Framing equity through a closer examination of critical science agency

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Abstract:

Science for all has been touted as the primary path to equity in science education in the USA. We argue that without attention to the power imbalances that both create and sustain dominant views of science education; such an approach is not equity-oriented but rather science colonizing. In this manuscript, we draw upon critical views of justice to argue that a more equity-oriented approach to science education focuses on *critical science agency (CSA)*—using science knowledge and other forms of distributed expertise to redress instances of injustice. Using critical participatory ethnography methodology with a social practice theory lens, we suggest that youth enact forms of CSA by directly incorporating their developing understandings of intersecting scales of injustices into their scientific knowledge and practice in an iterative and generative way. This process enabled the girls to reshape scientific knowledge and authority hierarchies in their science community. Finally, partly due to the disruption of dominant norms of science teaching and learning, the girls in our study utilized and shared expansive expertise enacting CSA. These findings advance our fields' understanding of CSA, and its potential for pushing science education to be more justice-oriented.

Keywords: critical science agency | equity | justice | identity

Article:

Recent reform efforts in science education have focused on supporting equity through increasing diversity of the STEM workforce, promoting access and addressing who gets access to prescribed science knowledge and practices (Philip and Azevedo 2017). This reflects equity narratives that reinforce a narrow view of what it means to become scientifically literate. Western (mainly white, male and middle class) cultural practices are viewed as the norm in science education (Stanley and Brickhouse 1994). The goals of such are to master the knowledge and practice of science. Students who draw upon other ways of knowing and doing are positioned as deficit. Such a stance disproportionately oppresses students of color and girls.

Further, little attention is paid to how scientific knowledge and practice may be contextualized, merged with other ways of knowing, and used toward local and global sustainability (Bang and Medin 2010).

We argue that the power imbalances that create and sustain dominant views of science are science colonizing rather than equity-oriented. Rather, a more equity-oriented approach to science education is grounded in the goal of *critical science agency.* We use the term critical science agency (CSA) to refer to opportunities to merge scientific and other forms of knowledge and practice to address instances of injustice (Basu, Calabrese Barton, Clairmont and Locke 2009). This presents a more complex view of science education for it suggests that a part of becoming literate in science is being able to use the knowledge and practice of science in conjunction with various other forms of expertise to take action on critical issues in one's life and society. Without taking into account how youth historically marginalized in STEM take up science as a part of their discourse and practice in the world, science education will remain defined and practiced as a separate culture, community, and power.

This study focuses on the following questions:

1. How do youth enact CSA during a green energy unit?
2. In what ways, if at all, does the enactment of CSA address injustice at multiple scales?

Taking a critical justice stance on equity

The term equity has gained traction in science education over the past several years. However, there is little agreement on what equity means or what the goals of equity should be in the teaching and learning of science. Because the term has been so widely applied, it has come to mean little more than a phrase about access. Such broad use has raised questions about access and opportunity—where is science being taught? What is the quality of the instruction? However, there is little interrogation beyond these ideals. This distributive view of equity, grounded in a liberal political view of equality (Rawls 1971), implies a sense of impartiality (Young 1990). We see this stance echoed in reform movements in the USA: The assumption that access to high-quality teaching, materials and standards will support the development of science mastery among all students.

However, access and opportunity are not neutral experiences. Within sociological studies, this view of equity includes both access to resources *and* the ways in which access has been historically institutionalized. We can think about this in terms of whom has been granted access and in what ways. Little attention is paid to the ways in which the distribution of resources is an artifact of institutionalized structures. Policy documents offer scant attention to how the cultural resources for reform-minded science education are grounded in western ways of knowing/doing, or to the deep gaps in resources that exist across schools and school districts (Basile and Lopez 2015).

Despite this dominant distributive view, more critically oriented views of equity have gained ground in science education. These views of equity, which include "relational" views (Dawson 2014), challenge the normative practices and power structures in science education.

Rather than focusing on equal access and opportunity, individuals' needs are taken into account in relation to who they are and what their lives are like. Nancy Fraser and Axel Honneth (2003) remind us that the goal of recognition is to recognize need and value difference rather than to promote assimilation to the dominant culture.

Further, the relational view of equity calls attention to how current policy documents frame the outcomes of science education in assimilatory terms, often involving uncritical and unidirectional border crossing (Aikenhead and Jegede 1999). Relational views of equity point out the ways in which youths' historicized experiences may not be a part of the standard curriculum. They also point out the risks individuals face when seeking to enter a potentially unwelcoming world. A relational view of equity reframes access and opportunity, situating the importance of promoting multiple points of entry and forms of movement through experiences.

We are concerned that even when both distribution and relation are valued, such views do not necessarily disrupt participation boundaries and knowledge hierarchies such that full participation in community is possible (Jurow and Shea 2015). We, therefore, draw upon critical views of justice to reframe equity in science education (Balibar, Mezzadra, and Samaddar 2012). Critical justice views of equity address sources of injustice in addition to seeking the goals of distributive and relational views of equity. Power dynamics are always at play in science classrooms, acknowledged or not. A critical view of justice acknowledges the importance of access and opportunity, and of recognizing the many ways of knowing children bring to school. However, a critical justice stance also has a "disruptive dimension" (Squire and Darling 2013, p. 61). This view calls into question traditional patterns of participation in science to expand upon who and what areas of expertise are recognized and valued, potentially disrupting participation boundaries and knowledge hierarchies (Jurow and Shea 2015). A critical justice view of equity challenges the conceptual and political underpinnings of equity in science education by putting attention on the need to re-shift relations of power and position within science education and its intersections with historicized injustice (Bang, Faber, Gurneau, Marin, and Soto 2016). This stance foregrounds attention to making visible and upending injustices located in current practice but grounded in historical, social and geographic histories (Balibar, Mezzadra, and Samaddar 2012).

In addition to critiquing dominant norms of participation in science education, a critical justice view of equity disrupts the expectations for learning outcomes by drawing attention to the importance of supporting outcomes that include but expand beyond disciplinary learning to also include critical agency (e.g., using disciplinary and other knowledge to take action on things one cares about) and social transformation (e.g., new patterns of participation). These more expansive perspectives legitimize meaningful outcomes for learners beyond those predetermined by the writers of science curricula and standards. Drawing on Gutiérrez (2008) and Engeström's (2001) work around expansive learning, we consider how disciplinary knowledge development intersects with youth's cultural practices as they navigate across their learning community. The science education community's hierarchy itself may be disrupted as youth use their expertise to work for more just outcomes.

Linking critical justice views of equity to critical science agency

Critical science agency (*CSA*) is an outcome of critical justice views of science education. CSA is a form of agency youth enact when they collectively use their scientific understanding in conjunction with other forms of expertise to investigate and redress injustice in their lives through seeking more equitable alternatives (Basu, Calabrese Barton, Clairmont and Locke 2009). To enact CSA, youth critically read their world (Freire 1970) to expose and understand oppressive norms and structures. Often, youth deepen their understanding of the historical rootedness of injustice as they investigate STEM-related inequities such as poorer communities suffering from lower air quality or access to green spaces or the prominence of fracking sites among lower-income communities (Finley-Brook and Holloman 2016).

CSA has at least three components: that youth develop expertise in both science and of their community contexts; that youth use these forms of expertise to identify and take actions collectively on problems within the community; and that such actions are justice-oriented. In this paper, we explore CSA as one expansive outcome that promotes more equitable engagement and futures in science and engineering. We believe that CSA is an authentic equity indicator in science education as it can reveal how, why and to what extent youth use science understandings to investigate their worlds. Through the enactment of CSA, youth may disrupt the power distribution both within and outside their classroom community.

A participatory critical ethnography approach

We used critical ethnography with participatory research approaches (Cammarota and Fine 2008) to understand how youth enact CSA to concurrently address multiple scales of injustice. Critical ethnography is “rooted in the belief that exposing, critiquing, and transforming inequalities associated with social structures and labeling devices (i.e., gender, race, and class) are consequential and fundamental dimensions of research and analysis” (Calabrese Barton 2001, p. 906). Participatory research methods align with this work as they may disrupt inequitable power dynamics commonly perpetuated by researchers on participants (Paris and Winn 2014) as this study investigates if youth enact CSA in their own community.

The study was embedded in a week-long informal summer program of a STEM sixth-grade unit focused on designing solutions that make school communities more sustainable. Our research team developed the unit and then co-revised it with youth and teachers. Throughout the unit, youth were engaged in investigations about energy production and transformations (with a focus on electrical system) and used community ethnography techniques to define problems connected to sustainability in their community and to design solutions that utilize a green energy source. The curriculum aims to support youth in developing science practices and knowledge as they deepened their understanding of community challenges and worked on their engineering designs. During the unit, youth iteratively engaged with their community, developed new expertise while designing a solution to make the school community more sustainable. First, the youth created electric art (artistic designs incorporating electric circuits composed of copper tape, batteries and LED lights) as a way for them to learn about circuitry. Then, they learned about different types of energy transformations through renewable energy stations where they balanced the constraints and affordances of using solar panels, hand-crank generators and piezoelectric pads to power their electric art. Next, they used community ethnography through an observation walk and interviewing community members about problems their community wanted to address. They chose a problem to address and designed an engineering solution that utilized lights, a simple motor and/or a sound maker and a green energy source. The youth then prototyped their design and refined it through another round of community feedback. At the end of the summer program, the youth shared their designs with their community through a showcase.

Ten girls and two boys from a range of ethnic/racial and SES backgrounds participated in the engineering summer program. Our work was participant-centered in how the problems in the engineering unit were defined, how we collaboratively sought action to address those problems, and the focus on transformation of local contexts toward empowering ends (Cammarota and Fine 2008). The critical nature of participatory critical ethnographic work was important to us, given that a central goal of this work was to enact engineering design experiences in ways that position the girls with power and authority in engineering and in their communities.

Our data include: (1) video recordings of the summer program, (2) conversation groups that occurred at the end of each summer program session, (3) field notes, (4) artifact interviews with youth about their engineering design, and (5) the youths' work. Data were analyzed in the grounded theory tradition, using a constant comparative approach (Strauss and Corbin 1998). The first phase of analysis involved open coding by perusing all generated data to surface (a) critical episodes of engagement in the engineering design work (e.g., group activities during the summer program or informal science spaces that featured particularly salient performances, in talk and actions, by the youth and were further invoked by the youth subsequently in time/space); (b) the knowledge and practices that youth drew upon during critical episodes; and (c) how they iteratively defined the problems they were seeking to solve. Weekly conversations were held among the authors as a way to work toward a more "expansive consensus"; that is to say that any differences in view were debated until new meaning was generated as a result of our differences. Youth participated in the analysis by sharing what they thought was important for researchers, teachers and youth to know about engineering and their experiences, providing critical feedback to help co-revise the unit and member checking the analysis. Participants created how-to videos to be shared with youth and teachers using the curriculum in the future, and two participants later lead-taught two STEM learning experiences to their peers in their own sixth-grade classroom.

With the help of our theoretical framework (critical science agency), we then worked to make sense of why youth took the actions that they did, and the meanings the artifacts youth produced had for them and why. This axial phase of coding was used to uncover relationships and connections between the youths' science and community knowledge and practice, and their efforts to solve problems with their knowledge/practice. The relationships and connections identified in this second stage of coding guided our selective coding and became categories and themes, from which our example cases were selected for final presentation. Codes that emerged included knowledge/practices (engineering, science, community), collaborative and distributed expertise (youth–youth, youth–facilitator, youth–other community members), defining problems, designing solutions, addressing injustice (identifying injustices, scale of injustice, resisting injustices), interaction between community expertise and science expertise (deepening science expertise to address community challenges, using community resources to develop additional needed expertise). Analysis was member-checked with participants throughout this process.

Two cases of engineering for sustainable communities

In this section, we present two engineering design cases: Emilia and Tara's design of the *Woot Wall*, and Gabby and Elise's design of *Robby the Trash Talking Recycling Bin*. We highlight the ways in which the youth moved through the engineering design cycle as they defined community problems and designed engineering solutions to those problems. Within each case, we look at how youth developed and enacted CSA, and used these developing knowledge and practices to address problems that mattered to their summer program and school communities along with their local neighborhood communities.

Emilia and Tara's Woot Wall

Building a Woot Wall: leveraging expansive expertise

Emilia and Tara are best friends and have attended public school together since kindergarten. They were rising eighth graders when they participated in the summer program. They decided to enroll together in the program as they enjoyed working together as they regularly do in school. The girls were the oldest program participants and were very interested in creating a sustainable design that was also educative for other participants. They felt they could provide this expertise to their classmates, and our teaching team did the best to recognize this effort. Their final design, the Woot Wall, was a hand-crank generator powered light-up three feet by six-foot bulletin board used to celebrate youths' accomplishments. It had sixteen LED lights laced around the perimeter of the board in one long parallel circuit.

The Woot Wall design, as they had sketched it, initially contained two lights in a series circuit. Feedback from peers led the girls to decide to expand the design to sixteen lights, four on each side of the board. Tara, upon analyzing community feedback, emphasized that the two-light design was "boring" for kids. Emilia further shared, "I think it is important because in order for it to be a proper hall of fame or [Woot Wall] it has to make the people who have their project on it make them feel special to have it on the board." Important here is the girls' recognition of community members' sense of accomplishment, while also educating others (such as teachers, other students, family and community members). Having more lights, as the community members identified, would be a way to be supportive of that effort.

After deciding on sixteen lights, they carefully began to construct the series circuit. A significant amount of time was put into making sure the LED lights flowed in the same direction, and that they were equally placed across the bulletin board so it would be aesthetically pleasing. However, after completing their circuit, it did not work. They checked to make sure the LEDs were properly placed and well connected in the circuit, but still found that they could not get them to light. They concluded that the hand-crank generator would not produce enough electricity to light up all the lights and were frustrated that they would not be able to realize their design. As Tara explained:

> The frustrating part was when our lights did not light up. We thought we did it perfectly, and it didn't work. That surprised us. But Christina [one of our teachers] said it was okay, and that maybe the problem was with the circuit. It's not like I was just going to give up, but I guess I was just frustrated about that.

As Tara noted, the two girls were encouraged to test the power requirements of their circuit. With their teacher, they searched through their previous investigations in the unit to recall how to test for power requirements. They recalled that parallel circuits have lower overall power demands than series circuits and wondered if this could be their problem. Together with a teacher, the three of them decided to test the LED lights in increasing fashion (beginning with one light, then two, then three) in the form of a parallel circuit. When they saw that three lights were successful, they continued to add LED lights until they completed the circuit with sixteen lights. The parallel circuit was a success, and they were able to light up all sixteen LEDs on their Woot Wall with one hand-crank generator. As Emilia explained:

> Emilia: At first, I was thinking, "Oh no, what did we do wrong?" I knew that it meant that we needed to spend a lot more time working on it and what was wrong. But, I know that we learned a lot from the experience even though it did take another hour of trying to find the problem to fix it
>
> Katie: How did you feel when you did get them to work?
>
> Emilia: It made me feel a lot better because I was able to find a solution to a problem and it helped by first making a small example on the wall and then kind of adding on to it and [LED lights] covered the entire wall

As Emilia's narrative illustrates, the learning experience of discovering what circuit would provide enough power to light up the sixteen LEDs was an important one. The girls did not want to sacrifice the community feedback of wanting to make a board that would do justice to their accomplishments. They wanted to "find a solution to a problem" by creating smaller opportunities for testing and refining throughout the engineering design process. As they discussed with their teacher, if it was not one long parallel circuit where they could light up all sixteen lights, it would have been smaller series circuits. However, the girls did not wish to sacrifice the social dimensions of the designs due to the technical constraints imposed, and worked with "small examples" until they were successful.

These constraints led to important learning experiences. The first is that Emilia and Tara, upon completing their Woot Wall design, served as mentors to other groups having problems with their engineering designs. This was not a trivial point. This learning experience in assessing power demands was critical for them, and they felt more willing and able to be mentors to other groups. Most of their peers found creating either simple or series circuits much easier than parallel circuits, and having help from their peers in constructing this lower power-demand circuits was important. Additionally, during a showcase of the designs at the end of the program, Emilia and Tara felt comfortable sharing their learning experience to their peers and peers' family members. They educated them on differences between series and parallel circuits and how the electricity flowed through their Woot Wall to brightly illuminate all sixteen lights.

Why the girls made the Woot Wall: scales of injustice

Tara and Emilia spoke about three concerns that informed the Woot Wall design. First, they identified the need to help improve class morale. They felt that the wall would be useful in recognizing youths' accomplishments often ignored in traditional classrooms such as kindness and other efforts that could support community among students. As Tara stated, "It turned out it was really fun because we could still put the achievements and designs of all of the other groups on there." They were particularly moved by the lack of recognition their classmates received in school, as well as the lack of positive motivation that their peers had to try to do new things. As Tara further elaborated, "[The Woot Wall] can help others to be motivated to reach their goals, too… They can make things too."

Second, Emilia and Tara connected their engineering design work to the larger-scale problem of global climate change. The youths' design mitigated negative impacts on the environment. They used a renewable energy source (the hand-crank generator) and recycled a previously used bulletin board. When the youth had initial problems with powering the lights, it was suggested that they use lithium batteries, but they refused as they drew on their expertise about climate change and energy source trade-offs. Tara explained that the batteries would end up in the landfill, and they should use a renewable energy source because they are better for the environment. In post-program interviews, Tara explained that the hand-crank was an important part of the design because "it's an energy source that won't harm our earth, and it's an energy source that is inexhaustible." She also shared how the Woot Wall showed one way to avoid using coal as an energy source:

> Tara: It's not like using coal, or using a battery. You are using mechanical energy to light up the lights
>
> Christina: Why is this idea of coal important to you?
>
> Tara: Because it's bad for the environment. it's not good for the environment because,… because you are burning coal and it's just not good
>
> Christina: Just the idea of using coal as an energy source is a bad idea?
>
> Tara: Because when you burn fossil fuels it's bad for the environment. It's making more CO_2 in the air and it's making climate change happen
>
> Christina: So fossil fuels, coal, CO_2 and global warming?
>
> Tara: Yes, but global climate change

Through this exchange Tara expressed concerns about global climate change and ways engineering designs can help to mitigate it.

Third, the girls described the Woot Wall as a way to educate others about the role humans play in climate change *and* about what kids are capable of doing. Emilia explained the design of the Woot Wall itself educates and could motivate others to use a hand-crank generator.

> They learned that is was possible, you can use something as simple as a hand-crank. Well, I guess some people might know about the flashlights with the hand-crank. They might have thought 'Oh yea the hand-crank can light up a flashlight so it would be useful.' But if they saw this board they could see a hand-crank that could light up an entire board, you know they could see that hand-cranks have a whole lot more potential and they also learn that with the hand-crank they can make different sorts of circuits like a parallel circuit to light up a bunch of lights, like we have sixteen lights on it.

The girls also put informational cards about other youth engineers' green energy design projects on the Woot Wall. This allowed others to learn about different ways green energy designs can be used to support communities. Emilia further elaborated, "They also learn from the projects that are on the board… other projects that other people did so they are learning about other alternative energy projects too."

Tara and Emilia also felt that the Woot Wall educated others about how girls their age were capable of making and engaging in engineering design, pushing back on the injustice of the dominant narrative about who can do science and engineering in meaningful ways. Consider Emilia's response when she was asked about what others would think about finding out that she made the Woot Wall: "They would see that this wasn't made by professors at an institute or something, but it was made by you know a middle school girl at that… I think, over the years, middle schoolers have gotten themselves a bad reputation, and since I am a girl it is not like the stereotypical scientist so yeah." Emilia backs up her point by elaborating on how during science class in school, students most often learned about male scientists:

> Emilia: Most of the scientists they have learned about like Albert Einstein are men and like women scientist in history are not really taught about in schools as much, but except in science this one PowerPoint it showed the opposite of stereotypical scientists
>
> Katie: …So if someone saw a picture of you on a PowerPoint and they said, "Is Emilia a scientist?", what would you say?
>
> Emilia: I would say yes especially if there was a picture of the Woot Wall in the background or something like that then they would be like, 'Yes!'

In this statement, Emilia called out education level, age and gendered stereotypes about who can engineer and do science. By creating the Woot Wall, Emilia pushed back on that narrative and recognized her own position as a scientist in that moment. Similarly, Tara recognized her own expertise and agency when she explained after finding success, "I didn't think I could make it, but now I gave myself more confidence that I can make something." She later elaborated, that people would see the Woot Wall and think "That I can make that kind of stuff and I can motivate other people to make that kind of stuff." Through the completion of this community engineering design, both girls pushed back on problematic narratives of who can use science meaningfully, and established for themselves and their community that they could.

Gabby and Elise's Bobbi the 'Trash Talker' recycling bin

Building Bobbi the 'Trash Talker' recycling bin: leveraging expansive expertise

Gabby and Elise are close friends. At the time of the summer program, they were rising sixth graders. They created *Bobbi 'The Trash Talker' Recycling Bin*, a solar panel-powered recycling bin that spun a wheel whenever the sun was shining, and powered a recording that said "Please recycle" when users pressed its button. Gabby explained, "The purpose of Bobbi is to encourage people to recycle positively. Not forcing them really, just positively encouraging them to." They designed Bobbi to encourage community members to recycle by attracting them to the recycling by both the technological additions to the repurposed recycling bin, but also by social considerations indicated by decorating the recycling bin to look like a lifelike "cute" and "funny" cartoon character.

Through multiple design iterations, Gabby and Elise considered both technical and social aspects of their design. Elise shared advice for other youth engineers, emphasizing connecting the design process to community perspectives throughout the design process, "I would probably tell them to ask other people about their, about what they thought… Because then it's not like, just what you think. Which is good. It's like what other people would use." When Gabby compared Bobbi to her and Elise's initial sketch up, she noted that she made many technical and social design changes throughout the engineering design process:

> Obviously you can see the voice box which is the greeting card and then the solar panel. That pretty much stayed, except that the voice box is battery powered, but it's eco-friendly. It's small battery-powered. We originally were going to have a button that had copper tape that completed the circuit but it changed to a switch. Originally we were not going to have a spinny thing but we really liked the spinny thing. We were going to add a hat, but with the solar panel on top and then a press me button on the hat, with a button. It wasn't going to have too much cardboard. but we were going to need more wire to run through because we had to run it all the way down to the bottom.

This quote shows that the girls balanced many design factors. They considered environmental sustainability in their design. While the spinny thing (the decorated electric motor) was powered by the solar panel, they also used a three-volt battery to power their sound recorder from a recycled greeting card. Their design was constrained by a limited supply of wire so they removed Bobbi's cardboard hat. They found a premade switch that they used to replace the switch they tried to make on their own from copper tape. Finally, they used their expertise developed earlier in the unit while creating electric art cards to construct the electric circuit for Bobbi. During electric art, the youth learned how circuits work and how to make them through a scaffolded activity exploring the parts of a circuit, some direct instruction with tips about how to make a circuit, observing models made by other youth and receiving one-on-one help from both adult facilitators and summer program participants. Below Elise explains how she figured out how to make an electric circuit through multiple iterations of designing an electric art card:

> I made a paper circuit for my dad for Father's Day. I used the copper tape. I just kind of put a line of it over, like, if this was the paper I put it just here. [Drawing the circuit with her fingers], and when I put the little light it was sticking out it was on the other side.

> And there was the battery was down here. So when I closed it, it completed the circuit and the light would turn on.

She also explained how working collaboratively helped, “It helped because then I knew about the circuits and how when you connected the circuit that if it was only connected on one side it wouldn’t work. If we worked on this alone without talking to them about it then it would not work.” She leveraged this new science expertise and working collaboratively to create the much larger circuit for Bobbi.

The girls focused on the aesthetics of Bobbi to increase attention and enjoyment by the would-be recyclers. They designed Bobbi’s eyes to look like the character BMO in the popular animated cartoon *Adventure Time*, which they knew their peers enjoyed. They created an allergy list that the girls wrote on a piece of metallic paper that they put onto Bobbi like a badge to make their design funny. Elise explained that the allergy list, which included things like food and band aids, was meant to teach people what can and cannot be recycled, “That’s just to show people what they can’t recycle because we don’t want people throwing food in there, and we thought it was funny.” Similarly, Gabby explained why they used the allergy list, “Because we always wanted to put a sort of a funny spin.” Drawing on both positive and negative school experience, she emphasized, “It should be fun for people because I know I learn better when the thing is fun.” Not only did she think people would be more likely to recycle if the design was fun, but it would also help them to learn more.

The girls collaborated with other community members as they worked to figure out the best place for Bobbi to collect recycling. Elise explained how they had to balance technical and social dimensions to figure this out: “Well we wanted to put it somewhere where it’s really sunny. Like by a window so, like, if we didn’t have the solar panel and we covered it up and then switched the button the thing wouldn’t spin. And then it would just be kind of like…not given attention.”

They studied the building to determine the best spot for their design. They made observations about the amount and quality of natural light available, and how many people walked by it. They decided it would be best by the café in the entry way of the summer learning program’s building because there are many windows and lots of people walk by it. They made sure to interview workers at the cafe because they would be most affected by the placement of the recycling bin.

When their project was completed, the girls designed a postcard explaining their design. As Elise explained: “[The card showed] that recycling is important and it’s really kind of difficult to make new inventions because they don’t always work. And you have to change your idea a lot.” They shared their postcards with others so they could learn about their recycling bin, but also to be motivated to do their own engineering.

Why the girls made Bobbi ‘the trash talking’ recycling bin: scales of injustice

Gabby and Elise designed Bobbi after engaging multiple community members in surveys and dialog. Even though they noticed that the building had multiple recycling bins, they learned from community members that not enough people were using them. Elise explained, “The people in the office wanted all the people walking around to recycle more. And then we just figured we could make a recycling can that did stuff that made people want to recycle." There was not a lack of recycling bins. Rather, individuals not using them was the problem. They also sought feedback from various community members during multiple stages of the design process to ensure that the community's perspective was included. As Gabby explained:

> When we got the idea when we decided to build Bobbi, we had to cause we decided that we wanted to make sure that was the proper idea that we wanted to know that would actually help the environment instead of just being a dud, and it just doesn't help…We wanted to make sure people wanted to recycle and not just that they wanted to think about recycling instead of just someone telling me to recycle so I should.

The pairs' perspective highlighted the purpose of engineering as helping community members.

The girls were also motivated by environmental concerns because of both personal experiences and learning at school and the summer program. They sought to use a green energy design that limited the release of carbon dioxide while trying to promote recycling because of concerns about landfills that affected their loved ones and larger community. The girls viewed these environmental challenges in both local and global ways.

Locally, the girls were concerned about landfills, which as Elise explained are "big piles of trash. And that sounds pretty gross." However, Gabby's family was directly affected by landfills. Her grandmother lived near one. She shared, "Right in front of our street, there's just a huge landfill, and I am like seriously and she is used to the smell and it smells really bad." She was concerned about her grandmother's quality of life as well as the challenges of reclaiming the landfill once it closed:

> …they should at least turn it into something that will help the community after they are done because everyone says it's going to take a million years to decompose and I am like exactly that hill is just going to stay there plus people even if you don't like know that your park is on top of a huge hill is not on landfill it's going to deteriorate after years and years and years. It's just going to get smaller and smaller. One year it's going to be really high and one year it will just be smaller and it's just not natural. You are going to hope people will recycle and create less landfill.

While both Elise and Gabby were motivated to help Gabby's grandmother, they also realized how landfills can cause challenges for whole communities now and also in the future.

Globally, the girls connected their design to climate change and coal usage. As Gabby explained, "If people recycle you are helping a little bit because global warming is coming from coal and so if you use eco-energy which is powering the recycling bin then that's less global warming and less carbon up on in the sky less asthma." While Elise did not know much about the effects of coal-produced electricity before the summer program, since learning she wanted to use renewable energy sources in her design to mitigate those effects.

Critical science agency in the two cases

Through the analysis of these two cases, we argue that youth enacted CSA by developing and leveraging their scientific and community knowledge and practice toward designing solutions to problems that mattered in their community. This aligns with the previous literature. However, we further argue that these two cases, examined in light of our critical justice view of equity, advance our understanding of CSA in three interconnected ways. First, in enacting CSA, the girls made sense of and addressed intersecting scales of injustices. Second, while developing their political consciousness of the injustices, they deepened and took ownership of their science expertise. Third, in doing so they reshaped the knowledge and authority hierarchy in the science community through using and shared expansive expertise while enacting CSA.

Intersecting scales of injustice

The girls made sense of and responded to intersecting scales of injustice that reflected local/global concerns grounded in historicized injustices throughout the design process. In the case of the Woot Wall, the girls put careful thought into the items they initially posted on the board, including examples and images of their peers' work on green energy engineering designs because they wanted to value their peers' accomplishments while also educating the larger community about what kinds of designs were possible. Emilia expanded who and what should be celebrated when she placed her own electric art card with a simple circuit on the Woot Wall. This motivated Tara, to add her own electric art to the Wall.

The girls also posted an explanation of their Woot Wall design, so that others could learn about how their design worked and why it was important. As Tara stated later most people "might not recognize" that they were solving a "classroom problem" and an "environmental and energy problem" if they did not provide them with some help to see how their design worked and why they made it. Through sharing their work and the design, they supported student morale, recognized students for their accomplishments, limited their carbon footprint, motivated others to mitigate global climate change, and provided a counter-narrative about who can meaningfully do science and engineering.

Emilia and Tara also provide inspirational hope that they could use science in meaningful ways. Both Emilia and Tara's CSA increased throughout their project, and they wanted others to know that they could engineer to address problems that matter, too. Similarly, Elise and Gabby created Bobbi to support others to make the choice to recycle. But in so doing, they also addressed climate change by not using coal-produced electricity, and limiting losing reusable objects to the landfill. These larger-scale environmental concerns were connected to personal and local concerns. The youth were motivated to create Bobbi because they knew Gabby's grandmother lived close to a landfill. They included cute and funny aspects into their recycling bin design to motivate rather than force others to recycle. From their experiences in school, they knew that being told to do something without an explanation does not lead kids to real changes in their behavior, and they wanted people to continue recycling in the future. All of these differing levels of concerns impacted their enactment of CSA when they designed Bobbi.

Deepening political consciousness and science expertise

Throughout the design process, Emilia, Tara, Elise and Gabby garnered a deeper understanding of the injustices that they were addressing, which was coupled with a need to further develop their science expertise. They sought to increase their understandings of energy production and its environmental impact, sources of renewable energy, and the power requirements of different types of circuits and circuit loads to better reach their goals. Both groups created designs that mitigated the impact of carbon emissions on climate change, and included renewable and clean energy sources in their designs.

The process of defining the injustices was active. Both groups relied on knowledge from home and community, such as Gabby's knowledge of community landfills or Emilia and Tara's knowledge that many of their peers do not feel valued in the science classroom. However, they also sought additional information to advance their designs, such as asking community members what would make people more interested in recycling or what might make it more fun. Their efforts represent the ways science education can promote equity by positioning youth to draw upon and build on cultural and science expertise in address community needs.

The youth used science in ways that mattered to them when they were enacting CSA. When they became stuck in their design work, they realized they needed to return to their investigations on series and parallel circuits to figure out how to power 16 LED lights on their Woot Wall. This deeper learning was a response to community concerns that the wall needed to do more to support increasing morale. The girls could have kept their design with only two LED lights because they had success in building a working series circuit with two lights. Instead, they were willing to dig back into what they had been learning about energy and circuits to find a solution to this design problem in ways that addressed community needs. We see a similar pattern when Elise and Gabby needed to further investigate how to include an effective switch on their recycling bin in order to make it more fun and effective.

Reshaping science education hierarchies through sharing expansive expertise

As the youth deepened their political consciousness and science expertise to address intersecting scales of injustice, the girls challenged the inequitable power distributions in their worlds. They were not simply solving problems that mattered in their community (although this is important), but rather they made connections between local issues they identified and systemic patterns of injustice. This point advances our thinking around CSA because it suggests that how and why individuals seek to address injustice involves making sense and addressing of individual problems in more systemic ways. To accomplish these goals, they needed to draw not only from the science they knew or even from their own personal experiences, but rather they also needed to change norms of participation in science education by seeking out what they needed to learn to address what mattered to their community.

Furthermore, by reshaping the hierarchies of their science education community, the youth were able to share and use their own and their community's expansive expertise. This advances our thinking around CSA because it calls attention to the ways in which the combination of youths' expertise with community members' perspective leads to more transformational and justice-oriented outcomes compared to if each girl was working autonomously. The youth collaborated with community members as they sought to define the problems they wished to solve and how they might do so. This collaboration was necessary for the youth to create an engineering design that mattered. They needed to engage in iterative dialogue with community and with each other to allow for a broader collective experience and expertise to inform their work. The community perspectives ensured their designs were useful. Furthermore, both the Woot Wall and the Trash Talking Recycling Bin included educative features meant to teach others the science needed for others to create their own engineering design solutions to address injustice. Through this multidirectional exchange and application of expertise, the youth disrupted who has the power to teach others, do science and make meaningful change.

We further see this aspect of their developing CSA as having a "disruptive dimension" (Squire and Darling 2013, p. 61). The girls claimed a rightful presence in science and engineering through their work. "Historical and geographic relations of injustice inform the assertions and/or assumptions of rightful presence that are enacted through the activities and encounters" (Squire and Darling 2013, p. 64). The girls pushed back against the "assumed stability that shapes activity" in science learning "often towards singular ends that perpetuate forms of privilege and power that produce and maintain profound inequalities" (Bang, Faber, Gurneau, Marin, and Soto 2016, p. 2). Each group engaged in design work that leveraged what they learned in the summer program, but toward unpredictable ends—ends that also opened dialogue around the problems they collectively faced and their capabilities in responding to them. As Emilia reminded us their project was made by girls not by "professors at an institute." The girls' design work supported them re-altering how they related to each other and the world through their engineering design.

Looking ahead

We have examined the ways in which four girls challenged and expanded our understandings of CSA during a green energy engineering unit, and we explored how they used CSA to address injustice. Our findings provide insight into the intersecting scales of injustice that youth seek to understand and address through the enactment of CSA. The girls' experiences push us to understand the ways in which the dominant narrative about equity focused on access to and the acquiring of narrowly defined science knowledge and practices fails to position youth to use science in meaningful ways. Both groups drew on both community expertise and science expertise to address social issues that are grounded in historical injustice that they identified such as environmental injustice and often oppressive schooling systems. This work furthers critical justice views of equity by supporting youth to challenge scales of injustice, disrupting normative expectations and goals of science education. Consider Emilia's statement about surprising people that she created the Woot Wall. If we only focus on expanding Emilia's access to science knowledge and practices, we would ignore the ways in which historical structures have led to multiple groups of people and their expertise to be marginalized in science education. Without understanding the problems in their classroom, connecting those concerns to intersecting scales of injustice and sharing expansive expertise, the girls would not have been able to enact CSA even if they knew how to design circuits and use renewable energy sources.

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