Supporting Teacher Visioning of Justice-Oriented Engineering in the Middle Grades

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*****Note: Table 1 can be found at the end of the article.**

Abstract:

There are well-documented justice-related issues in engineering education. How do teachers begin to develop a way of seeing forward in their teaching, both in how they understand their role and their hoped-for outcomes for students, in ways that bridge the goals of justice with required engineering disciplinary expectations? In this manuscript, we focus on how teachers envision teaching engineering in ways that attend to the sociopoliticaldimensions of STEM teaching and learning. Through participatory social design research, we ask: (1) How do two middle school science teachers' vision of what justice-oriented engineering for sustainable communities (EfSC) is and entails, develop across sustained professional development (PD) and classroom enactment of an EfSC curriculum? (2) What is the relationship between teachers' processes of visioning and student opportunities for consequential learning? Findings suggest that teachers' visioning of justice-oriented engineering teaching take shape as they started to see themselves as being in relationship to engineering and community, making others' experiences and their own important aspects of learning. Further, this work of visioning is filled with tension and contradiction. In learning alongside their students about how powered relationalities shape opportunities to learn, teachers had to see themselves inside the process. Implications are discussed.

Keywords: engineering education | social justice | STEM | middle school students | engineering for sustainable communities

Article:

Ms J was a long-time teacher in her city's elementary schools, beloved by students, school leaders, and parents alike. While she taught all subjects, she admitted that she felt most challenged by teaching science. Her expertise was literacy and "even social studies." Science, because of its knowledge base, worried her. With the introduction of the new science standards, she found herself in a position of having to teach engineering, which worried her because she did "not quite get what engineers do." Layered onto Ms J's concerns about teaching engineering were the realities that she had an over-enrolled sixth grade class due to the closing of school buildings in her district, and a wide range of social, emotional, linguistic, and learning needs as her school served the local refugee center as well as limited support staff to help with differentiated instruction. Despite her years of experience, she felt like a new teacher when she wondered how she could meet her students' needs while also teaching a domain that was new for her. How do teachers, like Ms J begin to develop a way of seeing forward in their teaching, in both how they understand their role and their hoped-for outcomes for students, in ways that bridge the goals of justice with required disciplinary expectations?

In this manuscript we focus on how teachers envision teaching engineering in ways that attend to the sociopolitical dimensions of STEM teaching and learning (Calabrese Barton & Tan, Citation2019; Gutiérrez, Citation2013) – how teachers make sense of nested (in)justices that operate through mundane STEM education and school practices. Therefore, we ask: (1) How do two middle school science teachers' vision of what justice-oriented engineering for sustainable communities (EfSC) is and entails, develop across sustained professional development (PD) and classroom enactment of an EfSC curriculum? (2) What is the relationship between teachers' processes of visioning and student opportunities for consequential learning?

Engineering education and issues of justice

There are well-documented justice-related issues in engineering education. The more visible presentation of injustice is the severe and enduring underrepresentation of women and people of color in engineering. For example, data from the engineering undergraduate enrollment in 2016 showed that only 21.4% of students are female, with African American females making up just 1.3% (National Center for Science and Engineering Statistics, Citation2016).

The lack of representation of specific groups of the population is related to a second, more hidden injustice – that of the enterprise of engineering itself. The norms and practices of engineering reflect the neoliberal agendas of governments and corporations for whom engineers work (Goldberg et al., Citation2001; Riley et al., Citation2014) and both reflect white, male, middle-class values. Thus, the epistemologies of engineering – what counts as engineering, by whom and what engineering values – have been called into question (Adams et al., Citation2011; Cech, Citation2013). Cech (Citation2013) argues that the problematic twin ideologies of traditional engineering education – depoliticization and meritocracy – frame engineering as an apolitical and benign enterprise, where "issues of inequality and justices [are] irrelevant to engineering practice" (p. 68).

Hynes and Swenson (Citation2013) assert that an equity agenda in engineering education needs to attend to how engineering is "a people-centric discipline" – how engineering is done for people, with people, and as people. In addition to the knowledge and practice of the engineering discipline, concomitant attention needs to be paid to the needs of people who will be impacted by design solutions as well as how people work together across different backgrounds, expertise, and stakes in a project. However, few studies investigate just how the social aspects of engineering by and with people may contribute to disrupting and transforming the social-spatial relationalities in and of engineering. As engineering is fundamentally a social enterprise, attention should be paid to the axiological underpinnings of engineering. What is good, what is right, and what is just in how people engage both the object and subject of engineering should shape how these technical and human/social aspects interact toward innovation. Indeed, the lack of attention to these axiological underpinnings is a contributing factor to the reproduction of injustices via engineering

(Strand et al., Citation2003). Whose problem is important and why, who are the expert engineers deemed capable of addressing issues and if these engineers are outsiders or from the community, and how does this shape activity and innovation are crucial justice-oriented questions to consider in engineering education (Riley et al., Citation2014). Such normalized power differentials that have come to be deemed “natural” between the “privileged server” and the “underprivileged served” (Henry, Citation2005) are in need of critique in engineering education (Nieusma & Riley, Citation2010).

K-12 engineering education

The Next Generation Science Standards (NGSS) designated engineering as a core and distinct part of the K-12 science curriculum (NGSS Lead States, Citation2013). Engaging K-12 students in engineering is believed to be productive not only for students’ increased achievements in related disciplines such as science and mathematics, but also for support of students’ appreciation for the interconnectedness of STEM fields and the important role engineers play in society (Brophy et al., Citation2008; National Research Council, Citation2012; Reimers et al., Citation2015).

Engaging K-12 students in engineering education has been shown to positively impact students’ interests, identities, and understanding of mathematics and science, with the caveat that teachers were most influential in impacting such outcomes (Ghalia et al., Citation2016). For example, Chu et al. (Citation2019) found that eighth graders’ engineering identities, which they operationalized as recognition and interest, actually decreased across the school year during an argument-driven engineering curriculum. They posit this was because teachers, short on time, cut out the societal connections and opportunities to iterate on design. In contrast, Mesutoglu and Baran (Citation2019) found that teachers’ recognition of the contribution of engineering design to society resulted in a higher level of understanding of the engineering design process. They also found that teachers had a better understanding of the intra-iterative nature of the design process when they knew that there was a good deal of reasoning needed in making design decisions during the process steps, to consider criteria and constraints, and about how design decisions were justified. However, no studies thus far have bridged the value of attunement to these social dimensions to the axiological underpinnings of engineering – we refer to this bridging as the sociopolitical dimensions of teaching/learning engineering. This lack of bridging limits possibilities for new forms of learning and being for students and teachers in engineering.

Research also shows that most teachers do not feel equipped to teach engineering (Hsu et al., Citation2011), and that there is a need for professional development focused on engineering education for K-12 teachers (Veety et al., Citation2018). Although teachers can and do emerge from such professional development experiences still holding onto inaccurate ideas about the engineering design process (Dym & Little, Citation2004; Hynes, Citation2012), professional development affords the necessary space and time for teachers to explore what exactly engineering can be about.

When teachers engaged in professional development that focused on a holistic practice-based learning process in which they explored science and engineering practices while unpacking their value and tested instructional strategies that would draw on specific practices, they “shifted their teaching philosophies related to their preferred learning environments and their instructional practices” (Brand, Citation2020, p. 10) as they, through embodied experiences, came to a deeper understanding and appreciation for what engineering practices entailed.

Taken together, K-12 science teachers may benefit from sustained professional development opportunities that focus on exploring the epistemology and practices of engineering in dialogue with the axiological underpinnings of engineering. Developing a nuanced framework – for what engineering is, who engineers might be, what they do and for whom, how engineering is inevitably sociopolitical – is important to the resultant kinds of engineering pedagogical strategies and practices teachers would then enact. We consider how teachers engage in the dynamic process of making sense of and bridging their understandings of the axiological dimensions of engineering with engineering knowledge and practices as they enact curriculum with their students as central to their visioning of a justice-oriented engineering education (see Figure 1 for logic model).

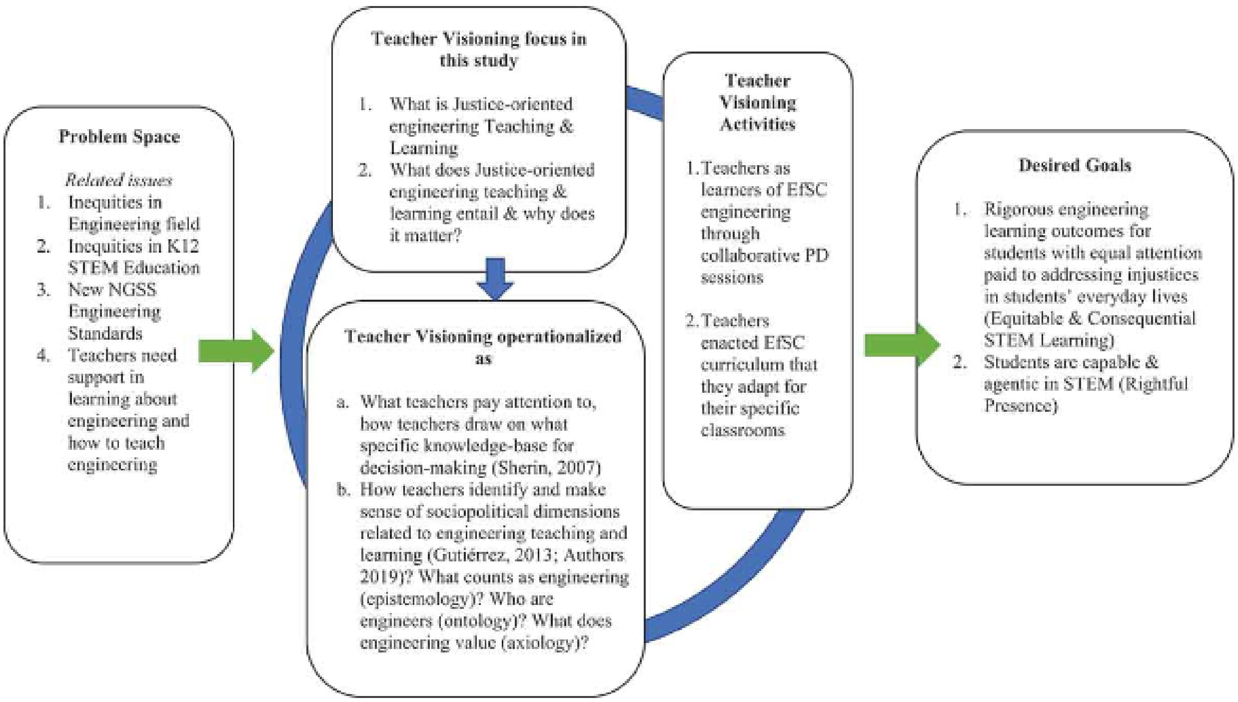

Figure 1. Logic model relating problem space to study design

Teacher visioning

Developing a professional vision involves "socially organized ways of seeing and understanding events that are answerable to the distinctive interests of a particular social group" (Goodwin, Citation1994, p. 606). Sherin (Citation2007) characterized teachers' professional visioning as encompassing two components: what teachers choose to pay attention to at a given moment, and how teachers draw on what specific knowledge-base to make sense about what they have noticed. These two components inform one another.

Drawing from both Goodwin and Sherin, we operationalize teacher visioning in this study to explicitly pay attention to the sociopolitical dimensions of STEM teaching and learning (Gutiérrez, Citation2013; Hara & Sherbine, Citation2018; Tan et al., Citation2019). Gutiérrez (Citation2013) argues that in addition to paying attention to mathematical epistemic content and pedagogy, teachers need to grasp the "political nature of teaching" (p. 8) as necessary knowledge important to teaching, especially in the STEM disciplines which not only confer status in society but are essential for the negotiation of socio-scientific issues in daily life (e.g., Zeidler, Citation2016).

Thus, we are interested in how teachers' emerging visioning of teaching for justice-oriented EfSC unfolds in what they choose to pay attention to and how they unpack and analyze what they noticed, both during the professional development sessions and when they taught the EfSC curriculum. Through their embodied experiences as evinced in what they say, do, and produce, we investigate how teachers' sense-making of the what, why, how, for whom, and to what ends of exploring and teaching EfSC supported the development of what kind of vision they began to hold for teaching EfSC.

Theoretical framework

Equitable and consequential STEM learning

Equitable and consequential STEM learning reflects increased learning and engagement patterns in particular ways. Equitable refers to expanding opportunities for disciplinary engagement and learning in culturally relevant and rigorous ways. Consequential suggests that such opportunities also promote students' rightful presence in disciplinary learning through altering participation and authority structures toward new social futures (Tan et al., Citation2019). Student learning processes and learning outcomes reflect on, depend on, and contribute to teacher visioning. For minoritized youth historically underrepresented in tertiary engineering education and in engineering professions, a sociopolitical turn that undergirds teacher visioning of engineering education is essential.

Rightful presence

Our stance on consequential learning is undergirded by an orientation to justice that centers rightful presence (Calabrese Barton & Tan, Citation2020; Tan et al., Citation2019). The rightful presence for justice-oriented teaching and learning framework proposes three tenets: (1) the necessity of allied political struggle to reauthor rights in disciplinary learning; (2) claiming rightfulness through presence by surfacing injustices; and (3) collective disruption of guest/host relationalities (Calabrese Barton & Tan, Citation2020). Rightful presence pushes beyond "equity as inclusion" as an end goal, since the modes of interaction governing such consign disempowered guests to perpetual marginalization, dependent on the extension of rights at the host's disposal. We argue that such an approach acts to maintain and reproduce inequities because the boundaries of gatekeeping, what it means to "be included," remain unchallenged.

Rightful presence helps us to see how consequential learning involves opportunities to participate in learning in new ways; learning involves the political struggle to belong and participate in new ways. That means the introduction of new discourses, practices, and materials that make both injustices incurred through dominant power relations visible while also orienting practice toward social transformation.

Of particular relevance to engineering is the suggestion that one way in which rightful presence can be claimed is by creating material artifacts, such as engineering prototypes, to literally "claim space" (Calabrese Barton & Tan, Citation2020, p. 6) for the creators. Such materiality acts as a reification of the sociopolitical disruption. Such a way of claiming space through material artifacts also directly shapes the physical environment and is generative of new social interactions, and emerging culture, tied to specific material artifacts that were heretofore nonexistent.

Methodology

We engaged in participatory social design research (Gutiérrez & Jurow, Citation2016), an approach that draws from design-based research (Design-Based Research Collective, Citation2003), formative experiments (Engeström, Citation2008), and equity-oriented forms of inquiry. This approach particularly suits our study for three key reasons: (1) the investigatory and analytical lenses are ecological rather than individual, focused on learning ecologies; (2) participants as "historical actors" who "coordinate past, present future-oriented actions and identities sets the conditions for new forms of agency central to realizing possible futures" (Gutiérrez & Jurow, Citation2016, p. 567); (3) equal attention is paid to transformative social change in tandem with a learning agenda.

With this approach, we position the two partner teachers as historical actors embedded in different learning ecologies including university spaces with researchers during the PD phases, and in their science classrooms with students during the enactment of the EfSC curriculum. Framing teachers as historical actors who engage in meaning-making processes that attune to their historicity of "becoming engineering teachers in middle school" across space and time is productive for insights into how teacher visioning may potentially unfold.

As participatory researchers, we were with teachers during all PD sessions, in the classrooms during the curriculum enactment, and engaged in follow-up reflective interviews after the school year, a period that spanned 12 months (July to June). All PD sessions were specifically tailored to the two partner teachers. Teachers engaged in participatory social design as collaborators in the research process by weighing in on decisions throughout the professional development sessions on focal areas they wanted to investigate, enacting specific adaptations to the draft EfSC curriculum, and electing to sit and consider "sticky points" more thoroughly. In these ways, teachers were involved more extensively in the form and function of the professional development phases, instead of being passive recipients of a scripted PD experience.

Context

The data drawn for this study were collected across one year in three different settings, across three phases of the project (see Table 1). The first phase was a two-day PD that took place at a local university's makerspace. Teachers experienced the curriculum as learners in Phase 1 and engaged in Design Challenge one, where they created an electric art card for someone they love. In Phase 2, teachers engaged in monthly PD in their school where they undertook Design Challenge two, building a prototype to address a community-identified problem. This required teachers to create and conduct a survey of their school community stakeholders, including fellow teachers and staff. Further, teachers also identified specific elements of the curriculum to tailor to the context of Sage. For example, they made decisions on when the EfSC curriculum enactment would flow most seamlessly in terms of extant science content sequencing and how many classroom periods each EfSC lesson would need, where they should place more emphasis in terms of classroom periods, and the available school materials that could be used as prototype-building raw materials.

Data sources across these phases include researcher fieldnotes, video and audio recordings of PD and classroom sessions, interviews with teachers and students, student project sketch ups and prototypes (see Table 1).

Data analysis was guided by Strauss and Corbin's (Citation1988) procedures on open-coding and methods of constant comparison. Coding schemes around teachers' developing visioning on justice-oriented EfSC teaching were developed through two phases of analysis. The first phase involved perusing PD data from Phases 1 and 2 for evidence of teacher visioning development in terms of teacher discourse pertaining to the engineering enterprise writ large, the EfSC curriculum and issues of concern teaching the curriculum; teacher discourse specifically pertaining to their sense-making of community ethnography and EfSC, as related to (in)justices in engineering and in K-12 STEM education; the EfSC process teachers undertook for design challenges across Phases 1 and 2. Teacher interview data were coded similarly using these categories.

The second phase involved primarily data from Phase 3, classroom enactment of the EfSC curriculum. We relied on fieldnotes and teacher reflection interviews to lend directionality for the moments-of-interaction (video data) and particular student projects (video and student interviews) to further hone our analysis. We coded for what distinguished these teacher- and researcher-identified moments as pivotal to teachers' visioning development in teaching justice-oriented engineering. We paid attention to how visioning informed teachers' pedagogical decisions in a dialogic manner, with regard to seeing EfSC as a social and technical enterprise with and for people and how engaging in an EfSC process relates to consequential learning and students' rightful presence in school science. With the help of our theoretical framework, we worked to make sense of the characteristics of teachers' emerging and developing vision on EfSC teaching and learning, including the epistemological, ontological, and axiological elements, and how they might relate to one another.

Sage Middle School and partner teachers

Sage Middle School serves a diverse population of students with 43% black, 38% white, 11% Hispanic, 5% biracial, 3% Asian, and <1% each Native American and Native Hawaiian. Fifty-eight percent of the students come from low income families. The school also serves 21% of students with a range of disabilities. Sage won the "Most Improved Middle School" award in the district and the "(Region) Signature School Award" the year this study took place, both for most improved test scores. While the school displays overt signs of solidarity and friendship for all, such as "This school serves ALL students" posters prominently in the building, incidences of bullying regularly occur. The school also reported a disproportionate data of disciplining African American boys.

We worked with a sixth grade teacher, Ms K., (white, 45 years old), who had taught for 12 years at Sage Middle School. Vivacious and warm, Ms K taught sixth grade science and social studies and was loved by her students. One student described Ms K as "da bomb dot com!" Ms K. had studied for K-6 licensure in education on a science-themed undergrad two-year cohort at the local public state university and had worked the first eight years of her teaching profession at a science magnet elementary school. When asked to describe her core teaching philosophy, Ms K said, "I think any child is able to learn, you just have to know how to reach each student … we see it done all the time … just so long as you find their way, and have the patience to do so; that is key" (teacher reflection interview).

Our second partner teacher, Ms M (white, 37 years old), taught eighth grade science. When we first met her, she had just won the “Teacher of the Month” award at Sage. Ms M was an ambitious teacher, putting her students in the forefront, saying, “All children can learn, but they do not learn at the same pace; and they do not appreciate the same instructional practices on the part of the teacher” (teacher reflection interview). She had recently taught PD workshops for other teachers in the district office. She was open and willing to try new pedagogical approaches recommended by her district, so trying engineering “fit right in.” Ms M specialized in integrated science in her undergraduate degree, then got her teaching degree afterward, and was in her ninth year of teaching science. She was in her sixth year of teaching at Sage at the time of this study.

Engineering for sustainable communities (EfSC) curriculum

The EfSC curriculum for middle grades (engineeriam.org) is a an 11-lesson sequence, each taking between one and three class periods, anchored in principles that reflect engineering for sustainable communities (Tan et al., Citation2019). Of note is how sustainable communities are operationalized to mean, in addition to environmental preservation, the sustained location of engineering expertise within community. There are two design challenges, each emphasizing the important feedback cycles of attending to both technical and social dimensions of engineering design prototyping. The EfSC curriculum stresses community ethnography as a key process to solicit for community input to collectively identify and define a problem space and to engage in community-solicited feedback during iterative design. Such an approach is productive in foregrounding issues of (in)justice present in middle school that students could engineer solutions for in response (Calabrese Barton & Tan, Citation2019).

Findings

Visioning justice-oriented engineering in the middle grades

In this first part of the findings, we explore how two middle school science teachers’ visions of what justice-oriented engineering for sustainable communities (EfSC) is and entails, and the ways in which these visions developed across sustained professional development and classroom enactment of an EfSC curriculum. We suggest that teachers’ visions of justice-oriented engineering teaching began to expand through their attunement to the social/community dimensions of engineering. This attunement centered broader sociopolitical questions of what is right, what is just, and what is good with respect to the engineering process, and what it meant to teach engineering. In particular, teachers began to see themselves in relation to engineering and their community, making others’ experiences and their own important aspects of learning. They also began to see and act within a dialectic between STEM/community, opening up new and generative spaces for further laminating their visioning.

Seeing engineering as, with, and for people

For both focal teachers, having recently been introduced to the new science standards, teaching engineering was a new experience. What this meant was that the teachers had not thought much about engineering generally, nor about teaching engineering as related to the injustices prevalent in the field of engineering. Consider the first few conversations we had with teachers during the fall PD. These sessions focused on sharing the anchoring principles of the engineering curriculum against the backdrop of the lack of representation of women and people of color, in tertiary-level engineering education and in the engineering professions. Both teachers were astonished at the statistics. They exclaimed that they "had no idea that only 4% of engineers are Black!" and "so few women." At the same time, both teachers also commented that they personally did not know any engineers, and that they were nervous about teaching engineering and did not really know how to approach it, although they could also "see how engineering is connected to science … there is science content here [in the curriculum] like circuits and electricity and energy transformations."

Vocalizing these different ways of thinking about engineering representation, e.g., who makes up engineering generally and how do I relate to engineering, created a critical space for teachers to negotiate a starting point for their visioning with respect to teaching engineering in justice-oriented ways. The teachers shifted from being surprised about the lack of diversity and of women in engineering – a fact external to themselves – to their own nervousness of feeling disconnected to engineering. They also considered their own relationships as science teachers and as white women, a more local and personal issue related to their identities as women and science teachers in a diverse community, with engineering as a profession and as part of middle-school integrated science.

As teachers moved to exploring the EfSC curriculum, they did so in a way that foregrounded a central tension that would come to shape their visioning work: STEM/community. For example, they readily engaged in dialogue around which science topics would be most complementary to the engineering unit. Each raised many ideas, used the language of the science standards to build connections, and brainstormed different possibilities. At the same time, however, they both expressed intrigue and concern about what involving "community" perspectives meant, how these perspectives would matter in their engineering work, and how they could solicit for it in their schools. They expressed concerns about the ways community input could support students' development of "rigorous" engineering knowledge and practices.

This tension appeared to be pivotal in both what they chose to pay attention to and how they unpacked and analyzed what they noticed in the remainder of the PD. For example, one activity involved exploring previous students' engineering designs. This included watching two video cases of youth participants who engineered artifacts to meet community needs identified through community surveys. One artifact was a light-up umbrella for residents living in a neighborhood with no working street lights. Another artifact was a wind-turbine powered jacket with an alarm system youth named the "Phantom Jacket" specifically for boys of color to avert police brutality. When the video featuring the light-up umbrella and the young black girl who created it concluded, Ms K exclaimed," That is awesome. BOOM! I love it!"

While both teachers were impressed with the evidence of science knowledge and engineering know-how in the youths' prototypes, they were more focused on questions and insights about community ethnography. For example, Ms M wondered about who and how to define community when she stated, "...I was also thinking what would constitute community in our school … is it level-wide? School wide?" while Ms K wondered about the knowledge that community members might share and how:

> … how do we know … about community knowledge? Like she [youth in video case] knew the concerns … especially those of the elderly., and so, they wouldn't have known had they not reached out, you know. So that, … I loved that … did you say surveyed? She used the internet, or she just asked people? (Fall PD transcript)

In short, both teachers began to wrestle with STEM/engineering knowledge and practice as being in dialectic with the importance of community perspectives in their EfSC visioning.

Working within the dialectic

As the teachers engaged in the design challenges and engaged in community ethnography themselves, their understanding of why community perspectives were key to EfSC and how one might solicit for such continued to expand. Below, we show first how engaging this dialectic oriented the teachers' visioning work both relationally and technically, as they began to see engineering as done not only for people, but also with people and as people. Then, we illustrate how this dialectic became a generative space for furthering this relational and technical work.

Engineering as for/with/of people

In the first design challenge where teachers had to create a light-up electric art card for someone they loved, Ms K chose to create a card for her boyfriend while Ms M created a birthday card for her son's upcoming birthday.

Both teachers thought hard about what design their cards should feature. Ms. K fretted that she was "not a good artist, I can't draw." However, she seized on a drawing tool called the Spirograph which was available in the university makerspace, played around with the various templates, and created what she described as a "beautiful flower-snowflake-like shape" that she thought her boyfriend would appreciate because he was "artistic." Ms M drew a cartoon version of her son with his characteristic curly mop of hair and a lightbulb because, as she wrote on the card – "I like how you think!" Ms M explained that her son was actively advocating for LGBTQ rights in his Catholic high school, persuading the school administration to start an LGBTQ club to support queer and gender-nonconforming students. Ms M spoke of how she is "so very, very proud" of her son. With this design challenge, considering the social aspects of engineering, or "community," took form through teachers' close personal relationships with the card recipients that informed the design.

For the second design challenge, teachers were tasked with innovating a working prototype to address a community-identified sustainability concern. This activity took place during the second day of PD at the university makerspace and continued into the school-based PD sessions (Phase 2). Ms K and Ms M deliberated and worked hard at crafting five survey questions that they posed to their colleagues at their middle school, using SurveyMonkey (surveymonkey.com). Both teachers had not utilized tools of community ethnography, such as surveys or interviews in their science teaching before. To their pleasant surprise, they received 21 responses across teachers, administrators and school staff, e.g., school librarian, within 24 hours. The survey consisted of five questions focused on what community issues might be prevalent, e.g., "What challenges relate to a healthy and happy school community do you think are most important? Select 2 or 3." Options given included "more opportunities to celebrate accomplishments," "needs to be more fun," "needs more sense of community," "needs to be more fair," and "needs to feel safer." Respondents could also elect to submit a response of their own.

Teachers and researchers co-analyzed the data collated by SurveyMonkey. Both teachers were compelled by these data: 82% of respondents said teachers and students should decide what is worthy of celebration; 40% of respondents felt that individual classrooms need to have their own celebratory moments. These data points caused Ms K and Ms M to conclude that "school is too stressful with the tests. We don't celebrate enough." Here, the teachers experienced what it entailed to design and enact a survey, recruit participants, and analyze survey results to surface salient community input. They experienced how to define and constrain a community-identified problem-space.

The teachers finalized the problem-space as "low morale in school" and a possible response as "needing more celebrations that include school and outside school achievements … like singing in the choir, friendship." This response informed what they decided to engineer – a "Sage Celebratory System" that consisted of a WOOT wall with a border of LED lights in a parallel circuit, powered by a hand crank that displayed different categories of occasions/news worthy of celebrating, and a WOOT wall suggestion mailbox where students and teachers could submit "Woots" (Figure 2). When a Woot suggestion written on paper is put in the mailbox, the person who submits it pushes a button the teachers had attached on the lid of the mailbox that was connected to a pencil that then pushes the switch of a sound-system hacked from a self-recording greeting card. The teachers recorded, in unison, the phrase "WOOT! There it goes!" onto the sound card, with a sing-song lilt, meant to encourage and celebrate the person submitting a Woot. Here, we saw the teachers developing an increasingly nuanced vision of EfSC, taking into consideration social elements of the design in dialogue with identifying technical next-steps.

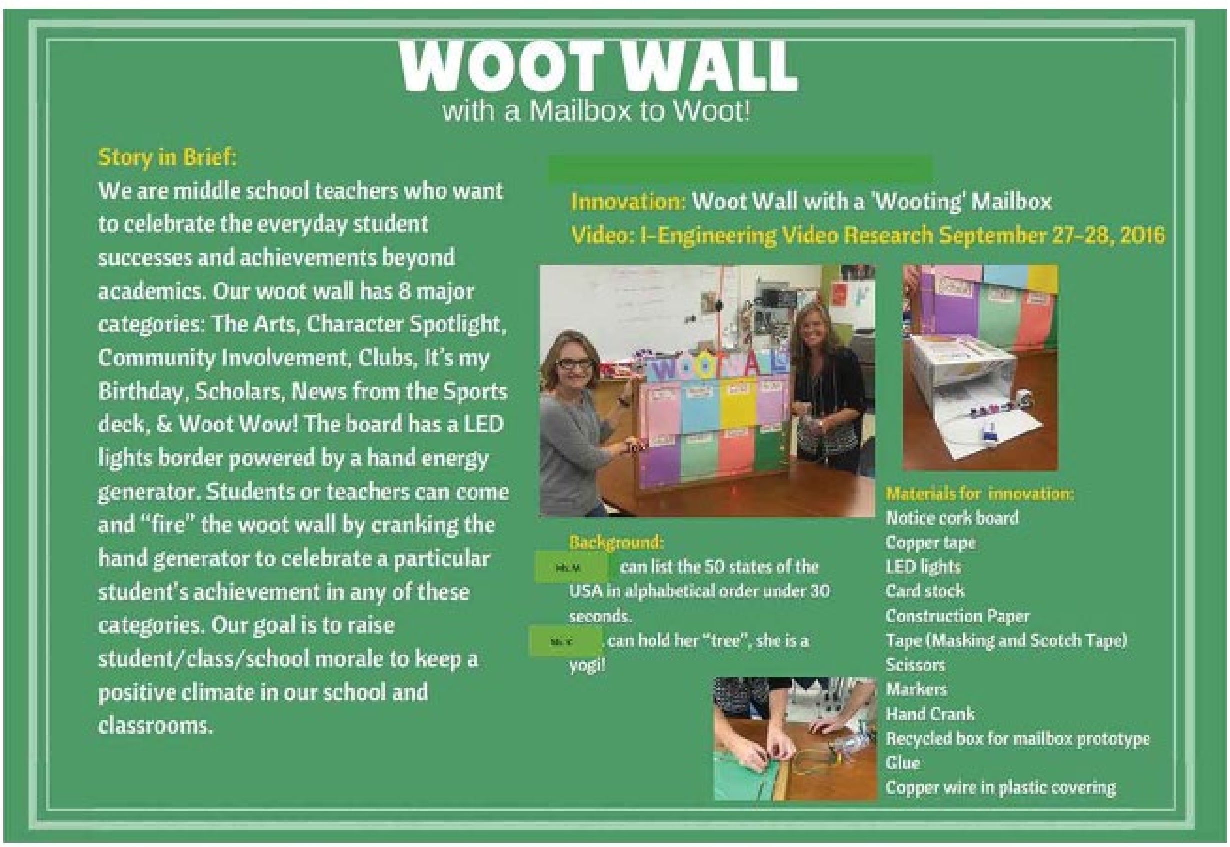

Figure 2. Project Postcard of teachers' Woot Wall

Through the processes of design challenges one and two, Ms K and Ms M experienced what engineering for sustainable communities could entail when translated into practice, drawing on the resources inherent in social relationships and community ethnography approaches such as surveys. These multiple opportunities to see patterns of concerns within their community offered new ways to help teachers seek and reinforce relationalities with their communities – both as they considered the social, political and ethical dimensions of the problems and solutions they hoped to tackle, as well as the importance of their work towards community development. In so doing, the teachers experienced engineering as a community-embedded enterprise, done for people, with people, and as people (Hynes & Swenson, Citation2013).

The generative space of STEM (technical/community/social)

One of the key tenets of the curriculum is the dialogic feedback loop between social/community elements and technical elements of engineering informing one another and lending directionality for iterative design. From engaging in the design challenges, teachers gained firsthand experience of how such a feedback loop might play out and the productivity of such a process while engaging in EfSC.

For example, teachers wanted a "border of lights" to increase the celebratory vibe of the Woot wall and to draw the school community's attention to it. This socially-informed design decision led to the teachers spending significant time in figuring out circuit types, power, load, and energy transformations. They also gained increasing material-related expertise – how to work with fragile copper tape, how to bend the "legs" of an LED light so that they are positioned in a circuit with copper tape but with enough of a gap to prevent short-circuiting, techniques of how to lay down copper tape to avoid bubbles and bumps that could break the circuit.

Ms M reflected on her experiences innovating the prototype: "I definitely felt like it [working on conducting a survey and designing a prototype] increased my confidence with this particular content, like with series and parallel circuits, absolutely. Because beforehand, I was like, uhhhh … *chuckle* … I don't know … I needed this." Ms K appreciated starting with the first design challenge, electric art card for someone you love, before tackling Design Challenge two, Sage Celebratory System: "Had we not done the cards first, I would not have felt comfortable jumpin' right in to it [design task two] without having experience with you."

When considering what green energy source they would use to power the lights of the Woot wall, the teachers first considered solar panels as they had used them for powering their electric art cards. However, a solar panel positioned near a window would mean the lights potentially would be lit constantly, as long as the sun or hallway lights are on. Further consideration of social elements put a pause on the plan and directed them to consider a hand-crank generator instead: Teachers deliberated when and who would light up the Woot wall. For example, Ms M explored how the social dimension related to school practices informed her work when she commented that "We have 10 minutes of dialogue from our principal anyway in the morning, so right after that? The designated time?" Likewise, Ms K also noted, "If it's in our homeroom, we can start our day with the Woot wall … the Woot time of the day!" These insights regarding the "designated time" for the board's use led the teachers to decide that the lights should only be lit then. This social element directed teachers away from the solar panel to the hand-crank generator. These considerations, pausing to note where and when within existing school structures might their innovation be most productively integrated, is yet another piece of evidence of how teachers are layering on complexity in their EfSC visioning. How, why, for whom, and in what ways their innovation would be used mapped onto the how, why, in what ways, and for whom of engaging in EfSC.

Another example of how teachers dialectically considered social and technical aspects of engineering design was evident in their determination to build the sound card circuit of the Woot mailbox. So as to "really encourage students and teachers to submit Woots," Ms M and Ms K wanted the mailbox to sound out their joyful "WOOT there it goes!" encouragement each time there was a Woot entry and the sender pressed a button. Towards that socially informed end, they iterated multiple times to create the circuit with the sound card, a solar panel, wires, and different classroom materials including a pencil, popsicle stick, short ruler and pipe cleaners as a switch that could connect the switch button and the circuit inside the mailbox.

Expanding visions and consequential learning

In the first part of our findings, we showed how teachers' visioning of justice-oriented engineering teaching began to take shape as they started to see themselves as being in relation to engineering and their community, making both others' experiences and their own important aspects of learning. They not only began to see and act within a STEM/community dialectic, but also in ways that challenged their own understandings of how and why community knowledge and experience mattered in engineering.

In the second part of our findings, we explore how teachers engaged in further visioning work even as they began to enact teaching engineering in justice-oriented ways to support consequential learning. First, teachers gained insights into how injustices relevant to middle-school engineering can often reside outside of the science classroom. Of the student projects that emerged from both sixth and eighth grade classrooms, community survey data (N = 83), low school morale, bullying, high stakes testing stress, teacher showing favoritism were identified by students during data analysis as important community issues to address through EfSC. Both teachers expressed surprise at the range and intensity of injustices students solicited through community survey and unpacked through collective data analysis during the EfSC unit. The teachers' discourses shifted from worrying about students not being able to come up with "ideas for engineering" to "I did not know students felt so strongly about silent lunch [a disciplinary measure] … I guess it is miserable to not be able to socialize with your friends during that one time you can [lunch time]" … to encouraging students to seize the opportunity to address injustices they cared about: "Now is the time you can really do something about this!"

We illustrate with student project examples the following related points: how injustices students experienced and their responses through EfSC to disrupt and transform these injustices were materially made visible; and how supporting students through this process seeded new teaching practices that further informed Ms K and Ms M's visioning on what it means to engage in justice-oriented engineering teaching.

One of the student projects from Ms K's class was a solar powered light-up "Happy Box" that featured a cheerful design of cartoon children holding hands in a circle, with an LGBTQ child, denoted by half pink and half blue colors, in the center of the design. Four of the cartoon children featured LED lights, including the LGBTQ child. Individualized envelopes for each classmate sit in the box, ready for encouraging messages. The Happy Box group built their prototype to counteract "low school morale" and "only hearing about test scores in the morning announcements." Once the box was completed and placed near the window for the solar panel to work, Ms K wrote notes to every student in her class. In writing these notes, Ms K noted that she was "amazed at how we are actually using what they [students] made to solve an actual problem" and that she was "psyched to see the students receive their letters and see their smiles." Some students posted Ms K's notes on their lockers, others stuck them onto their school-issued laptops.

In Ms M's class, a group created a board game for in-class play because "52% of those surveyed said school needed to be more fun and 32% wanted to celebrate the good they do." The board game was meant to reduce classroom stress by letting students take a break with friends and socialize during pockets of spare time, e.g., when students finish a task early. Ms M commented that while she made sure to chat with particular students who she knew were having a hard time for various reasons outside of class time, the idea of "building fun into my classroom" was a new idea that EfSC and student ingenuity made possible. Both teachers reflected that they gained insights into a deeper level of how "fun" is important and that the lack of fun is often always related to school-based injustices, that they admitted they "mostly had no idea of." Further, "fun" need not be a frivolous concept but one deeply relevant to middle school engineering.

Second, teachers became attuned to how students may engage with the social aspects of engineering, specifically the importance of community ethnography and the iterative process of considering social and technical elements in problem-space definition and in prototype innovation. While enacting the curriculum, both teachers stressed the importance of paying attention to the relationship between social and technical aspects of engineering. Ms K called the class together at various times of the lessons when groups were prototyping, to ask them how they paid attention to the "social and the technical aspects. You need to pay attention to both and tell us how they are represented in your prototype."

When a group of students decided to build a light-up class basketball hoop so "kids can get their energy out when they need to and not get into trouble, " Ms K enthusiastically found a waste-paper basket from the classroom that they could cut the bottom out of and repurpose for a basketball hoop. The students wanted bright lights around the rim of the hoop to bring attention to it and to make it "fun like a celebration, so kids would use it." Ms K talked with the basketball hoop designers about why it was important to them that the hoop conveyed "fun like a celebration" and students explained that for some students who find it hard to sit still for a long time, "people will say some of them … take medication. call them ADHD" in derogatory ways. To offset any social stigma students might feel, the group insisted on a "fun like a celebration" design, which necessitated a long, flexible parallel circuit supporting eight LED lights that could be wrapped around the hoop rim. Although both teacher and students found this technical specification challenging, they worked together at length to create this circuit.

Likewise, Ms M allowed significant class time for her students to delve into community data and figure out the scope of the problem-space important to students. Being willing to prioritize class time for sense-making of community data and iterative engineering design is not trivial. Given that teachers felt enormous pressures to limit science time in order to meet literacy and math time requirements, teachers still prioritized slowing the process down and spending time with these community data. For a group of students who wanted to address teacher favoritism along racial lines, Ms M gave the students space and a sense of safety in her classroom to discuss an uncomfortable sociopolitical, school-based issue.

Open-ended responses in the community survey revealed that some students felt that there was injustice in how black students received heavier disciplinary measures for the same infractions as white students. The "No More Favorites" group concurred, with two members sharing their own experiences related to such. They created a poster intended for the school teachers' lounge, with three red LED lights calling attention to current unjust practices – (1) Teachers giving some students special punishment; (2) Students feel disrespected; (3) Teachers may not get along with certain students – alongside three green LED lights lighting up suggestions – (1) Treat students with equity; (2) Treat every student with respect; (3) Have a one-on-one talk – for how to engage with black students. Ms M was not aware that some students were experiencing such inequitable favoritism from some teachers and was deeply concerned. She was equally concerned that the student innovators would get into trouble should the solar-powered "No More Favorites" poster be displayed in the teachers' lounge as the students intended.

Discussion and implications

The teachers in this study engaged in a sustained, embodied process of visioning what justice-oriented engineering teaching and learning in the middle grades could be. Over two phases of professional learning, teachers embodied experiences of "doing" the engineering in conjunction with learning more about their community's needs and desires. By embodying these experiences within this STEM/community dialectic, teachers were attuned to the social dimensions of engineering learning to ask and to see how engineering itself could build a better world because they experienced firsthand what EfSC meant and entailed when one paid attention to social/community factors. This put the epistemology and practices of engineering – what knowledge and practices count as engineering – in dialogue with the axiological underpinnings of engineering – what engineering values and, in this case, addressing injustices – became key to teachers' visioning and made an orientation for consequential learning possible.

Early in the process, teachers had opportunities to question their own and to author new relationalities with and in engineering as people who do engineering as they considered whose voices mattered, how and why, and how this related to entrenched inequities in representation. We conjecture that the teachers' embodied learning and experiences as community-responsive engineers addressing authentic community-sustainability issues resulted in teachers' emerging ability to see themselves as people doing engineering with and for other people. As a result, they were more able to recognize and support students' efforts in similar engagement. When teachers explored prior students' engineering designs, and later built their own, they began to use the dialectic between the social and technical to further shift their own relationalities with and practices of teaching engineering as engineering for, by, and of people. This visioning work that teachers did through their attunement to the social elements helped them to learn to see the unseen – the injustices that structures of oppression make invisible – as things upon which one could act, in an engineering classroom. Teachers' attunement to the social elements was related to how they further made sense of the axiological underpinnings of EfSC, engineering for sustaining the well-being of specific community members, as collectively defined. As teachers made sense of their students' experiences in the world, they did so with an ever-widening view of who they are as classroom STEM teachers in relation to their students, STEM, and the world. Teachers' visioning in this EfSC context was one of sense-making of engineering practices and that of justice as youth make visible their own hoped-for futures.

These findings offer insight into how and why the teacher visioning process should be viewed as always embedded in sociopolitical practice, rather than individualistic meaning-making. That is, teacher visioning develops over space and time as teachers engage as "historical actors" (Gutiérrez & Jurow, Citation2016), laying down a pathway of their embodied sense-making, involving thinking, talking, and doing with human and material resources, that act to orient teachers in future visioning directions. As teachers imagined and enacted their own professional roles as engineering teachers, they did so in dialectic with how their students saw, imagined, and enacted engineering in their lives and classroom communities. Thus, teachers' own visioning occurred alongside their students' experiences of EfSC. Ms K and Ms M's community survey to their school colleagues first exposed them to community concerns currently at work in their school, specifically those of low student morale and lack of celebrating achievements beyond test scores. This led them to innovate the Sage Celebratory System. When facilitating their students' sense-making of community survey data, the teachers and students further delineated the ways in which and for whom "school is unfair" and "low school morale" unfolded in everyday, often through mundane school practices, and what they could engineer to address that problem space, yielding student projects such as the Happy Box and Board Game.

Lastly, we note that this work of visioning is filled with tension and contradiction. In learning with and alongside their students about how powered relationalities shapes opportunities to learn, teachers had to see themselves inside the process. They had to layer into their visioning their own complicity in the injustices named by students, whether that be the lack of fun in their classrooms or different kinds of bullying not fully evident to teachers. They had to share the authority to engineer with students in order to more fully address these concerns as a part of learning engineering.

Implications of this study suggest that teachers need opportunities to build their vision through a range of activities in practice – as co-learners alongside each other and then alongside their students and in taking up EfSC-specific tools from the curriculum, such as community ethnography and iterative design. In our study, it was not so much that teachers needed the time and space to act on a vision they may already have (e.g., Parsons et al., Citation2014), but rather that the visioning process itself took form, developed, and laminated through practice and co-learning grounded equally in both engineering content and know-how and community insights. Further, teachers should be encouraged to view the process of visioning as not only about what it means to teach or learn, but also how teaching and learning are situated in sociopolitical context (Hara & Sherbine, Citation2018), as these understandings underpin how they enact pedagogical practices. This means that opportunities to critically engage with how discourses and practices of power typically legitimized in school spaces actually act to oppress learning opportunities, particularly for students of color, should be considered integral to visioning work. In our case, this kind of engagement occurred as teachers co-learned engineering alongside their students, primarily in their classroom enactments, and created spaces for teachers to develop and fine-tune their justice-oriented visioning, in relation to their students' experiences. Teachers and students together engaged in visioning and meaning-making of EfSC, experiencing the possibilities when questioning what is good, what is right, and what is just when one engages in engineering.

Conclusions

This twinning of teacher visioning with students' hoped-for social futures is necessary toward justice-oriented engineering education. Such a twinning takes a critical stance on teacher visioning and involves learning to see the unseen in order to challenge unexamined assumptions related to schooling, teaching, and learning. As teachers develop their vision of what it means to teach toward the goal of justice-oriented engineering in middle school science that would support students' rightful presence, they simultaneously hold in dialogue who students are and can be, what it means to engineer for community, and their own sense-making as a primary stakeholder in this work. Such a dialectic form of visioning is essential toward supporting an expansive engineering learning outcome for students that prioritizes epistemic gains, justice-oriented presents, and hoped-for futures.

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Table 1 Phases of the project, data collection and analysis

	Phase 1 two-day university-based PD (10 contact hours)	Phase 2 five sessions, Monthly school-based PD (7.5 contact hours)	Phase 3 11 days curriculum enactment with lunch + afternoon iterative time (16 contact hours per class)
Setting	Local university makerspace	Sage Middle School	Ms K's sixth grade & Ms M's eighth grade science classrooms
Participants	Teachers + researchers		Teachers + students + researchers
Activities	Teachers explore video case studies of youth who engineer to solve community issues Teachers engage in and experience the EfSC curriculum as learners with researchers facilitating. Teachers engaged in Design Challenge one: make a light-up card for someone they love	Teachers engage in Design challenge two, involving community ethnography: build something to address a community-identified problem. Teachers identify specific activities/lessons in the curriculum to adapt to suit school context. Researchers are facilitators	Teachers enact EfSC curriculum in their science classrooms. Researchers are participant observers and co-teachers when required
Data collected	Video & audio of sessions (17.5 hours), field notes, teacher reflection interviews (8 hours, on the PD sessions (overall impression, what was helpful, what they learned about EfSC & community ethnography, as related to their engineering		Video & audio of lessons during classes (32 hours), fieldnotes, teacher reflection interviews (4 hours), student artifact interviews (10 hours), student artifacts sketch ups + prototypes
Teacher visioning