacy in the girls' bathroom due to "too short" cubicle doors. The common thread with the bathroom issue in the class discussion was a general reluctance to use said bathrooms, resulting in students having to "hold for a long time" during the school day.

Mandy further explained that lack of privacy and getting “peeped at”, even unintentionally from girls, is traumatic. Another classmate shared how they would detour to the media center and ask the language arts teacher with a private office there with an ensuite, if they could use that bathroom. Indeed, we had noted a steady stream of girls asking Ms. L. (teacher) for permission to use the single-stall bathroom with a built-in door. This has led to reprimands from teachers when students were late for the next class as a result of the detour.

While desiring to address the “bathroom stall privacy” issue, the girls spent time in the girl's bathroom explaining to Dr. Tan what they meant. They engaged in embodied performance –from walking into the bathroom, how if you were more than 5 feet 2 inches tall you could see over the top of the bathroom stall cubicles unless you intentionally averted your eyes away. How, when you are in the cubicle you immediately felt exposed, and you have to crouch to get ready to use the bathroom. How, when after you were done using the bathroom you still had to crouch to minimize the length of your body, while standing up from the commode to put your clothes back in place. Mandy wondered about how to “make the door longer” and the idea of making a door extender that could be attached to the back of the cubicle door was seeded.

5.3.2 | Vignette 3: Hybridizing the engineering solution

In this section, we show the girls' hybridization of the social and technical aspects of engineering, more specifically how the girls spent time in the girls' bathroom to further refine the design of the Pride Slide, figuring out relevant technical specifications such as width and height of the Pride Slide, how the mechanism might work with a fixed and movable panel, and possible ways to affix the extender to the inside of the cubicle door to be utilized by the person occupying the stall.

When the girls shared with Ms. S. their idea (Figure 6), she was impressed and very enthusiastic telling the girls that a door extender is “a great idea” and that she would never have thought of that. In fact, Ms. S. admitted that as a teacher, although she was a woman, she had no reason to visit the girls' bathroom. She was completely unaware of the problem. When she did look inside the girls' bathroom, she exclaimed that the doors really are “short!” Ms. S. agreed with the group that they needed to investigate the problem space in the bathroom and get accurate measurements since they were working on an existing material – cubicle doors. Ms. S. requested that Dr. Tan accompanied this group during these on-site investigations while she remained in the classroom with the other groups.

While in the bathroom, the taller girls Mandy and Deira re-enacted how they would contort their bodies to be as small as possible, to maximize how much of their person could be shielded from view by the too-short doors. This embodied performance was important as it gave them an idea of how much taller the Pride Slide needed to be to make the door extender suitable for complete privacy without bodily contortions. The group then measured the length and width of the cubicle door, including the space between the hinges and the door. They sketched up a design for a sliding panel that could be attached to the back of a cubicle door and extended especially when a taller girl is using the cubicle. Through iterative design and testing that included back and forth conversations and activities in the classroom and back in the bathroom, with Ms. S. (Figure 6), their classmates, the researcher and a visiting engineer, the final Pride Slide mechanism prototype featured the following:

- Two pieces of cardboard, one as an anchoring piece, one as a sliding piece.
- Cardboard brackets to keep the two pieces together.
- Adhesive Velcro to attach the Pride Slide system onto the back of cubicle door.
- An attachment system with sized cut-throughs in both sliding and anchoring pieces that line up when the sliding piece is extended.
- Cardboard pegs that fit into the cut-outs that would hold the sliding piece in place.
- Solar panel as green energy source for circuitry on lights to bring attention to extended door panel when in use.

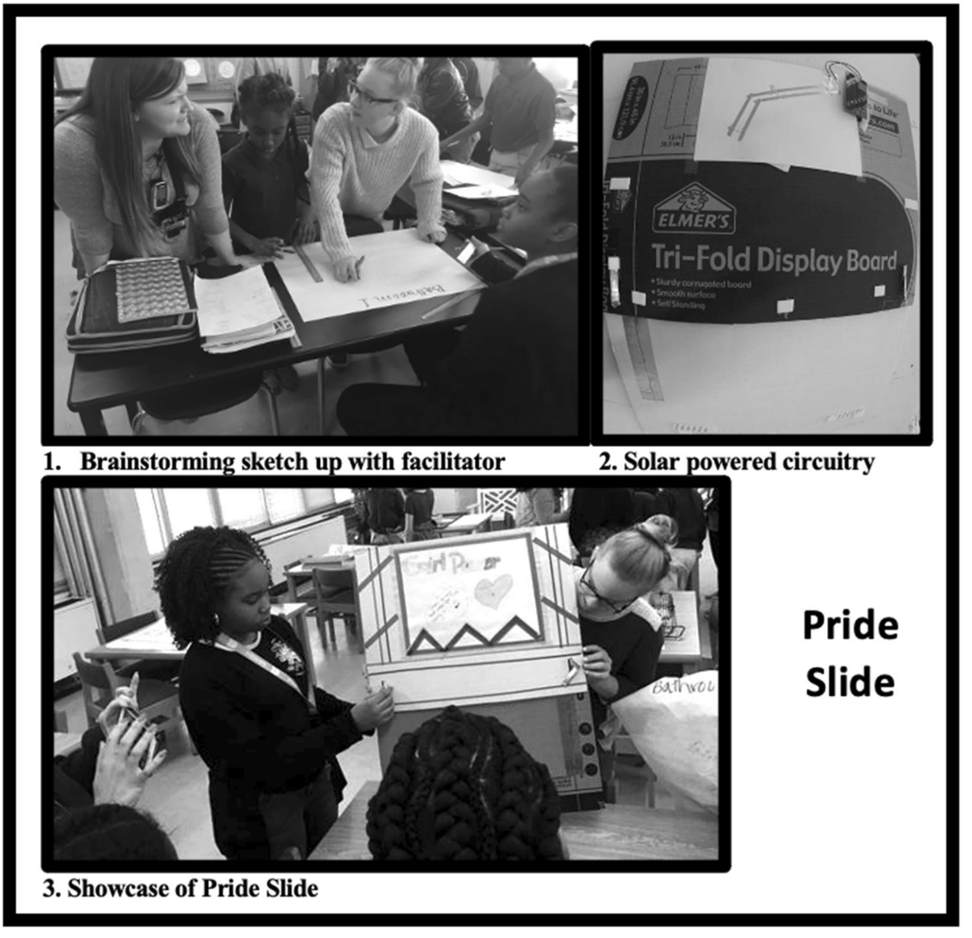

FIGURE 6 The Pride Slide design process.

After the mechanism prototype was done, the girls started to work on the decorative part of the panel. They wanted the panel to be attractive and be something that would "make you want to use it" and decided on a slogan—GIRL POWER!! with a light-up design and cheerful colors that would suit their panel. They worked to create a paper-circuit with copper tape in the back of the sliding panel. They chose a solar panel as a renewable energy source, as the bathroom had a window that would provide enough sunlight to power the solar panel (Figure 6).

At the showcase, Mandy, Zari and Deira were very proud of their prototype, talking to many students, teachers and visitors who asked them about the Pride Slide. They explained both the reason for why they made it, how it works as a sliding panel, and how they created the girl-empowering art to encourage girls, on the sliding panel. The group was frustrated that they could not show how the panel actually worked in the bathroom since the showcase took place in the school media center. They requested that Ms. S. let them set up the panel in the 6th grade girls' restroom so that "people can actually see how it works." While setting up the finished prototype in the bathroom, Zari, who was small and petite and barely 5 feet tall, reflected on how because she was short, she did not feel as threatened by a lack of privacy as her taller friends because of the cubicle door height. Through the project and especially through walking through the motions of how a tall girl might have to maneuver her body to work around the short door, Zari realized the problem, and that while she could not see over doors, taller girls could, which was also a problem.

TABLE 1 Summary of key sections of case studies across the three cases

EfSC 6th grade engineering projects	1. Hall stop sign	2. Look this way! Too tall for the stalls bathroom lights	3. Pride slide
Girls leveraged upon their embodied knowledge/practice as interpretive lenses for what community problems technology can solve.	Daily experiences of crowding in the hallway during classroom transitions; Lacey and Tanaiya's learned response to being the last two to leave and trying to avoid being jostled.	Daily experiences visiting the 6th grade girls' bathroom observing the too-short cubicle doors, either unintentionally seeing the occupant because of one's height (Paris) or being on the receiving end when one is in the cubicle (Kelsey, Hanna).	Daily experiences visiting the 6th grade girls' bathroom observing the too-short cubicle doors, Mandy & Zari both experienced being "looked at" over the cubicle doors while they were in the cubicle
Girls organized/put into action the values, ideals and desires of communities as critical evidence for engineering design as their embodied experiences pointed out key decision making points in design.	Community data: "Need to feel safer in school", open-ended response "students need to watch our surroundings and be cautious of what is going on" layered on embodied knowledge/practice → to value student safety in a crowded hallway shoving at hall door is an important engineering problem-space	Community data: "Need to feel safer in school", open-ended response "in the girls' bathroom the stalls are too short. We want more privacy and not to feel like we don't have privacy" layered on with embodied knowledge/practice → 6th grade girls deserve privacy in the bathroom	Community data: "Need to feel safer in school", open-ended response "in the girls' bathroom the stalls are too short. We want more privacy and not to feel like we don't have privacy" layered on with embodied knowledge/practice → 6th grade girls deserve privacy in the bathroom
These processes worked together to create increased opportunities to iterate designs in STEM-rich, meaningful ways.	Iterative design produced a functional, LED lit stop sign attached, hidden and could be extended from the lockers outside the classroom door, for more regulated traffic control	A to-scale model showing "Occupied lights" above each stall to signal vacancy/occupancy	Extendable panel mounted onto the back of cubicle door with a girl positive message in LED electric art powered by a solar panel

Table 1 summarizes the key sections across the three cases.

5.4 | Looking across the three projects

In this section we bring to note a third claim related to research questions 2 a and b, in line with our Rightful Presence theoretical framework, which is supported here by cross-case analysis. The girls' new forms of participation in user-centered engineering design (Wallisch & Paetzold, 2022), including the roles and practices they took up, worked together to produce new cultural signifiers, themes, symbols, and practices of engineering. These were made present in the girls' engineering process and products, indicating a more equitable culture in middle school engineering education.

5.4.1 | New cultural signifiers, symbols, and practices in an emergent engineering culture

A new signifier for engineering was the girls' communicating, in animated discussion, school community issues that were important to them. Then they engaged in "making present practices" (Calabrese Barton & Tan, 2019) during the engineering process. Through defining their problem spaces, followed by iterative design of a functional prototype to address these problems, the girls made present in and through 6th grade engineering, what had been elided and made invisible.

The issues the girls chose to address acted as symbols of their participation in engineering and were social-spatial in nature, girls' experiences which impacted their well-being and that took place outside of their science classroom shaped their work inside the classroom. In this we mean that girls' experiences arose out of particular social interactions that were bound to particular spaces. The girls hybridized resources such as: community survey data with their personal lived experiences; and what problem spaces count as engineering worthy, why, where, when and for whom. These resources were configured along the contours identified by the girls. By moving out of the classroom to investigate the problem space on site, girls also made present their embodied presence in the spaces that were typically "out of bounds". Rules existed for these sites such as 'no loitering in the hallways' or 'only when necessary' for bathroom visits, with a teacher permission pass, during class times. The girls were seen by other teachers and students at their on-site investigations, increasing the chances of being recognized by community members as girls engaging in engineering. Students moving out of the classroom for on-site investigations became legitimized as a practice and a symbol of engineering at Sage.

Having opportunities to anchor their engineering work in their embodied experiences, as both interpretive lenses and as indicators of critical decision-making points, helped to broaden the boundaries of what counts in 6th-grade engineering. Girls' on-site and embodied investigations also made visible material resources in school infrastructure that would inform their prototype design –such as the 0.5 cm diameter holes already present at an ideal height in a locker wall that became the pivot point on which the Hall Stoplight prototype was attached. Similarly, the Pride Slide group measured the space between the cubicle door, hinge, and wall to decide on how they might design brackets to hold up the fixed and sliding panel that could be moved to lengthen the door. In this way, physical infrastructure in school spaces that typically are irrelevant to school science became visible as material resources important to the engineering process. Deininger et al. (2017) found the use of readily available existing structures and existing objects or combinations of existing objects when applicable as one of the best practices to engage in for prototype design. Existing school infrastructure was integral to all three groups' designs.

Lastly, by locating and investigating these particular problem spaces, girls engaged in the practice of flipping the gaze from behaviors and personal responsibility on students' parts (do not shove, do not push, do not look over bathroom stalls) to the infrastructural inadequacies of the school building. The girls' projects revealed inadequacies such as too-short cubicle doors that have not been renovated for the past 60 years or only one doorway to the hall for a double-sized classroom used simultaneously for students' entrances and exits. Their design process was a symbol of real and potential power sharing with school authorities (teachers, administrators) in engineering.

5.4.2 | New practices in an emergent engineering culture: New forms of participation

We further explored how this evolving, EfSC iterative design process that centered on solving real, local problems in the here-and-now disrupted inequities in opportunities to learn in 6th grade STEM. It did so by fostering new forms of participation and roles in learning. This process, by making learning contingent on girls' embodied experiences, engendered new practices and expanded the possibilities of fostering a more girl-centered engineering culture. Researchers Brotman and Moore (2008) in a review of research on girls in science noted practices in research findings such as: girls' perceptions of their science ability decreases over the school year; girls prefer biology and science that "helps people" (p. 973) to sciences such as engineering; and girls often perceive science as uninteresting. We found in post-interviews that for most girls in this study their perceptions of their ability increased over time, that they enjoyed engineering that helps the community more than regular science class; and they were interested in their engineering design and implementation as evidenced in interviews, observations and artifacts. These new forms of participation and the practices of cooperation and collaboration, which they greatly valued in their post-interviews, also signified how girls were more rightfully present in middle school engineering.

5.4.3 | Theme: Engineering for real people in our community in the here-and-now

Across the three cases, the problem spaces girls decided on were authentic, local, and "live" issues that continued to unfold. Arriving at these problem spaces required participating in nontraditional engineering-related experiences including, (1) Learning how to solicit community data through conducting surveys and interviews; (2) Learning how to analyze data through parsing descriptive statistics representations such as pie charts and bar graphs, and coding open-ended responses to specific themes; (3) Delving deeper into specific threads of the data by soliciting corroborating experiences from one another during class discussions that add nuance and details to broader survey themes such as "need to feel safer in school"; (4) Literally building the prototype through iterative engineering process—working from ideas, to two-dimension sketches, up to three dimensional functional prototypes.

These four experiences worked together in concert to open up new ways of participating in school science and engineering for the girls. They took on new roles, including learning how to be a community researcher through conducting surveys and interviews, how to analyze data where follow-up and corroboration could be sought from real-life community stakeholders. The immediacy of access to data, related to the primacy of the school community in the way this engineering unit took shape at Sage set the stage for the girls to, in the words of Mandy, "actually [do] something. We actually solved a real problem." The opportunities to hold their personal experiences in dialog with community data also lent legitimacy and rigor to how the girls were able to define their engineering problem spaces in the ways they did. They mapped 25% of respondents want school to be safer, and identified different parts of the school spaces where safety might be an issue, to the ones involved at these spaces that contribute to how such spaces might not be safe, and for whom. Bathroom non-privacy and an unwillingness to be jostled in crowds during class transitions were stressful experiences the girls (and some others in the community) were experiencing. The problem spaces were active, current, and personal—located in the here-and-now.

To Zari, an important outcome in the engineering unit was that they solved a community issue. As she stated, "We solved the privacy problem. Because a lot of girls in the bathroom did not have privacy when they used the bathroom." Mandy added that with the Pride Slide, girls' privacy is more assured because "people can't peek over anymore." Lacey was compelled by the process of an idea that would help others at her school community, that their Hall Stoplight design idea would "actually come true".

Actual fabrication of their design into a three-dimensional functional prototype was meaningful for the girls, both epistemologically and ontologically. Undergoing the processes of actual fabrication also opened up a different dimension of the iterative design process. Especially for the Hall Stoplight and Pride Slide groups, testing out how their prototypes-in-progress would function on-site was essential to further refining and testing. For example, the Pride Slide group had to consider the optimum height for mounting the prototype so that the door opening and closing movement is not hindered and that girls across a height range could use the prototype easily by manipulating the movable panel.

5.4.4 | Theme: Girls' rigorous meaning-making as central to engineering

We see the importance of girls' embodied experiences in supporting their rigorous meaning-making during the engineering process in two ways. First, their personal experiences were related to the problem space and positioned them as expert informants to defining and refining the problem space (a new role for them in the classroom culture). Second, moving to the problem space added rigor. For example, Mandy and Deira's re-enactments of how they had to crouch and contort their bodies to stay hidden behind the too-short cubicle doors were important to their subsequent determination of the technical elements of the Pride Slide's design, including the movable panel and how tall the panel needed to be to fully obscure an average sized 6th-grade girl from sight. Paris, a taller girl could show how, upon entry into the girls' bathroom one had to consciously avert looking at eye-level to not accidentally see over the two-short doors, illustrating how easy it was to be peeked at and how this concern of preserving one's privacy in the bathroom was shared by many girls in the 6th grade. In their to-scale model, the girls made an educated conjecture on how high up from the top-most line of sight of the cubicle, the occupied-indicating light needed to be. These embodied performances are examples of making present practices—literally manifesting unjust experiences related to girls' everyday school lives—that are important to working towards Rightful Presence in school science.

5.4.5 | Theme: Moving engineering to the physical problem spaces

Being able to move into the physical spaces where problem spaces are located to engage in embodied engineering practice was important. For example, Lacey and Tanaiya walked the hallway outside the classroom to figure out where their stop sign should be located to more effectively direct foot traffic; asking in-coming students to wait in front of the stop sign at the class door as students were leaving the classroom through the same door—using the stop sign dropped from a hinge attached to the lockers at a particular height that would bisect at the height of an average 6th-grader's chest. These embodied observations were literal and professional data-gathering site visits not unlike the practices of professional engineers. It was contingent on such embodied learning opportunities, related to both refining the problem space and informing the design process of the prototypes, that the girls were able to identify to a much finer degree of detail, what technical elements of their prototype they needed to pay attention to in order for their prototypes to function in the ways they intended, aligned to address the nuances of the problem space they understood to be important.

The girls reflected on these embodied experiences as a transformational way of learning science in 6th grade. Hannah described her experiences as such:

> I like the hands-on learning experience because it was, when you watch a video, you get like one reaction, response to it. But, if you're actually doing it, you might get a different response, and you get two ideas of what it's about. And also, when you‘re watching a video you kinda have to think about what's happening, and then while you're thinking you might forget what the video is saying. But, if you're actually doing it, you can, like, do it multiple times, and it's [science] not so hard. (Hannah)

The Look This Way group agreed that “hands-on [engineering] really prepares you for the future”. Mandy, Zari, and Deira, creators of the Pride Slide, spoke of the process as “indescribable, a whole amazing journey we went through, building things” and that it was “hard” and that there were times when they were “frustrated and angry” when things did not work as imagined. However, in the end they were proud of themselves, and they thought it important, with the iterative engineering process, that they got to “feel successful” and experience “how science feels and how we work together as a group.” The girls further emphasized how they wanted to “have more hands-on projects, ‘cuz that's the only way you can, like, predict or hypothesize things from science—like, if it works, if it doesn't.”

5.4.6 | Cultural signifiers: Engineering as a creative process and hands-on learning

Two cultural aspects of EfSC that girls mentioned and were visibly pleased about in interviews were seeing their design solutions to issues revealed in community surveys materialize in 3D, and the "hands-on" aspects of engineering iterative design. A literature review of engineering education research by Arik and Topçu (2020) revealed that the dominant approach taken in the engineering design process was to have students address a pre-established problem scenario. Researchers Chabalengula and Mumba (2017) found that, of the K-12 engineering education programmes they analyzed, optimizing engineering design solutions was not prioritized, (design/ build/ create/ make/ test/ show/ engage in iterations); while Arik and Topçu (2020) later found 'making' prevalent in engineering design research studies that they reviewed. But, the act itself of taking an engineered design idea and making it and testing it in 3D in K-12 classrooms—despite this being a powerful experience, especially when addressing community injustices (Tan et al., 2019)—was new in school for most of the girls (a few had done out-of-school engineering programmes in the past), and something they wanted more of.

Further considering the classroom culture, we note that some of the girls recounted that they were skeptical and fearful of engineering when their teacher first told them about the unit. "I didn't think we could actually do it", one girl said. The girls across all three groups said they were proud of themselves and the prototypes they created. Tanaiya summed up her positive sentiments, that she had learned and understood engineering well after co-creating the Hall Stoplight. She stated, "[N]ow that we understand more [of engineering], then we could teach other people to understand as well."

6 | DISCUSSION

In this study, we sought to document from girls' perspectives (Prieto-Rodriguez et al., 2020; Seron et al., 2018) their engineering process from identifying and refining a problem space, to the nature of their iterative engineering process to the material manifestation of their prototypes. We expand upon our findings to consider the themes and symbols of engineering that were evident when engineering centered upon girls' embodied experiences and local community concerns. These themes and symbols are cultural signifiers of a more equitable engineering culture. The impetus for this focus is our concern with the prevailing canonical cultures in engineering education and in integrated school science that act to deny girls a rightful presence (Calabrese Barton & Tan, 2020). We conclude this section with the seeds of Rightful Presence that were evident for girls during this engineering unit.

6.1 | Themes of an emergent engineering culture

Here we introduce a theme that surfaced from the cases, that of engineering for social-spatial justice. From the ways in which the girls took up engineering, we posit that an engineering culture anchored in socio-spatial justice was emergent. Across the three projects, the girls' innovations were designed to help to right a spatial *in*justice (Rubel et al., 2016), This expanded the epistemological parameters of the engineering learning space by recognizing the validity of personal experiences girls have from their lives across school spaces. Social-spatial justice became a part of middle school engineering problem solving.

An engineering culture that works towards social-spatial-justice contests the limits of traditional school science culture and canonical engineering culture. It centers girls' everyday embodied experiences as relevant to engineering when real spaces in which middle school girls negotiate connections and tensions played out in daily social dynamics are positioned as integral to engineering. This emergent engineering culture also runs counter to the neutrality and objectivity that undergirds canonical engineering culture.

A study by the National Academy of Engineering (2008) reported that engineering taglines that most appealed to girls are "Engineering makes a world of difference" and "Engineering is essential to our health, happiness and safety", the latter having overwhelming appeal amongst African American girls aged 16–17, and all ages of Hispanic girls included in the study. Based on the problem spaces they chose to engineer a solution for, these same taglines would resonate with the girls in this study. We posit that one way to capture the kind and degree of "a world of difference" that directly impact "our health, happiness and safety" in middle school engineering is through mapping engineering onto the local social spaces, in the here-and-now.

We also introduce a second theme, the technically rich and socially specific nature of the girls' iterative engineering process. Spruill et al. (2021) found that the inclusion of social elements that were important to girls in their user-focused design process acted to "disrupt traditional boundaries that bounded what engineering 'was'" (p.1). Wieselmann et al. (2019) similarly explored girls' barriers to participation in STEM, but they contrastingly took on a social cognitive perspective, which did not investigate the lack of inclusion of social elements in engineering design as a barrier. Ing and colleagues (2014) via a large-scale quantitative approach, investigated gender differences in the consistency of middle school students' interest in engineering and science careers. They concluded that middle school boys and girls both showed interest in engineering and science careers that are related to new discoveries that would benefit human health and the environment. They also found that boys, more than girls, showed interest in designing, inventing, solving problems and technology (Ing et al., 2014).

To this point of techno-centrism versus a people-social focus, we suggest that it is not so simple a binary that was at work during the girls' engineering process. The girls did not shun technical aspects to focus only on people-centered dimensions, but showed that one informed and is contingent on the other. Both social and technical elements existed in a dialogic relationship. In fact, we argue that the girls delved deeper into more technical aspects of their design through testing the functionality of their prototypes with specific users of the end product in mind. For example, Lacey and Tanaiya were strategic in designing their Hall Stoplight sign to be not only attached permanently to the locker wall in the hallway but that there is a hinge to allow it to fold away neatly away from sight when not in use. They were aware of ensuring that the design is as easy as possible for Mr. M., a very organized teacher, to use. Upon testing, they found that the single LED light on the sign was insufficient to calling attention to the sign. Lacey and Tanaiya reworked their circuit from simple to parallel to support more LED lights as a key design feature. Thus, an engineering culture anchored in facilitating meaningful and rigorous engineering for the girls in this study is contingent on prioritizing and integrating both technical and social elements of the engineering process.

6.2 | Symbols of engineering

The symbols of engineering we here introduce that were produced by the girls include physical artifacts such as the two-dimensional sketch-ups of their prototypes, with markings and edits that reflected the changes made during the iterative design process, and the actual functional prototype. The embodied, onsite investigations were another symbol of what engineering entailed for these students – leaving the classroom for the hallway and the 6th grade girls' bathroom. Their designs themselves symbolized the fact that local community members experiencing problem spaces can also engineer solutions for them.

Engineering, as experienced by the girls in this unit is: (a) at once personal and community-based, (b) grounded in both STEM epistemologies and social narratives, (c) involved taking up, in novel ways, both material and human resources, and (d) social-spatial in nature and justice-oriented. As described in our findings, social-spatial justice was a theme evident in the emerging engineering culture in these middle school classrooms. This is a departure from the typical tropes found in middle school engineering resources where problem spaces can be an imaginary rendering of a "real-world" problem from outside of students' real world. Prosthetic tails for fish on the Engineering is Elementary (EiE) website (eie.org) or building bridges with popsicle sticks (e.g., Barroso et al., 2016) are typical tropes distant from students' everyday lives. We suggest that anchoring the problem space in real-life experiences where students are involved from the inception of the engineering process—in identifying and defining the problem space—is productive towards fostering a more student-agentic and personally meaningful engineering culture.

These symbols of engineering reflect seeds of Rightful Presence in middle school engineering. The ways in which girls took up and engaged in engineering in this EfSC unit were supported by expansive entry-points into the world of engineering. These entry-points offered both flexibility and directionality for extensions that supported girls' engineering in this unit. For example, the mapping of embodied experiences to specific community data resulted in two different approaches to address too-short cubicle doors in the girls' bathroom. What guided iterative design decisions were the different types of funds of knowledge that students brought into play which were nurtured along with classroom science learning experiences to create hybrid forms of knowledge (Calabrese Barton & Tan, 2009b; Rosebery et al., 2016). Girls' funds of knowledge of their need for physical safety when jostled at the doorway, their realization that students only respond to teacher authority to regulate hall traffic in their school setting, and their knowledge of how stop signs are used in school traffic crossings all informed how Lacey and Tanaiya designed their Hall Stoplight prototype.

6.3 | Seeds of rightful presence

Rightful Presence foregrounds the necessity of shared political burden in renegotiating rights in how students can participate in their learning (Calabrese Barton & Tan, 2020). One visible way in which rights were reauthored was the girls leaving their science classroom confines to conduct on-site investigations. Before this unit, students did not leave the science classroom. Another example of reauthored rights was soliciting for community data as legitimate engineering texts to parse and make sense of in middle school engineering. There was no prescribed engineering problem to solve, students had to identify and locate authentic problem spaces within the school community. This allowed for the parts of students' lives (hallway and bathroom usage) that had been positioned as irrelevant or disruptive (e.g., going to the bathroom in the middle of class) to be positioned as students' learning in 6th grade science, and as central and integral to students' developing engineering expertise.

As authoritative science teacher figures, both Mr. M. and Ms. S. were fully supportive of the problem spaces the girls wanted to investigate. They were supportive even when they themselves were unaware and unfamiliar with these specific problem spaces. The teachers learned alongside students during classroom discussions unpacking community data. They relinquished teacherly control by supporting the ways in which girls drew from materials and resources. They affirmed and acknowledged the value of girls' personal, embodied knowledge and practices that intersected with community problem spaces.

We centered this study on girls in two ways: (1) we documented and unpacked, from the perspectives of girls, how they made sense of and engaged in an engineering unit that is focused on engineering for sustainable communities; and (2) the engineering problem spaces of two of the three cases were physically located in the girls-only 6th grade bathroom space. While five of the girls self-identified as White and three as Black, we make no claims along the lines of intersectionality of minoritized identities pertaining to gender and race, as related to the girls' engineering experiences.

In undertaking this study, we do not take the stance that how boys and girls engage in engineering differ in static, binary ways. Indeed, as shown by Ing and colleagues (2014), both middle school boys and girls were equally interested in engineering and science careers that would further human and environmental well-being. Holly (2021) found that for Black boys, to engage in relevant engineering pedagogy requires political clarity in curriculum design and implementation, and that we use students' lived contexts as authentic to engineering. It is possible that these themes of engineering, symbols, and seeds of Rightful Presence are equally relevant to boys in the classrooms.

Structurally, before the engineering unit, middle school science as taught in the two classrooms reflected traditional science pedagogical norms and practices, teacher-driven curricular decisions that were no doubt grounded in Mr. M. and Ms. S.'s care and commitment to their students. Students remained in the classroom, mostly working independently on writing-intensive activities. In addition, before the engineering unit where the girls were supported in framing problem spaces meaningful to them, community issues located in sites outside of the science classroom were irrelevant to science teaching and learning. Using a structural intersectionality lens within our Cultural Ways of Learning theoretical framework helped us to identify concretely what kinds of social hierarchies within a school community across spaces and student activities might be fertile ground for seeding Rightful Presence for girls in STEM and for envisioning a more girl-centered engineering culture.

7 | CONCLUSION

Middle school engineering could be composed of powerful learning experiences for girls when engineering problem spaces are personally meaningful and locally authentic, informed by and impacting real-life community stakeholders (Tan et al., 2012). We suggest that an iterative design process grounded in embodied experiences and the hybrid activation of material and human resources that result in three-dimensional, functional prototypes is productive towards developing both (1) epistemic and technical expertise, and (2) sealing the rightful presence of social texts as legitimate in middle school science Discourse. Engaging in middle school engineering in these ways necessitated new roles and practices for teachers and students. Investigating from girls' perspectives the arc of their STEM learning experiences is necessary for the field to gain much needed insight into designing STEM teaching and learning experiences that draw and springboard from girls' ideas, concerns, and brilliance. This study contributes to the larger discourse on girls and equity in integrated science by centering the focus on soliciting and leveraging girls' embodied experiences across social spaces in school settings, as valuable resources for rigorous integrated science teaching and learning. Such a focus is productive to making visible how the culture of a school science learning space could be shaped and transformed to one where girls are more rightfully present.

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CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

Data are available on request due to IRB privacy/ethical restrictions.

ORCID

Aerin W. Benavides http://orcid.org/0000-0001-9876-0216
Edna Tan http://orcid.org/0000-0002-4583-4557
Angela Calabrese Barton https://orcid.org/0000-0002-9555-5214

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